Applicability and Potential of BREEAM's Framework to Support Building Circularity Assessment in Taiwan

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Executive Summary

Growing depletion of natural resources and ever-intensifying pollution of the environment has heightened the awareness for changes in our life and living. As an alternative to the traditional take-make-use-dispose production model, Circular Economy (CE), which focuses on recovering and regenerating products and materials, has been gathering interest. In particular, its application to the construction industry, which is responsible for a high percentage of global carbon emissions and resource consumption, is of both need and significance.

In Taiwan, the construction industry has been highlighted for the government-initiated CE transition. However, as elsewhere in the world, the construction industry has been slow in embracing circular principles and strategies. Among the challenges is the lack of an assessment metrics for gauging CE performance. Existing schemes for assessing building circularity are few. In 2018, the Building Research Establishment Environmental Assessment Method (BREEAM) from the United Kingdom proposed a framework of circular indicators (BREEAM-C) on the basis of its original green building certification scheme (BREEAM-G).

This thesis is an in-depth analysis of BREEAM-C on its applicability and potential for adoption in Taiwan to assess building circularity and to promote circular construction. Methods applied include literature review, cross-case analysis and collecting expert opinions using semi-structured interviews.

The analysis involves scrutinising whether the indicators are rooted in CE principles, are realizable through circular strategies, cover well different impact areas, structural layers and life-cycle stages of buildings, and can recognise circular building practices implemented. The applicability of BREEAM-C in real-life contexts is further examined using two circular building projects, Venlo City Hall of the Netherlands and TaiSugar's Circular Village of Taiwan. The cross-case analysis also serves to identify BREEAM-C's strengths, inadequacies as well as room for improvement.

Results showed that BREEAM-C is applicable, practical and can be adopted for building circularity assessment in Taiwan though not without adaptation or localisation considering different concerns with respect to climate and safety. Green building rating schemes, which have been widely adopted in the past decades offer an excellent platform for developing equivalent assessment schemes for circular buildings. In particular, for practitioners and stakeholders in Taiwan, using its own green building certification system, **E**cology, **E**nergy saving, **W**aste reduction and **H**ealth, as the basis would make new building circularity assessment scheme to be introduced, accepted and followed easier, which in turn would facilitate the promotion of circular construction.

Acknowledgements

This research project has been a long and challenging endeavour, especially with much disruption due to COVID-19. My thesis would not have been completed without the help of many people to whom I am truly grateful for their assistance and support.

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I appreciate much the valuable aid from the two CML IE student advisors, Kiki Boomgaard and Paula van den Berg. They have been very sympathetic for my struggles in studying and living overseas and very supportive in accommodating my needs. Thanks to their assistance, administrative and academic, psychological and social, many obstacles on my path have been removed.

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Last but not least, I am grateful to my friends and family who encourage and support me through all the hard times. Thank you for believing in me and keeping me company when I need it most.

My final thoughts on this thesis project is that building a circular economy will require coherent change in consumer behaviour, governmental policies and business practices. The construction industry in Taiwan has just left square one on its path to a circular future. Circularity promises a prospering economy and a thriving ecology for all of us; yet, the shift, though worth the effort, will not be easy. Indeed, goals, metrics and certifications all have a role to play; and so do hearts and minds of all those involved.

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Abbreviations

ABRI - Architecture and Building Research Institute, Taiwan

BAMB - Buildings As Material Banks (BAMB, 2019)
BCI - Building Circularity Indicator (Verberne, 2016)
BCIX - Building Circularity Index, proposed by Alba Concepts (2018)
BIM - Building Information Modelling
BREEAM - Building Research Establishment Environmental Assessment Method
BREEAM-C – expansion of BREEAM-G into a framework for circular buildings with suggested indicators catered for assessing building circularity (Kubbinga et al., 2018)
BREEAM-G – BREEAM's original version for green building assessment

CB – Circular Building
CE – Circular Economy
CE-30 - 30 circular practices identified from CE-focused building projects by (Tserng et al., 2021)
CI - Madaster Circularity Indicator (Bronsvoort & van Oppen, 2018)
C2C - Cradle to Cradle design

DGBC - Dutch Green Building Council

EEWH – Ecology, Energy saving, Waste reduction and Health (Liu et al., 2019)
EMF - Ellen MacArthur Foundation (EMF,2019)
ENVLOAD - Envelop Load in unit kWh/myr

FIABCI - Taiwan Prix D'Excellence Awards Planning & Design Excellence Award

GBCA - Green Building Council Australia

HEA - Health & Wellbeing.
HVAC - Heating, Ventilation, and Air-Conditioning

IE - Industrial Ecology

LEED - LEED Green Building Rating System (Kriss,2014)
LCA - Life-Cycle Assessment / Life-Cycle Analysis

MFA - Material Flow Analysis
MCI - Material Circularity Indicator (Verberne, 2016)

NTIO - Netherlands Trade and Investment Office in Taiwan
PCI - Product Circularity Indicator (Verberne, 2016)

RE - Resource efficiency
Roadmap - Roadmap of Circular Land Tendering: An introduction to circular building projects

SCI - System Circularity Indicator (Verberne, 2016)

TABC - Taiwan Architecture & Building Center
Taisugar - Taiwan Sugar Corporation[1]
TCEN - Taiwan Circular Economy Network[2]
TCV - TaiSugar's Circular Village

UNEP - United Nations Environment Program (2018,2020)

VCH - Venlo City Hall (Eurbanlab, 2015)

WM - Waste management
WP - Waste prevention
WST - Waste management

[1] https://www.taisugar.com.tw/english/index.aspx
[2] https://circular-taiwan.org/en/about/

1. Introduction

This first chapter of the thesis provides the research context of the study and describes the problem to be examined. In particular, the relevancy of this thesis research to Taiwan and to the research field Industrial Ecology is described. Then the research aim is defined with the main research question and sub-questions formulated, followed by a description of the research design and methods employed to seek answers to the questions raised. The chapter ends with a summary of contents from Chapters 2-7 and a schematic depiction of the research flow.

1.1 Research Context

The construction industry with its salient role in the built environment poses significant impact on both humans and the natural environment. On one hand, the construction of buildings consumes large quantities of materials and energy, not only when putting up buildings but also when pulling them down and during their operations in between. On the other hand, in these processes and throughout the lifespan of buildings, wastes are generated and harmful substances are emitted. As described in the fact sheet of the Green Building Council Australia (GBCA, 2021), buildings are responsible for 50% of global material use, consuming 42.4 billion tonnes of material annually, and account for approximately 40% of energy-related global carbon emissions with around 25% of all building emissions related to material production and construction. It is no exaggeration to say the construction industry is the major consumer of the world's precious but limited resources and a significant contributor to global greenhouse gas emissions and wastes. The economic model adopted by the construction industry has all along been linear with the take-make-waste mentality (Benachio et al., 2020). Materials and resources are taken and extracted for one-time use, the construction of buildings, and are then disposed during and at the end of the building's lifespan.

Circular economy (CE), an industrial economy that is restorative and regenerative by design and aims (Ellen MacArthur Foundation (EMF), 2013), has been prioritised as an alternative to the prevalent linear production model and consumption mentality. It promises a way to decouple economic growth from resource consumption (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015). Hence, transition to a CE in the construction industry is the key to achieving a 'resource-efficient' and 'resource-sufficient' society for long-term and continued development.

1.2 Problem Definition

Although CE transition has been gathering attention and momentum, its application in the construction industry is still largely confined to construction waste minimization and recycling (Adams et al., 2017). Limited knowledge and tools hampers CE transition in the construction industry (Foster, 2020). Despite of a common need to develop circularity assessment tools, **the plethora of CE definitions make it difficult to reach a consensus on what aspects of circularity are to be measured and how**. Moreover, **tools or indicators developed so far focus more on circularity assessment of products or materials but not buildings**.

Existing building circularity assessment systems are few and under development. In contrast, different schemes and certifications for evaluating and verifying green buildings are available worldwide and have all been in use since the 1990s. Their focus is on assessing the impact of building on society and environment with the goal to reduce carbon dioxide emissions during the use of the buildings and their construction processes. Hence, their direct application to circularity assessment would not suffice to serve the purpose of waste minimization through enhancing circularity or resource efficiency.

BREEAM, which stands for Building Research Establishment Environmental Assessment Method, is generally accepted as the first green building rating scheme in the world. Developed in 1990 by the Building Research Establishment of the UK, BREEAM has been used for sustainable building certification in more than 80 countries. In 2018, BREEAM expanded their original version for green building assessment (BREEAM-G) into a framework for circular buildings with suggested indicators catered for assessing building circularity (BREEAM-C) (Kubbinga et al., 2018). To the knowledge of the author, till the time the thesis research was carried out, BREEAM-C has never been applied to circularity assessment of constructions; hence, its applicability and practicability have not been validated.

In sum, there is a prevailing need for circular building assessment metrics; and the most relevant framework for circular buildings – BREEAM-C still needs to be tested for its applicability and practicability.

1.3 A Case for Taiwan

Construction is one of three industries highlighted in Taiwan's CE transition roadmap together with food and textile (Chen et al., 2021). Nevertheless, till now only a few CE-focused building projects, mainly housing complexes, have been proposed and implemented.

The circular building pioneers, such as a state-owned enterprise Taiwan Sugar Corporation (TaiSugar), the first business establishment attempting to implement CE in their construction projects, and the Taipei City government, the first city in Taiwan trying to put CE to practice in social housing projects face significant challenges and obstacles due to the lack of tools, in particular, a suitable assessment system for gauging CE application and execution. Believing in "what gets measured gets done", actors and practitioners involved in circular transition share the common need of making circularity measurable and quantifiable. Project owners and other stakeholders of these CE-focused constructions in Taiwan frequently ask whether there is an assessment or accreditation system for circular constructions as that for green buildings.

Currently, Taiwan has its own green building assessment system, the EEWH – **E**cology, **E**nergy saving, **W**aste reduction and **H**ealth. While EEWH emphasises waste and emission reductions, the main prerequisites for accreditation are daily energy conservation and water conservation. These green economy focuses render EEWH insufficient for building circularity assessment, especially considering the huge amount of materials and products involved. In short, to facilitate turning the CE concepts into defined action plans, practical strategies, and concrete policies, Taiwan is in need of a circularity assessment metrics for buildings.

1.4 Relevance to Industrial Ecology

This thesis project aims to seek an answer to the prevailing need of a building circularity assessment metrics in Taiwan for gauging the performance of CE strategies put to practice and for promoting circular construction. Evolved from Industrial Ecology (IE), which is the study of material and energy flows through industrial systems and the environmental impacts of industrial activities, CE as an industrial model aims at creating a circular flow of materials and cascading energy flows. Circular buildings are also characterised by optimal and high material efficiency achieved through different R-imperatives, which are consistent with IE goals of ecoefficiency and dematerialisation. Both CE and IE are recognised as suitable approaches to achieving sustainable development (Geissdoerfer et al., 2017; Schroeder et al., 2019).

1.5 Research Aim and Research Questions

The aim of this research is to evaluate the applicability of BREEAM-C as a building circularity assessment metrics and its potential application to Taiwan for promoting circular construction.

Hence, the main research question of this thesis is

Can BREEAM-C be adopted for building circularity assessment to promote circular construction in Taiwan?

To answer the above main question, the following sub-questions are formulated to guide a thorough and comprehensive investigation.

1. How can CE principles guide building circularity assessment?

2. Which kind of system would Taiwan need for building circularity assessment?

3. How does BREEAM incorporate material circularity indicators into its existing green assessment framework?

4. What is the applicability of BREEAM for building circularity assessment?

5. What are the strengths and inadequacies of BREEAM?

6. What lessons can Taiwan learn from BREEAM's attempt in incorporating material/resource circularity indicators into an existing green building assessment system for building circularity assessment?

1.6 Research Design and Methodology

This study uses qualitative approaches to examine the research problems. In addition to literature review and cross-case analysis, a small-scale survey was conducted using semi-structured interviews to solicit expert opinions on the issues studied.

To address the questions formulated in Section 1.5, this research begins with a literature review on how circular transition can mitigate the negative externalities attributed to the construction industry and built environment. The need for building circularity assessment both for gauging CE performance and promoting circular construction in Taiwan is highlighted. The literature review serves to establish the theoretical basis on how CE principles can guide building circularity assessment.

Among current circularity assessment systems, BREEAM-C is selected for critical analysis in view of its suitability for meeting Taiwan's needs. A careful scrutiny of the proposed circular indicators of BREEAM-C involves examining whether its indicators are rooted in circular principles, realisable through circular strategies, and have given due consideration to circularity in different impact areas, structural layers and life-cycle stages of buildings.

To examine the applicability of BREEAM-C, the indicators are matched against prevalent circular practices and applied to circularity assessment of two case studies, Venlo City Hall (VCH) of the Netherlands and TaiSugar's Circular Village (TCV) of Taiwan to shed light on its strengths, inadequacies, room for improvement as well as variation in performance when assessing circular constructions built for different purposes in different regions with different climates.

Taiwan is practically in square one on the path to CE transition. Related studies in the literature are scarce; hence, the interviews with actual practitioners and stakeholders involved in CE-focused building projects would offer insiders' understanding of the actual situation in Taiwan and their unique perspectives on the research issues. The questionnaire used in the interview comprises statements to which the interviewees are asked to indicate their agreement using a five-point Likert scale, and open-end questions for collecting their narrative data. Appendix A contains both original Chinese and translated English versions. Prior to the interview, general background information of BREEAM-C and the questionnaire were sent to the respondents. A face-to-face meeting in person or over the Internet then followed with all exchanges audio-recorded for review.

The three methods, literature review, cross-case analysis and expert interview, used in this thesis research complement each other to reveal an across-the-board and in-depth perspective on the research questions.

1.7 Outline of Thesis Chapters

The schematic illustration of Figure 1.7.1 and the following descriptions provide a structure of this thesis and outline the contents of each chapter.

Chapter 1 introduces the research context (1.1) and research problem (1.2), explains the relevancy of this thesis research to Taiwan (1.3) and to Industrial Ecology (1.4), defines the research aim and formulates the main research question and sub-questions (1.5), and describes the research design and methodology (1.6).

Chapter 2 details the negative impacts of the construction industry on the finite resource supply and the natural environment (2.1), presents the concept of CE, its origins, principles and guidelines for circular strategy generation (2.2), describes related benefits and challenges of CE transition in the construction industry (2.3), draws attention to the need of a building circularity assessment system, reviews existing building circularity indicators (2.4), and presents circularity targets for different life-cycle stage of a building on the basis of CE aspects (2.5).

Chapter 3 explains the vision for Taiwan to go circular (3.1), discusses the perspectives from experts in the related field regarding the challenges (3.2) and needs (3.3) for promoting circular construction in Taiwan, and reviews the current building performance certification system used in Taiwan (3.4), focusing on how circularity metrics can help promote circular construction economy and what kind of circularity metrics would suit the need of the domestic construction industry (3.5).

Chapter 4 is an in-depth review of BREEAM-C, a candidate building circularity assessment system for adoption by Taiwan, tracing its evolution from its original green building certification scheme (BREEAM-G) (4.1), focusing on how circularity indicators for materials, energy and water are incorporated into the existing green building assessment framework (4.2), and examining whether BREEAM-C indicators are realisable through circular strategies and has given due consideration to building circularity in different impact areas, structural layers and life-cycle stages (4.3).

Chapter 5 evaluates the applicability of BREEAM-C for circularity assessment using a two-pronged approach. On one hand, BREEAM-C indicators are matched against prevalent circular practices to assess its capacity in identifying circular practices if implemented (5.1); on the other hand, a cross-case analysis is performed using BREEAM-C indicators to assess two CE-focused building projects to demonstrate and evaluate its application in a real-life context (5.2).

Chapter 6 discusses the potential of BREEAM being used as a building circularity assessment metrics in Taiwan (6.1), details BREEAM's inadequacies and room for improvement/expansion focusing on how BREEAM can be adopted for use (6.2) and what Taiwan can learn from BREEAM's attempt to incorporate material/resource circularity indicators into an existing green assessment system (6.3), and ends with presenting stakeholders' expectations of circularity assessment for Taiwan (6.4).

Chapter 7 concludes this thesis, providing a summary of research efforts (7.1) and results with potential uses of findings (7.2), examining limitations of research (7.3), suggesting directions of future research efforts (7.4).

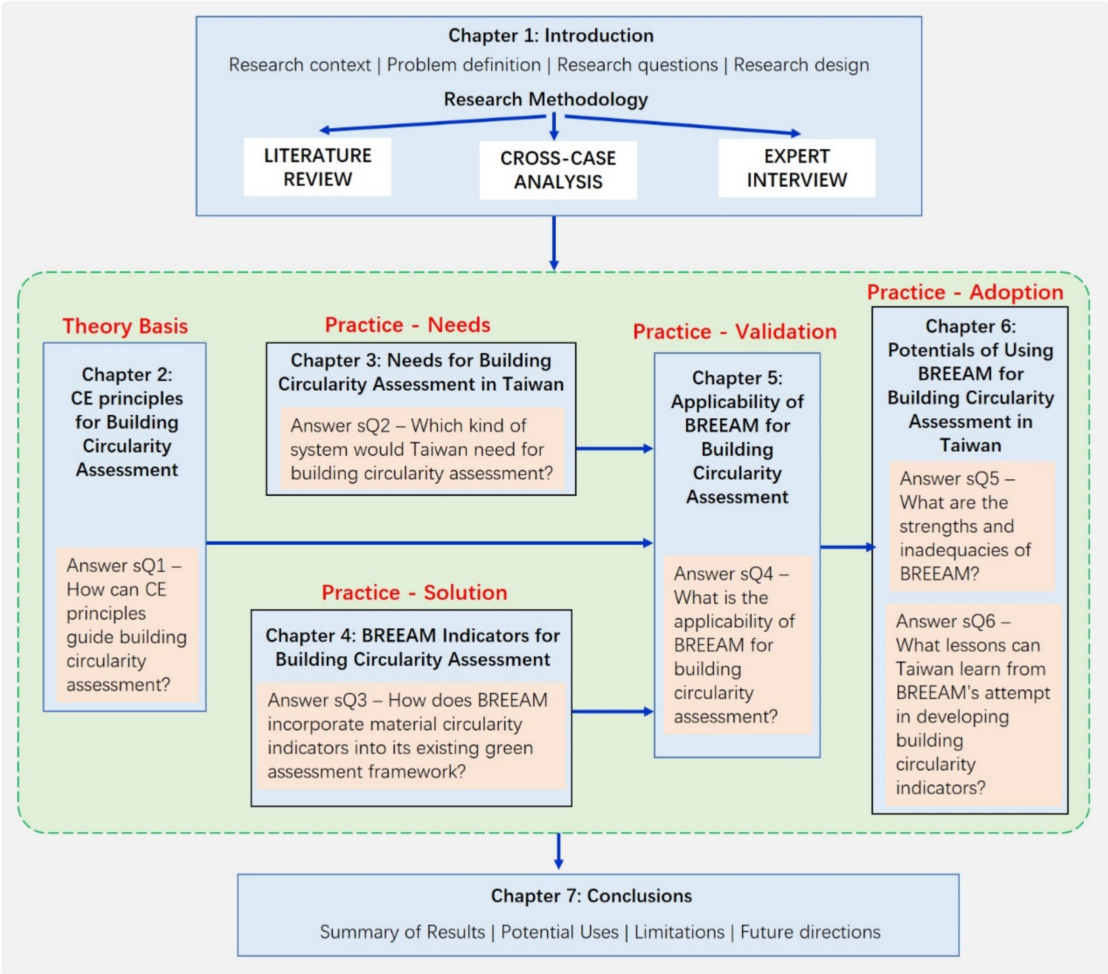

Figure 1.7.1. Schematic figure depicting the contents and flow of this Thesis.

2. Circular Economy Principles for Building Circularity Assessment

This chapter presents a literature review aiming to understand how CE principles can guide building circularity assessment (sub-question 1), serving as the theory basis of this thesis research. It covers the following. First, the negative impacts of the construction industry and the built environment on the finite resource supply and the natural environment are reviewed (2.1). Then the concept of CE as an inspiration for a sustainable built environment is examined, tracing its origins, the different schools of thoughts, and its principles (2.2). Based on the CE principles, the frameworks for generating circular strategies are presented, followed by the benefits and challenges of CE transition in the construction industry (2.3). Finally, existing building circularity indicators are reviewed (2.4), and the need of a building circularity assessment system that incorporates the CE principles for achieving circularity targets throughout the life cycle of buildings is highlighted (2.5).

2.1 Impacts of Construction Industry and Built Environment

Built environment, in contrast to natural environment, is "the human-made space in which people live, work and recreate on a day-to-day basis" (Roof & Oleru, 2008). According to the Construction Industry Council, the built environment encompasses all forms of building and civil engineering infrastructure both above and below ground and includes the managed landscapes between and around buildings.[3] The term built environment, or built world, came into widespread use only in the 1990s (Haigh & Amaratunga, 2010). Nevertheless, building activities or the construction of some form of shelter using primitive tools date back to the time when humans leave nomadic life. Today, the construction industry has an extensive scope of work including planning and surveying, land development and site preparation, structural construction and installation, renovations and extensions, maintenance and demolition for both buildings and infrastructure.

Despite new terms coined and innovations adopted for building activities and the construction industry, the building process itself has remained so far linear, as depicted in Figure 2.1.1.

[3] https://www.designingbuildings.co.uk/wiki/Built_environment

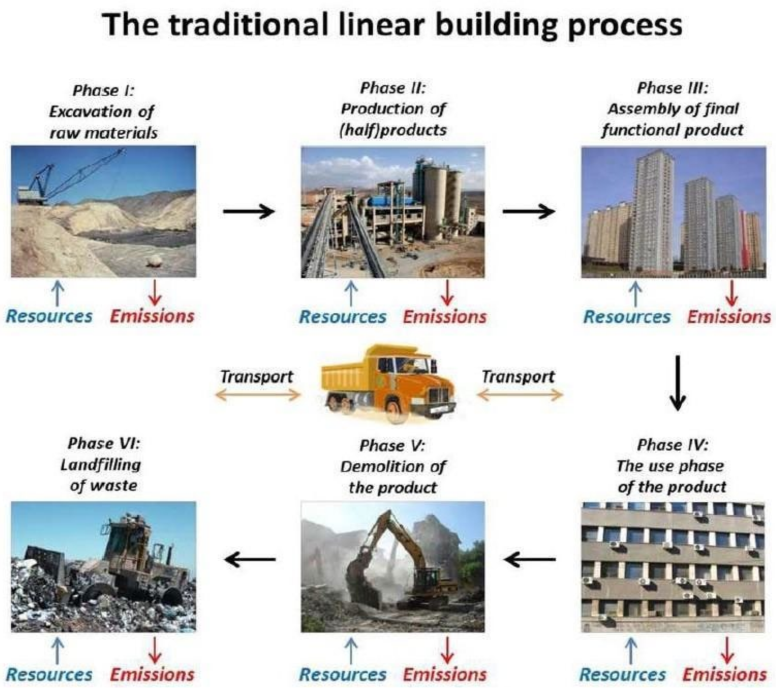

Figure 2.1.1 Traditional linear building process in six phases, each phase involving transportation, input of (raw) materials (resources) and production of wastes in form of liquids, solids or gases (emissions).

Adapted from: Lecture notes, CIE4100 Materials and Ecological Engineering, TU Delft, 2021.

2.1.1 Natural Resource Depletion & Waste/Pollution Generation

In the first place, the construction of buildings and the infrastructure surrounding them consume large quantities of materials and minerals. According to Bribián et al. (2011), 60% of the raw materials extracted from the lithosphere went to constructions. Most of these materials and minerals are non-renewable and continuous extraction causes their supply to become critical (Yellishetty et al., 2011). Places with limited local reserves will eventually face the problem of resource scarcity, thus threatening their resource security, and be forced to pay high prices for imported materials. In addition, non-replenishable metals and minerals used for constructions come from ores, with some approaching their production peaks and some already past their peaks, thus making their mining and processing more difficult and of higher cost (Prior et al., 2012).

According to the Circularity Gap Report 2020, only 8.6% of the world economy is circular; that is, less than one-tenth of the minerals, fossil fuels, metals, and biomass which enter it every year are subsequently reused. The insignificant rate of recycling used resources in the construction industry means that ~91% of all raw materials are wasted after their first use, and end up in landfills or burnt in incinerators. Either way, they will become sources of pollution, turning our environment into waste reservoirs.

The reason for such enormous material loss is that buildings are designed and constructed in a way that is not conducive to breaking down parts into recyclable, let alone reusable components (EMF, 2013). Furthermore, under rapid urbanisation and development, C&D wastes would continue to increase (Manowong, 2012), causing mounting pressure on sustainable waste management in the construction industry, not only for decreasing the related cost incurred but also for mitigating the negative externalities.

2.1.2 Energy Consumption and Greenhouse Gas Emissions

While materials are mostly used in the production and construction of a building, energy and water are consumed throughout its lifespan, from processing raw materials to manufacturing construction parts, from when it is being put up to being pulled down, and during its operation in between. According to the information sheet of the United Nations Environment Program (UNEP, 2018), buildings use about 40% of global energy and 25% of global water. Operations of residential and commercial buildings alone consume approximately 60% of the world's electricity.

The more significant impact of energy consumption lies in the energy-related carbon dioxide (CO2) emissions. According to the 2020 Global Status Report for Buildings and Construction (Global Alliance for Buildings and Construction, 2020), CO2 emissions reached their highest level ever, with those from the operation of buildings contributing the most share. As a result, 38% of the total global energy-related CO2 emissions is connected to buildings and the construction industry, which marks an increase from 33% reported in an earlier study of Ness and Xing (2017). In other words, buildings and the construction industry are not on track for realising decarbonisation. Climate action entails driving down emissions through aggressive reduction in energy demand of the built environment. Hence, the construction industry should target both material and energy efficiency, not only for preserving resources but also reducing emissions.

In all six phases of the traditional linear building process depicted in Figure 2.1.1, resources including raw materials, labour and energy are consumed and transportation is involved while wastes in forms of solid, liquid or gaseous emissions are generated. Estimates of the United Nations Environment Programme (UNEP, 2020) show global building floor area doubled by 2050, while the global extraction of primary materials is set to triple (Gallego-Schmid et al., 2020), not to mention the accompanied increase in energy demand and the construction-related GHG emissions. Realising the finite supply of resources and high environmental costs due to pollution and wastes, the construction industry sees an urgent need for an alternative to the prevailing linear approach to consumption and production so as to achieve sustainability in the built environment.

Looking toward the future, the European Commission (2020b) commented,
"There is only one planet Earth, yet by 2050,
the world will be consuming as if there were three."

Against this seemingly bleak scenario, the "Vision 2050: Time to Transform" of the World Business Council for Sustainable Development (WBCSD, 2010) put forward a way out and it is

"for the built environment to embrace the circular economy model, become net-zero carbon, inclusive, resilient and healthy for the people and the planet."

2.2 Circular Economy for a Sustainable Built Environment

Circular economy (CE), as a concept, a new branch of scientific study, an economic system and an industrial model, has been attracting worldwide scholarly interest and much attention from governments, industries and businesses. Research works on CE for the built environment have been booming. The bibliometric analysis of Norouzi et al. (2021) found a significant rise in number of journal articles from 2008 to 2020. In just a year between 2018 and 2019, the yearly publications more than doubled, rising from 63 to 153, respectively (Munaro et al. 2020). The rapid growth of scientific publications on CE research reveal wide-ranging perspectives of what a circular economy means and what it entails. Amidst diverse understandings, the common ground is that CE has been prioritised as an alternative to the prevalent linear production model and consumption mentality.

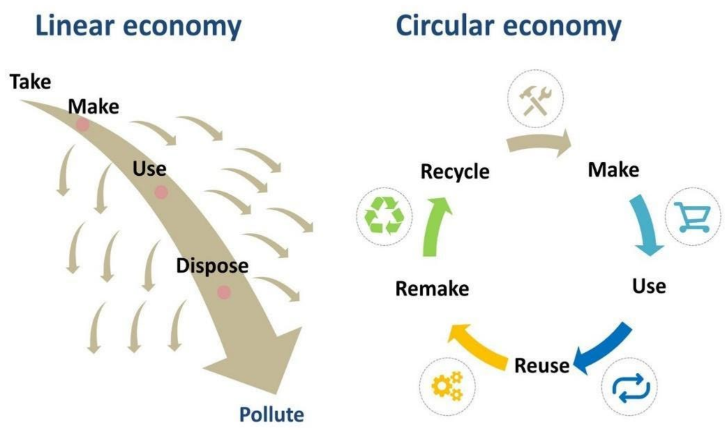

Figure 2.2.1. Schematic figure depicting differences between linear and circular economy.
Adapted from: https://clustercollaboration.eu/community-news/difference-between-circular-economy-and-linear-economy

Owing to its interdisciplinary nature, CE has many different definitions. In their attempt to conceptualise CE, Kirchherr et al. (2017) analysed 114 definitions used in scientific literature and professional journals and came up with the following:

> ***A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations.***
>
> (Kirchherr et al., 2017)

The systematic literature review of Benachio et al. (2020) found that the Ellen MacArthur Foundation (EMF), a charity dedicated to promoting global transition to CE, is the most cited source of CE definition. According to the EMF,

> ***A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.***
>
> (EMF, 2015)

The plethora of CE definitions reflects the wide spectrum in the understanding of this concept, making it difficult to reach a consensus on the focus and aspects of circularity assessment.

2.2.1 Emergence & Roots of Circular Economy

The concept of circularity, though seemingly novel, has origins tracing back to the notions of cycles in living systems and feedback in the real physical world. Circularity emphasises closing the loop of material flows, replacing extract and exhaust with recycle and regenerate, thus ensuring restoration and resiliency to ultimately achieve sustainability.

Initial notion of CE appeared in 'the spaceship theory' put forward by Boulding (1966), who likened the earth to a closed spacecraft without unlimited reservoirs of anything. The sustainability of such a closed economy depends on **reproducing the limited inputs and recycling waste outputs**; otherwise, it cannot escape the eventual fate of destruction. The term CE was first formally used in an economic model by Pearce and Turner (1990), and its theoretical underpinnings have been drawn from different primary schools of thoughts with contributors from diverse disciplines

(Murray et al., 2017; Wautelet, 2018), as depicted in Figure 2.2.2 and briefly discussed below.

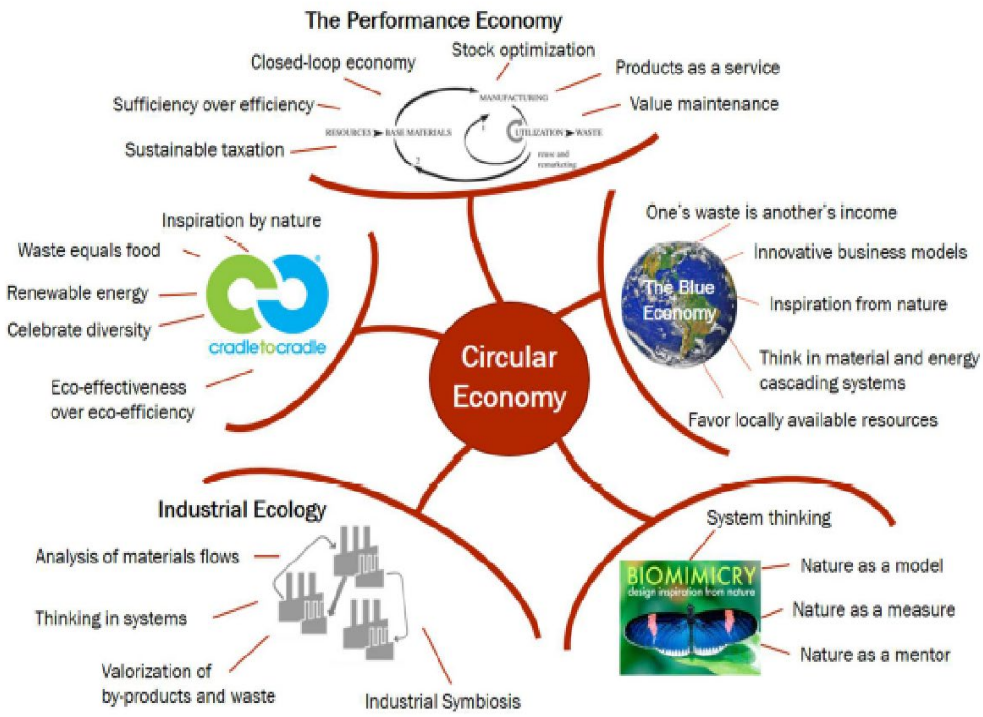

Figure 2.2.2 Groundworks of CE from different schools of thoughts.
Adapted from Wautelet, T. (2018). The concept of circular economy: its origin and its evolution. http://doi.org/10.13140/RG.2.2.17021.87523

The term "**Industrial Ecology**" (IE) first gained attention in 1989 as it appeared in the article written by Frosch and Gallopouos (1989). They raised questions on "why would not our industrial system behave like an ecosystem, where the wastes of a species may be resource to another species? Why would not the outputs of an industry be the inputs of another, thus reducing use of raw materials, pollution, and saving on waste treatment?" Primarily, IE aims at creating **close-loop processes for material and energy flows, in which waste is seen as input**.

In 1994, Lyle, a landscape architect, published a practical guide to the theory and design of regenerative systems. He viewed the prevalent one-way system with linear flows from source to sink as degenerative and the conventional industrial development that results in resource depletion and environmental degradation is destroying what it depends on. The **regenerative design** Lyle put forward replaces linear systems with "cyclical flows at sources, consumption, centres and sinks", aiming to provide for "**continuous replacement of the energy and materials used**" in the system operation (Lyle, 1994). A representative regenerative design is the **Cradle to Cradle** design (also referred to as **C2C**) developed by Braungart and McDonough (2002) as the antithesis of 'cradle to grave'.

The Swiss architect, Walter Stahel, who coined the phrase 'cradle to cradle', also put forward the notion of **Performance Economy** (Stahel, 2010). As the founder of the Product-Life Institute, Europe's oldest sustainability-based consultancy, Stahel's Performance Economy is not only a key tool for an economy to become sustainable, but also a business model with goals of increasing wealth, creating more jobs and **reducing resource consumption through performance enhancement**. The emphasis shifts from 'doing things right' to **'doing the right things'**. Similar paradigms or comparable "economies" have been proposed, all with the ultimate objective of achieving sustainability. They include the Green Economy (Makower, 2008), the Blue Economy (Pauli, 2010), and the Bio-economy or Bio-based Economy (Sanders et al., 2010), to name a few.

Finally, **Biomimicry**, as defined by Benyus (1997), is "a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems." That is, Nature serves to "Model, Measure and Mentor, with the objective of achieving sustainability.

2.2.2 Principles of Circular Economy

Concepts and models related to CE, though many and diverse, arise from the need and urgency to respond to earth resources under strain and human sometimes irresponsible and excessive consumption. The challenge for enhancing resource efficiency leads to new thinking and approaches that seek inspiration from nature's cyclic pattern for sustainable growth. The abovementioned schools of thoughts all gravitate around three key principles of CE as described by EMF (2013).

Principle 1 – Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows

Principle 2 – Optimise resource yields by circulating products, components and materials at the highest utility at all times in both technological and biological cycles

Principle 3 – Foster system effectiveness by revealing and designing out negative externalities

In line with the above principles, a circular economy would manifest the following fundamental characteristics:

- **Design out waste**
  - Non-toxic biological materials are to return to the soil
  - Human-made materials are to be recovered, reused and upgraded (EMF, 2013)
- **Build resilience through diversity**
  - More resilient and diverse systems with modular, versatile, adaptive and flexible features to stand the test of external challenges (EMF, 2013)

✧ **Rely on energy from renewable sources**

- Aiming to become less resource-dependent (EMF, 2013)

✧ **Think in "systems"**

- A holistic approach for better management of individual but related systems (EMF, 2013)

✧ **Waste is food**

- everything in a CE should be an input to everything else.

The 'Butterfly Model', as depicted in Figure 2.2.3, put forward by EMF (2019), visually presents and characterises the continuous flows of technical and biological materials in a circular economy. In essence, CE emphasises creating closed loops of material flows and reducing consumption of virgin resources. Beyond these resource-oriented goals of using less primary materials, CE also stresses maintaining the highest value of materials and products and changing utilisation patterns.

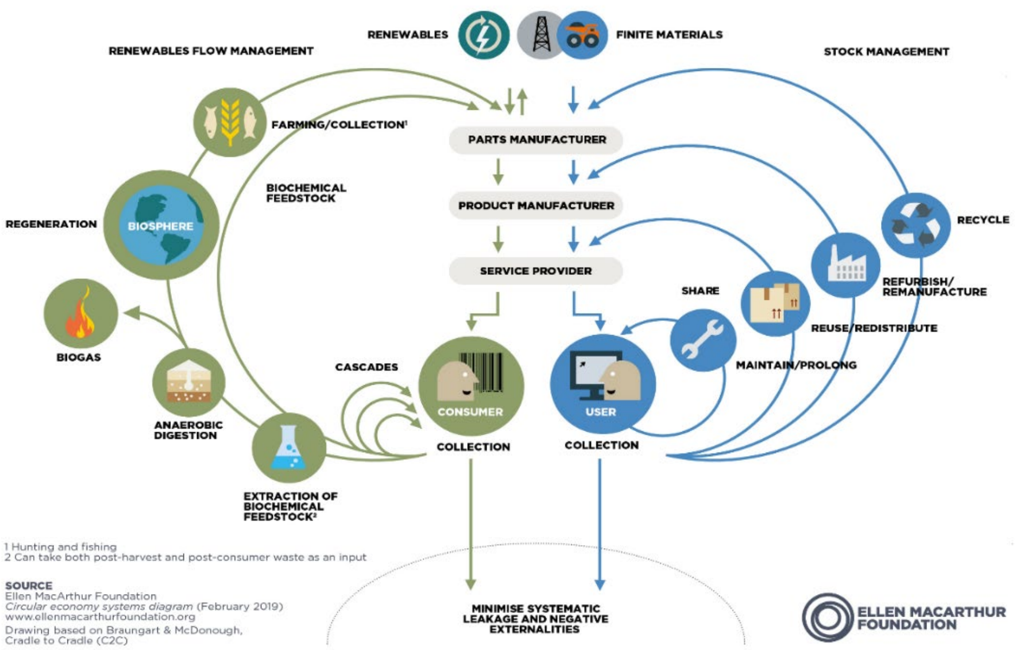

Figure 2.2.3 "Butterfly" model, showing flows of materials, energy and resources
Adapted from: Ellen MacArthur Foundation, 2019
https://ellenmacarthurfoundation.org/circular-economy-diagram

Besides being a hot trend, achieving circularity does promise a sustainable future with benefits not only to the environment, its original aim and purpose, but also to the economy. As a result, CE is a field of interest to environmentalists and economists, academia and practitioners, businesses and governments. More and more countries as well as different businesses and industries, including the construction industry, are inclined to make a shift in their production and consumption mode with greater focus on positive society-wide benefits and less material usage.

2.2.3 Basis and Framework for Generating Circular Strategies

To enhance circularity, the R-imperatives in various combinations serve as a basis while the ReSOLVE framework developed by the EMF and McKinsey (McKinsey, 2015) offers guidelines for generating circular strategies, which are applicable to products, buildings, neighbourhoods, cities, regions or even national economies.

R-Imperatives

The full list of 10R-Imperatives (Lombard Odier, 2020) are

- ***Refuse*** unnecessary and unsustainable products
- ***Rethink*** with a focus on production/consumption with least environmental impact
- ***Reduce*** consumption of raw materials through “doing more with less”
- ***Reuse*** to achieve zero-waste and extend the life of product as long as possible
- ***Repair*** to lengthen the product life cycles and to preserve rather than throw away
- ***Refurbish*** to restore otherwise discarded product, thus avoiding waste
- ***Remanufacture*** with reused parts to maximise resource efficiency
- ***Repurpose*** or upcycle a discarded product into a new one with a different function
- ***Recycle*** used materials to cut down the need of virgin resources
- ***Recover*** materials from biodegradable waste to generate energy or reduce pollution

These R-imperatives are sometimes condensed or combined into 5Rs - Reduce, Reuse, Recycle, Repair and Recover; or even 3Rs - Reuse, Reuse, Recycle. For illustration, Figure 2.2.4 shows the 9R framework for achieving circular economy objectives at different circularity levels. (Kirchherr et al., 2017)

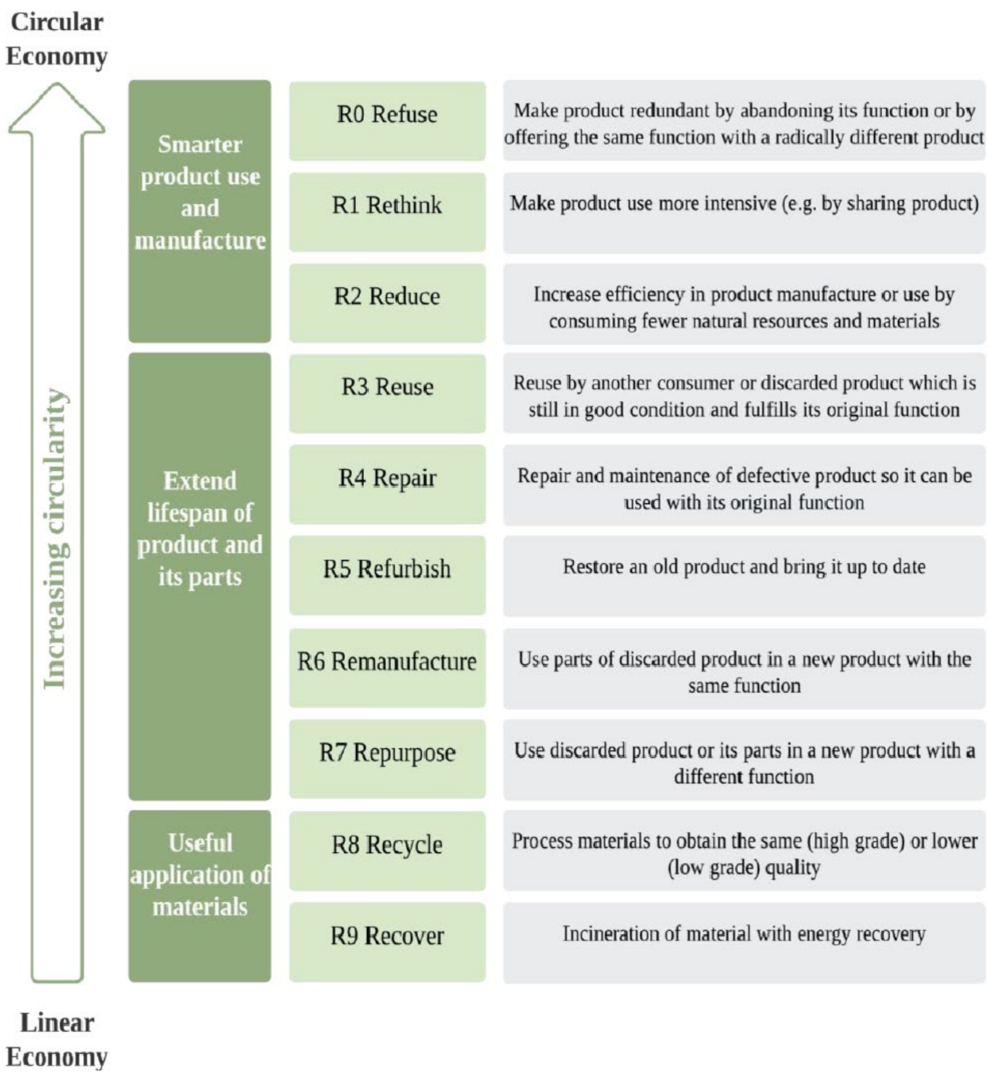

Figure 2.2.4 9R framework of Circular Economy, showing circularity levels from low to high. *Adapted from Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221–232.* https://doi.org/10.1016/j.resconrec.2017.09.005

ReSOLVE

Six actions namely, **Regenerate, Share, Optimise, Loop, Virtualize** and **Exchange** are proposed for generating circular strategies, all with the goals of maximised utilisation of physical assets through waste elimination, asset life prolongation and resource shift from finite to renewable sources. Though separate and distinct, these six actions reinforce and accelerate the performance of one another. Table 2.3.1. summarises the six actions and their elements as well as corresponding circular strategies that can be adopted by the construction industry for transforming the built environment.

Table 2.2.1 ReSOLVE framework applied to built environment

Actions	Key Elements	Transforming Circular Strategies
Regenerate	• Regenerate & Restore natural capital • Safeguard, restore & increase of ecosystems • Return valuable nutrients safely to biosphere	• Renewable energy use • Land restoration • Resource recovery • Renewables production system
Share	• Maximise asset utilisation • Pool asset usage • Reuse assets	• Residential sharing / co-housing • Parking sharing • Appliance & tool sharing • Office sharing & flexible seating
Optimise	• Optimise system performance • Prolong life of assets • Decrease resource usage • Implement reverse logistics	• Industrial processes • Smart urban design • Energy efficiency enhancement • Passive design
Loop	• Keep products & materials in cycles • Prioritise inner loops • Remanufacture & refurbish products & components • Recycle materials	• Modular & off-site construction • Stage by stage demolition • Material banks of demolition waste for remanufacturing • Recycle demolition waste
Virtualize	• Displace resource use with virtual use • Replace physical products & services with virtual services • Deliver services remotely	• Technology innovation • Tele-working • Virtualization of products & processes • Smart honest big data and connected appliances
Exchange	• Select resources & technology wisely • Replace with renewable energy & material sources • Use alternative material inputs • Replace product-centric delivery models with new service-centric ones	• Better performing materials • Better performing technologies • 3D printing

Adapted from The Circular Economy in the Built Environment Report by ARUP (2016) and The Circular Economy: Moving from theory to Practice by McKinsey's Center for Business and the Environment (2016)

While these guidelines are helpful for developing circular strategies, the path to CE transition is not without obstacles. The following subsection reviews some of the problems and challenges the construction industry faces when putting CE to practice.

2.3 Transition to Circular Economy in Construction Industry

2.3.1 Benefits of Circular Transition in Construction Industry

With CE concepts incorporated into the building process, Figure 2.1.1 will have a different look, as illustrated in Figure 2.3.1. This ideal closed building cycle or cyclic building process involves only four phases. Of the former six phases, two are eliminated. First, there is no end-of-life waste landfilled; instead, wastes are reinjected into the building cycle as useful resources. With such inputs, there is no or minimum excavation of raw materials. In this way, resources can be kept in use for as long as possible with the maximum value extracted whilst in use. Consequently, both the demand for non-renewable virgin materials and the production of waste in forms of solid, liquid or gaseous emissions can be reduced.

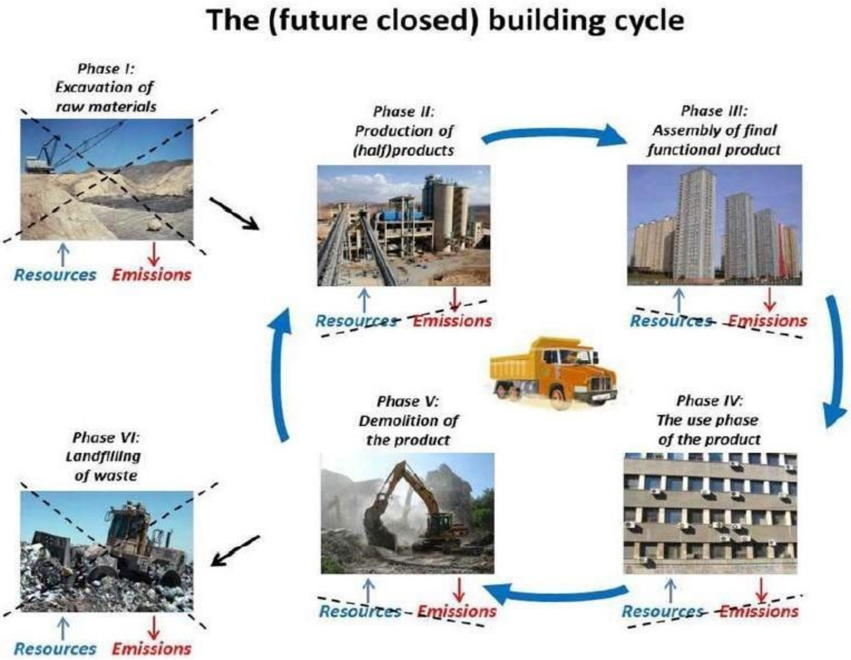

Figure 2.3.1 Sustainable cyclic building process. In a fully sustainable building cycle (from 'cradle to cradle'), neither (hardly) is input of new raw materials required, nor do emissions of (harmful) compounds occur, and waste is considered a useful resource.
Adapted from: Lecture notes, CIE4100 Materials and Ecological Engineering, TU Delft, 2021.

Of note is the direct relationship of the amount of building materials, elements components, modules and the entire building itself recycled or reused with economic and environmental benefits as shown in Figure 2.3.2. In other words, the higher the circularity of a building, the greater the economic and environmental benefits it can bring.

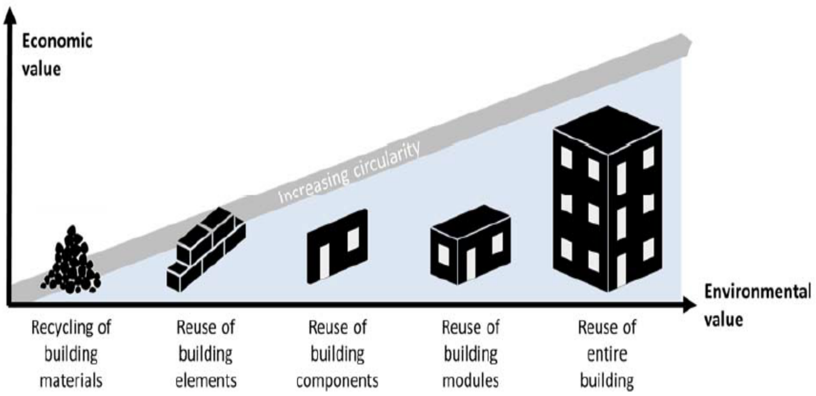

Figure 2.3.2 Linear relationship of circularity with economic and environmental values
Adapted from: Eberhardt et al. (2019). Potential of Circular Economy in Sustainable Buildings. *https://doi.org/10.1088/1757-899X/471/9/092051*

2.3.2 Challenges of Circular Transition in Construction Industry

Though aware of the necessity and the benefits to shift toward more circular and life-cycle thinking for the built environment, the construction industry has been slow in embracing the CE concepts and related strategies.

As pointed out by Hart et al. (2019), the application of CE in the construction industry is largely limited to C&D waste minimization and recycling despite the high C&D waste recovery rate. Research of Adams et al. (2017), Bilal et al. (2020), Cruz Rios and Grau (2019) and Hart et al. (2019) have broadly categorised the enablers/drivers and barriers/challenges for adoption of CE in the construction industry into four types, namely **economic/financial, technical, cultural and regulatory.**

The study of Hart et al. (2019) identified the following **7 sectoral challenges**.

Integral	Complexity	Insufficiency
The industry itself – conservative, uncollaborative, adversarial	Long product life cycles for both buildings and materials	Lack of bandwidth compounded by absence of coherent vision for the industry
	Complexity/confused incentives	Insufficient use or development of CE-focused design and collaboration tools, information and metrics.
	Technical challenges regarding material recovery	Lacking standardisation

In their April 2021 Council Meeting, the European Network of Construction Companies for Research and Development (ENCORD) identified **eight major challenges** for transition to a circular construction industry as named by their members and shown in Figure 2.3.3.

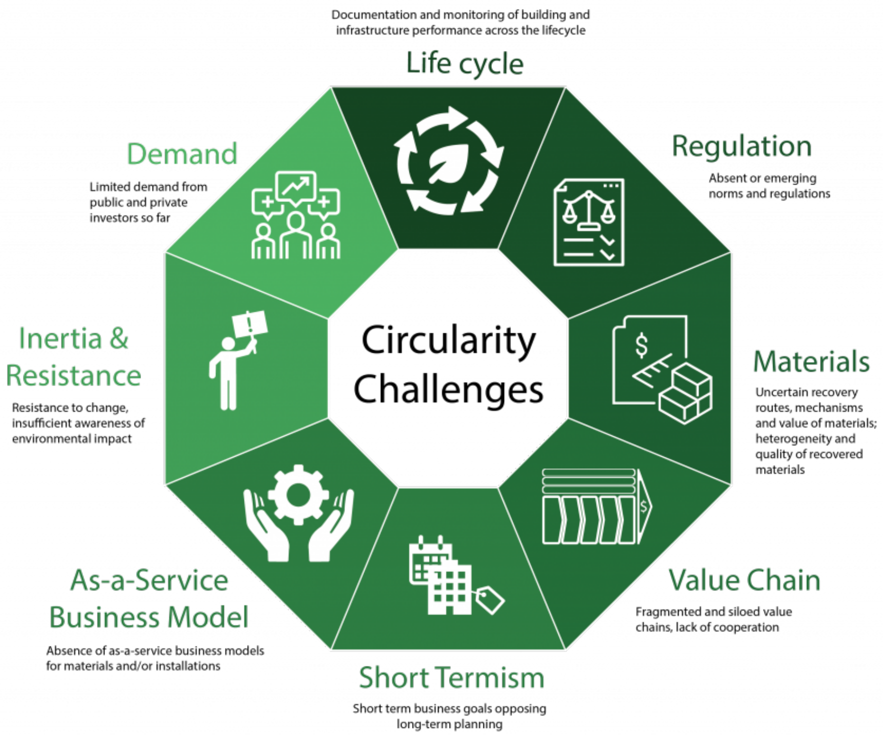

Figure 2.3.3 Eight challenges towards a circular construction industry

Source: European Network of Construction Companies for Research and Development http://www.encord.org/?p=2157

The lists of challenges identified so far by Hart et al. and the ENCORD members are all rooted in the **complexity of buildings**. To quote Arup, a company providing engineering, architecture, design, planning, project management and consultation services (Zimmann, 2016),

> "Complexity is one of the defining features of the built environment... Built environment assets tend to have long life cycles in which multiple actors with diverging priorities and incentives interact... Multiple stakeholders and long lead times also mean there is rarely continuity of ownership and control."

Echoing Arup's comments, buildings are inherently complex because each building is a unique entity comprising layers and layers of materials and components in multitude, featuring different characteristics, serving different functions and having different lifespans (Eberhardt et al., 2019).

Brand's **'shearing layer' concept**, illustrated in Figure 2.3.4, shows the six layers making up a building and their potential service life. Moreover, each separate layer involves multiple stakeholders: users and owners - 'stuff' and 'space plan' layers; installation companies – 'service' layer; engineers, architects and construction companies – 'skin' and structure' layers. CE stresses sharing, highlighting the need for various stakeholders of different building layers to collaborate so as to avoid waste.

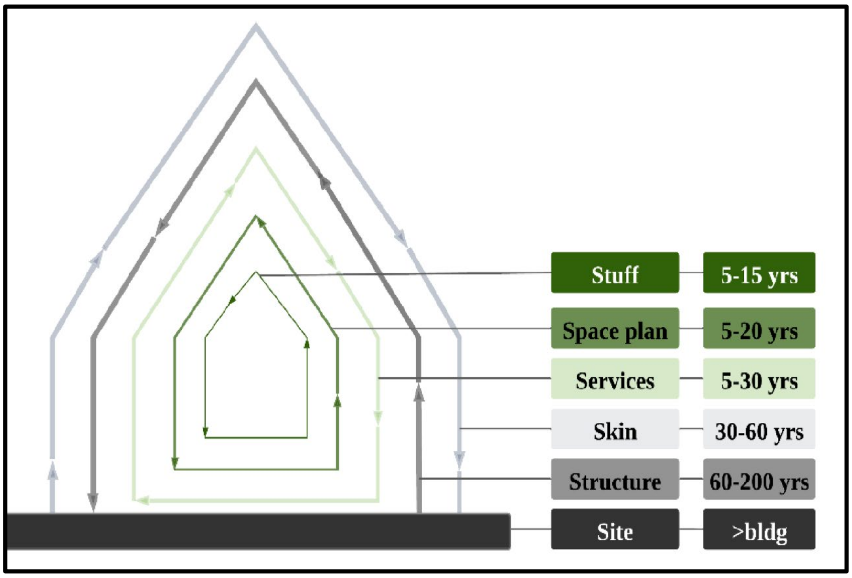

Figure 2.3.4 Brand's Building Layers and their lifespans.
Adapted from: Brand, S. (1995). How buildings learn: What happens after they're built. https://www.overdrive.com/search?q=1FA701FE-EC71-4D4E-805D-04F4CCA4E23E

While the construction industry has great potential for CE implementation (Brambilla et al., 2019), the challenge is that a specific scale of measurement for the construction industry to guarantee its future sustainability is missing (Nuñez-Cacho et al., 2018). With varying rates of renewal/replacement and different potential retrieval for reuse/recycling during the life cycle, a building can be taken as a temporary storage (Heisel & Rau-Oberhuber, 2020) with constant flow of resources requiring individual management. However, material recycling and reuse poses another challenge as it involves not just building materials but also elements, components, modules and the entire building itself, as depicted in Figures 2.3.2 and 2.3.4.

As highlighted by Foster (2020), **lack of knowledge and tools** hampers CE transition in the construction industry. These tools include design tools and guides covering design for CE, design for disassembly, design for adaptability, a range of collaboration tools, building and material information tools and circularity metrics (Hart et al., 2019). Thus, this research will explore how the CE principles can be used as a guide to fill the knowledge gap and offer the tools needed to facilitate circular transition of the construction industry.

2.4 Circularity Assessment for Buildings

As the well-known saying "what gets measured gets done", the circularity breakthrough of the construction industry demands to make circularity measurable and quantifiable, considering the complexity of buildings. The recent review of Bilal et al. (2020) on the current state and barriers to CE in the construction industry highlights a lack of research specifically focusing on the assessment of CE implementation for the construction industry in the context of developing countries.

In Munaro et al. (2020), 39% of research works they analysed are on the theme of recycled/reusable materials while only 17% cover the topic on tools and assessment to support circular construction. Moreover, circularity metrics of the construction industry developed so far (Pomponi & Moncaster, 2017; Figure 2.4.1) are more on assessment of materials and manufactured components at the micro-level but not buildings at the meso-level. Compared with buildings, these manufactured components entail less complicated production processes and are of a shorter life span. As mentioned in Section 2.3.2, a building is a complex structure made up of and made from a wide range of materials and products that will last different lifespans. The built environment, besides being more complex, involves multiple stakeholders, massive investments, capital risks and long lead times. Hence, evaluating building materials and manufactured products only is insufficient for assessing how circular a building is. This study aims to contribute to the **circularity assessment concerns of individual buildings** being evaluated for their performance in implementing circular strategies, echoing the perspective of Pomponi and Moncaster (2017).

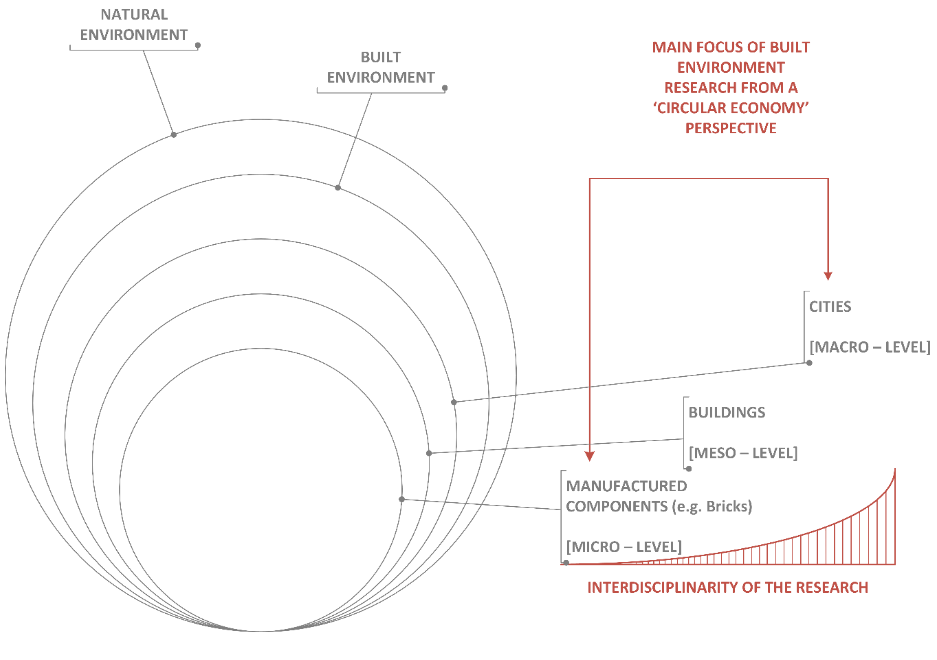

Figure 2.4.1 Framing of built environment research

Adapted from 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

2.4.1 Key Concepts

It is essential to clarify the key concepts in order to know the aspects of building circularity that needs to be assessed according to the CE principles.

Circular Building

Similar to the concept of CE, there is no consensus yet on what circular buildings are. Definitions abound with different focuses. With reference to the 11 definitions gathered by Zhai (2020) from recent literature, Table 2.4.1 lists some of those from English publications of the past five years, citing their sources and highlighting their CE-related emphases in bold.

Table 2.4.1 Definitions of circular building extracted from related literature

Year	Source	Definition
2016	CE100	A truly circular building acts as a **raw material depot**, through **modular and reconstructible design**, documented in a raw **materials passport**.
2016	Bakx et al.	A circular building is a type of building that is **self-sustaining** with **renewable energy** and stimulates **diversity**, whereby the building is built up of the circular building product levels that are designed for **disassembly and adaptability**. To guarantee the possibility of the proposed re-life options in a hierarchical way and effectively accommodates the evolving demands of its context, the selection of **sustainable materials** should enable the **re-life options**.
2017	Pomponi & Moncaster	A building that is designed planned, built, operated, maintained and deconstructed in a manner **consistent with CE principles**
2018	Bokkinga	A building that is designed, developed, managed, and used according to the CE system, a central aspect of the building is a **decrease in the use of raw materials and maximizing reuse**. The aim is to use as few new raw materials as possible and where products, raw materials and systems are used, keeping them as long as possible (on a high-value level) in the construction chain
2018	Leising et al.	A **lifecycle approach** that **optimizes the buildings' useful lifetime**, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a **material bank**
2020	Jia et al.	The use of **practices**, in **all stages of the life cycle of a building**, to keep the materials as long as possible in a **closed-loop**, to reduce the use of new natural resources in a construction

Adapted from Zhai J. (2020) BIM-based building circularity assessment from the early design stage. Master Student Thesis, Department of the Built Environment, Eindhoven University of Technology.

The above definitions, especially those terms and phrases in bold type, have pointed out characteristics of a building to be categorised as circular and the practices to achieve circularity in buildings. For instance, CE-consistent concepts include building as a material depot/bank and better management of material flows through documentation in a material passport; circular designs are modular and reconstructible, flexible and adaptable for re-life options; preferred choice of materials and energy should be sustainable and renewable; and CE targets are decreased use of raw materials and reuse maximisation. Most important of all, the circular approach to construction should be holistic and applied throughout the life cycle of the building.

Summarising the above, a technical definition of circular buildings can be

A construction with circular material usage in both biosphere and technosphere, contributing to material regeneration and value retention, and future-proofed circular designs with flexibility and adaptability enable renewal and repurposing throughout its lifecycle for achieving durability, adaptability and waste reduction.

Building Circularity

Same as CE and circular buildings, building circularity has diverse interpretations but no clear or consensual definition. Geldermans and Rosen-Jacobsen (2015) described building circularity as an approach that facilitates the closing of material loops of the building. In Zhai (2020), building circularity is considered:

A way of designing and managing the circular building during its lifecycle in accordance with circular building design principles to reduce use of raw materials, maximise reuse and recycle of materials and eliminate waste.

Prompt and appropriate gauging of building circularity not only plays the key role of informing different parties on progress and development (Rahla et al., 2019), but also reveal flaws for necessary actions to be taken for improvement so as to achieve what is set out to perform. **The evaluation criteria are of great use to building designers and engineers for making better informed choices**. Hence, the development of a practical assessment scheme for presenting and predicting building circularity is of both need and importance for advancing CE transition in the built environment.

Circular/Circularity Indicators

As defined by Saidani et al. (2019), an indicator is a "quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor". Such definition reveals an essential function of indicators as a metrics for measurement and evaluation, making it analogous to an assessment tool/model. On the other hand, an indicator, like a pointer, also designates aspects of significance that require attention, serves as a signpost that the actors should aspire for transition to CE; and can be used as a decision-making tool for designers. As building circularity is still a developing concept, terms like circular/circularity indicators serve to signify which aspects of CE should be featured in circular buildings.

2.4.2 Obstacles in Building Circularity Assessment

Like the sectoral challenges encountered by the construction industry, obstacles for building circularity assessment abound, which account for the lack of or the existence of few assessment tools/models.

The first obstacle is **not knowing what to assess**. As mentioned above, there exists a plethora of definitions and interpretations (Rahla et al., 2019) on CE, circular building and building circularity, making it difficult to determine the focus or delimit the aspects/items to be assessed.

The second hurdle arises from the **inherent complex nature of the building** (Rahla et al., 2019). The average life cycle of modern buildings ranges from 65 to 70 years while that of most other manufactured products do not exceed a decade.

Thirdly, **buildings contain many different products**. Some account for considerable proportions of the total masses/volumes, others could be of special relevance to environmental or health impacts. **Each product has its own life span and has to be replaced during the building's lifetime**.

Fourthly, the building itself might undergo **major changes**, like refurbishment, additional constructions/extensions, other occupants **with different resource consumption patterns**. Finally, buildings usually have a **unique design** and that may complicate the development of a standardised tool.

2.4.3 Existing Building Circularity Indicators

As said, the notion of circularity in buildings and the built environment is emerging and has not taken deep roots in the related construction industry. In addition, there are obstacles to building circularity assessment as described in Section 2.4.3. Consequently, there are only few existing building circularity assessment metrics/indicators, which will be briefly discussed below.

1. EMF's Material Circularity Indicator (MCI) at product level

Among the established assessment models for measuring how circular materials can be, the most well-known is the Material Circularity Indicator (MCI) developed by the Ellen MacArthur Foundation and Granta Design (EMF & Granta Design, 2015). **MCI measures mainly how restorative the material flows are at the product level with focus on the end-of-life process of circularity**. Its focuses are on the technical cycles and materials from non-renewable sources including fossil fuels, coal and natural gas. Product characteristics taken into consideration are (1) the mass of virgin raw material, (2) the mass of unrecoverable waste, and the utility factor.

2. Verbene's Circularity Indicator at building level

Verberne's (2016) work is the first attempt at developing an assessment tool for determining the circularity level of a building. His proposed model focuses on **technical and functional indicators** for assessing CE performance of buildings and involves four consecutive and hierarchical calculations. First, to assess the input of a building, the **Material Circularity Indicator** (MCI), based on EMF, is calculated. Second, the **Product Circularity Indicator** (PCI) is developed to assess the products in the system with additional and adjusting disassembly factors. The practical circularity value for a product revealed by PCI complements the theoretical circularity value obtained by MCI. Third, the **System Circularity Indicator** (SCI) is developed to assess the circularity of products in a system according to their weight of sales revenues. Finally, the **Building Circularity Indicator** (BCI) assesses the circularity of separate systems as a whole with a factor for the level of importance for each system. In this way, the input, functionality and output performance of a building is respectively assessed. Verbene's BCI has its root in EMF's MCI and incorporates circularity at the different building layers into one aggregate score through multiplying the score of each respective layer with the importance/weight of that layer.

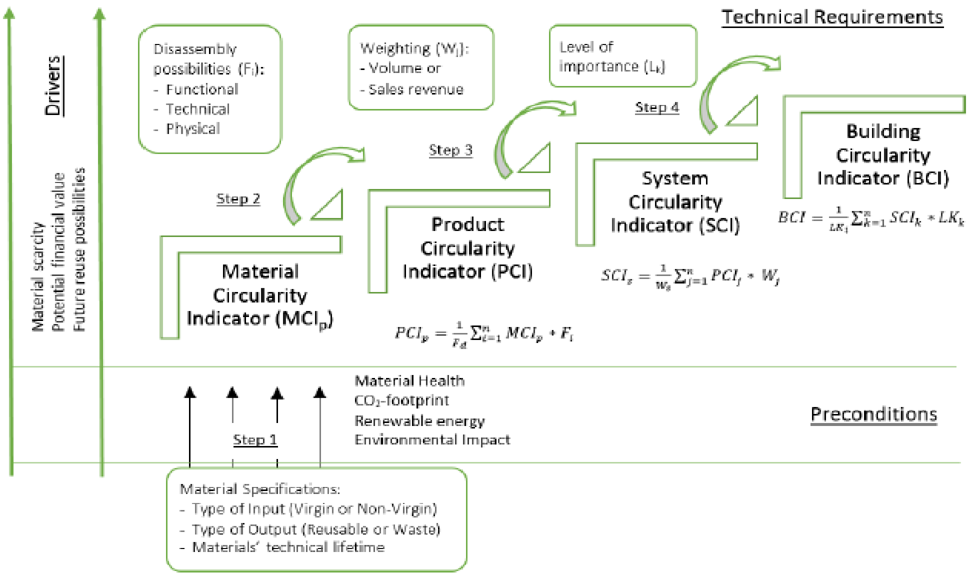

Figure 2.4.2 Verbene's building circularity assessment model of materials within technical cycle
Adapted from Verberne (2016). Building Circularity Indicators: An Approach for Measuring Circularity of a Building

Redeveloping Verbene's BCI, van Vilet (2018) put forward another BCI model with focus on assessing the disassembly potential. With similar focus on the technical cycle and disassembly potential, Alba Concepts (2018) proposed the Building Circularity Index (BCIX). Though all these assessment metrics are developed in the Netherlands, none has been recognised as a certification or labelling methodology for Dutch constructions (Zhai, 2020).

3. <u>Madaster Foundation – Madaster Circularity Indicator at building level</u>

The Madaster Circularity Indicator (CI) (latest version 0.2 published in 2018) developed by the Madaster Foundation (Bronsvoort & van Oppen, 2018) has its basis also on EMF's MCI. It is further improved and adapted for buildings to measure the **circularity scored according to the circular properties of materials and products used during the construction, in-use and end-of-life phases**. While due attention has been given to circularity throughout the entire lifecycle of the building, circularity of different layers of the building has not been taken into account.

With the Madaster platform as a database for building-related information, the assessment provided by the CI aims to offer an incentive for different stakeholders, including owners, investors, architects and designers, suppliers, contractors and waste management companies, to improve building circularity.

4. <u>Platform CB'23 at building level</u>

Platform CB'23 published respectively in 2019 and 2020 *Guide for Measuring Circularity in the Construction Sector 1.0 (*Platform CB'23, 2019) *and 2.0 (*Platform CB'23, 2020) with **goals for material preservation, environmental protection and value retention**, which form the basis of the core measurement method proposed. Correspondingly, with regard to material preservation, indicators 1-3 and their sub-indicators cover quantity of materials used, quantity of materials available for the next cycle, and quantity of materials lost, respectively; indicator 4 concerns environmental impact in different aspects; as for value retention, indicators 5-7 cover techno-functional and economic values, initial, available for the next cycle and lost, respectively.

Platform CB'23 comprises both **quantitative indicators for objects or sub-objects and qualitative indicators listing adaptive properties for each building layer** that merits attention. In other words, in addition to optimising the overall impact of material stock, the quality of the environment, and existing value, Platform CB'23 evaluates adaptive capacity of the building. However, this assessment model is still developing, lacks an overall BCI and has not been put to practice.

Overall, these existing technical assessment models all contribute to develop the following building circularity indicators (Zhai, 2020):

- Percentage by mass of renewable materials
- Percentage by mass of virgin materials
- Percentage by mass of reused materials
- Percentage by mass of recycled materials
- Total mass of materials
- Toxicity of materials

✧ Building circular product levels
✧ Disassembly potential
✧ Adaptability potential
✧ Percentage by mass of reusable materials
✧ Percentage by mass of recyclable materials
✧ Percentage by mass of materials sent to landfill
✧ Percentage by mass of materials sent to incineration
✧ Recycling process efficiency

The above indicators show the focus of assessing the amount of virgin materials used, the amount of unrecoverable waste, and the lifespan of the building. While these existing indicators are still under development, they do serve to arouse more attention to renewability of input resources, the use phase for possibility of material/product reutilization and the potential recoverability of materials at the end-of-life phase (Cottafava & Ritzen, 2021). Among them, only the Guide developed by Platform CB'23 has environmental impact assessed. While designing out waste and salvaging residual value are chief concerns of achieving CE, environmental impact should not be left unattended when aiming for waste elimination and value retention.

2.5 Building Circularity Targets

When assessing circularity performance, CE principles would serve as targets that are required to achieve. Review of related literature reveals diverse CE aspects applicable at different life-cycle stages as listed in Table 2.5.1. These **CE aspects form the backbone of circular building strategies and can guide the development of building circularity assessment indicators**, which will be further discussed in the following chapters and the case studies to shed light on whether the theoretical basis is valid and whether these targets are incorporated in the candidate assessment metrics evaluated in this thesis research.

Table 2.5.1 CE aspects as basis for building circularity targets according to life-cycle stages

Life-cycle Stages	CE Aspects for Building Circularity Targets
Design	Design for demolition Design for adaptability Design for flexibility Design for durability Design out waste Design in modularity Green Procurement Specify reclaimed materials Specify recycled materials

Manufacture & Supply	Eco-design principles Optimise material use Use less hazardous materials Use secondary materials Use recycled materials Design for product disassembly Design for product standardisation Take-back schemes Reverse logistics Increase lifespan
Construction	Procure recycled materials Procure reused materials Off-site construction Minimise waste
In use & Refurbishment	Minimise waste Minimal maintenance Easy repair & upgrade Adaptability/Flexibility Smart renovation & retrofit Imaginative reuse
End of Life	Pre-demolition plan Selective demolition Reuse products & components Closed-loop recycling Open-loop recycling

Adapted from Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: Current awareness, challenges and enablers. Proceedings of the Institution of Civil Engineers - Waste and Resource Management, 170(1), 15-24.

To conclude, the literature review detailed in this chapter on one hand highlights that thinking and acting circular in the construction industry is a way for achieving a sustainable industry and built environment in view of its enormous consumption of materials and energy as well as its negative impacts on the environment. On the other hand, examining the emergence and roots, principles and benefits of CE as well as basis and frameworks for generating circular strategies help establish the theory basis for application of CE aspects for building circularity assessment. **Building circularity targets can serve as the benchmarks for assessment or criteria to be met for being recognised as circular building**. The availability of an assessment metrics for CE performance is considered a common need of the construction industry and an enabler/driver behind CE transition. However, existing assessment models and circularity indicators are mostly of building materials and products, while those at building level have neither been proved valid nor applied. Despite ongoing development of building circularity metrics, the need remains unmet.

3. Needs for Building Circularity Assessment in Taiwan

The unmet need for a standardised scale to assess building circularity has posed a barrier to accelerating CE transition in the global construction industry, with Taiwan being no exception. This chapter presents the vision for Taiwan to go and build circular (3.1), discusses the perspectives from experts in the related field regarding the challenges and needs for promoting circular construction in Taiwan (3.2), and reviews the current building performance certification system used in Taiwan (3.3). Tracing the development history of Taiwan's green building assessment system, the EEWH, and its contribution to promoting green construction inspires how circularity metrics can help promote circular construction economy (3.4) and sheds light on what kind of building circularity assessment system would suit the need of the construction industry and be most likely accepted and adopted (3.5).

As mentioned in the Research Methodology (Section 1.6), related literature on CE transition in the construction sector of Taiwan, a new player in the field, is scarce; hence, interviews were conducted with actual practitioners and stakeholders involved in CE-focused building projects to gain insiders' understanding of the actual situation in Taiwan and their unique perspectives on the research issues.

The experts interviewed have been involved in CE-focused building projects, serving to represent actual practitioners and stakeholders in the related field. The four respondents included the following:

- Project manager, Mr Audi Chow (*PM Chow*);
  responsible for managing the construction of the social housing complex in Taipei City, comprising a total of 1500 units in 2 buildings each with 23 floors. This housing complex to be constructed would be the flagship project demonstrating what circular buildings are and how they are constructed according to CE concepts.
- Director of Feng Yu United Engineering Company Limited, Mr Ji Yeh Hsieh (*Dir Hsieh*);
  the construction company responsible for building TCV.
- Principal Architect of Bio-architecture Formosana, Mr Chang-Lien Lin (*PA Lin*);
  the architecture firm responsible for designing TCV.
- PhD candidate Ms Tracey Chang (*Chang*);
  an academic involved in research and promoting application of CE to construction

3.1 Taiwan's Vision – Think, Act & Build Circular

In Taiwan, as in other parts of the world, CE has been gaining both interest and momentum, particularly after the government promulgation of the "Five plus Two Innovative Industries Plan" in 2016. Indeed, there is every need for Taiwan to think and act circular. Taiwan has a high population density, and yet it is a resource-scarce island highly dependent on imported energy and food. According to the Taiwan Circular Economy Network (TCEN)[4], a domestic non-profit foundation, like the EMF, dedicated to advancing the CE concept, Taiwan imports 98.8% of its fossil fuel, 98% of its metals and 71.8% of its biomass needs. The review of Liu et al. (2020) on Taiwan's Food Security Strategy showed that its self-sufficiency rate in 2018-2019 was a mere 35%. Hence, to enhance resource sufficiency and security is not only to ensure survival but also to maintain competitiveness. Impacts of climate change and pressures from increasing pollution and waste have made such need ever more imperative and importunate.

Among the innovative industrial spearheads, two that aim for reaching sustainable development goals are Green Energy and CE (Van Bueren et al., 2019). Construction is among the three industries highlighted in Taiwan's roadmap for CE transition (Chen et al., 2021). That came as no surprise because estimates of Taiwan's Environmental Protection Administration showed that the construction industry used about 25 million tonnes of raw materials and generated nearly 2 million tonnes of solid waste annually (Lai et al., 2016). Circularity enhancement is further necessitated by the low recycling rate of construction materials. Besides metal being almost 100% recycled, more than 90% of bricks and tiles and more than 60% of concrete are simply disposed of or landfilled. Transition to CE is of need in the construction industry so as to alleviate the pressure on Taiwan's scarce natural resources and inadequate facilities to deal with C&D waste, not to mention the resultant emissions and pollutions. Hence, to realise the vision for long-term sustainability, Taiwan's construction must go circular.

Although the paradigm shift to CE in Taiwan is initiated from top-down as a development goal and a government policy to be launched and complied with, the construction industry in Taiwan has not responded with great enthusiasm. Only a few CE-focused building projects, mainly housing complexes, have been proposed and implemented. Among the project owners are a state-owned enterprise Taiwan Sugar Corporation (TaiSugar), the first business establishment attempting to implement CE in their construction projects, and the Taipei City government, the first city in Taiwan trying to put CE to practice in social housing projects. Both projects are public constructions, revealing that the government-led go-circular policy is yet to gain support from the private sector. More details and discussion of these projects will be presented in the case studies in Chapter 5.

[4] *https://circular-taiwan.org/en/about/*

3.2 Challenges for Promoting Circular Construction in Taiwan

Of all the seven challenges taken from Hart et al. and listed in the first part of the questionnaire, there is none that the respondents disagree with. Among the challenges, "**Construction industry being conservative**", "**Long product life cycles for both buildings and materials**" and "**Lacking coherent vision for development in circular construction"** were ranked by the respondents under "**Strongly Agree**", implying that they were comparatively the major obstacles to promoting circular construction in Taiwan.

Apart from the seven challenges stated by Hart et al. (2019), the respondents also pointed out other deterrents to CE transition in the construction industry in Taiwan which are summarised as follows.

- **Rigid laws and stringent regulations as well as inflexible business models**, which echo the obstacles encountered in other parts of the world as reviewed in the literature study.
  Dir Hsieh: "*Relaxation of procurement regulations is the key to promotion of circular construction*."
  PA Lin: "*Current regulations on wooden buildings are very restrictive. Laws on procurement and commercial contracts are more favourable for a linear economy and need to be adjusted*."
- **Need for industrial integration and better coordination between construction and management**
  Dir Hsieh: "*Most construction companies in Taiwan are of small scale with silo operation. Their impact on implementing/enhancing building circularity is small*.
- **Narrow focus of research on building circularity**
  Chang: "*Emphasis has been on circular use of building materials and mainly concrete and recycling of its mixing components. Studies on modular construction or disassembly techniques are lacking. Use of wood is not preferred due to safety concerns; neither is steel as it has to be imported*."
- **Lack of financial incentives**
  PA Lin: "Development of circular construction is hard without the incentive of commercial benefits."

The above comments revealed the following. First, the seven **challenges** pointed out by Hart et al. (2019) are rather **universal**. That is, Taiwan, like the rest of the world, faces similar problems when trying to apply circular practices to construction. Though CE as a transformation strategy in Taiwan is meant to be incorporated in different sectors, the circular approach takes time to catch on. The **lack of a systemized, nation-wide policy and a clear definition for all stakeholders of what CE actually is** certainly not conducive to CE transition in any sector.

Second, the domestic practitioners deemed the **construction industry in Taiwan**, same as its western counterpart, conservative and passive as well as reluctant to embrace new ideas and approaches. Being **risk-averse** and **overly concerned about safety** causes Taiwan's construction industry to be less keen on making changes. It is particularly so as most of the construction companies are **small enterprises** which cannot afford risky undertakings or financially draining ventures. Indeed, the impression of most practitioners and even the general public is that environmentally friendly production or construction means cost increase. **Lack of foreseeable monetary gains** for the construction industry leads to reluctance in practising circular strategies. Hence, convincing them to change is difficult if not impossible.

Given the situation in Taiwan, 'bottom-up' initiation for CE transition can hardly be expected from the construction industry or construction companies. That is to say, for the new concept of circular construction to infiltrate and take root among practitioners and stakeholders, the impetus for **change of mentality and behaviour has to come from the 'top' and the demonstrative role has to be played by the authorities concerned**.

3.3 Needs for Promoting Circular Construction in Taiwan

With CE designated by the Taiwan government as one of the transformational strategies in national development, the current condition in Taiwan can be said to be favourable for promoting circular construction. Support for circular construction can be in the form of 'carrots and sticks'. On one hand, **market incentives and financial subsidies should be provided and innovations are to be rewarded**. On the other hand, **regulations for circular standards should be set up as benchmarks to follow and legislations should be enacted to ensure compliance**. This is echoed by the respondents expressing the need for the government to provide clear directives coupled with laws enacted, as it did for promoting green buildings. Such is also considered crucial for "*harmonising the diverse interests of stakeholders and standardising the direction of development*" as commented by *PA Lin*.

Moreover, *Chang* pointed out that "*A clear goal in the direction of development would facilitate the establishment of an assessment/accreditation system and indicators in the circularity assessment/accreditation play the guiding role for formulating and implementing circular strategies in the construction industry*." This viewpoint supports the development of a circularity assessment/accreditation system or adoption of a current metrics for promoting circular construction in Taiwan. According to *Chang*, "*The significance of an assessment/accreditation system is that to the construction industry, it provides targets for devoting efforts; while to the government, it provides directions for formulating promotional policy*."

Comments from the different stakeholders interviewed pointed unanimously to the need for an assessment/accreditation system. Their views are consistent with that of Chen et al. (2021), who are also familiar with the local context and development of sustainable constructions in Taiwan. They also regarded regulation and assessment as critical driving forces behind CE transition in Taiwan.

Past experience of the respondents with green building development and promotion has taught them **the crucial role of the government in playing the lead and the essential role of an assessment system in providing the goals and directions.**

The next subsection reviews current building performance certification in Taiwan and traces the history of green building development and promotion to understand the role of regulations and legislation as a promotional strategy in government policies related to buildings and construction.

3.4 Building Performance Certification in Taiwan

Taiwan is one of the forerunners in Asia in setting environmental policies and has a long and successful record in promoting green constructions. Taiwan's green building certification system, **EEWH** standing for **E**cology, **E**nergy saving, **W**aste reduction and **H**ealth has been in use since September 1999. EEWH is the first Asian green building certification system and the fourth in the world developed after BREEAM, the LEED Green Building Rating System (LEED) of the United States, and the Canadian Green Building (GB) Tool (Liu et al., 2019).

EEWH

As indicated by its acronym, EEWH has four categories of indicators. The original version of EEWH comprised only seven assessment indicators; two more were added in 2003 due to increasing global interests in indoor environment quality and biodiversity. EEWH emphasises affordable environmental load, energy saving, resource efficiency enhancement and indoor environmental quality (Liu et al., 2019).

Table 3.4.1 summarises the nine indicators categorised under Ecology, Energy saving, Waste reduction and Health, items evaluated under respective categories and maximum scores awarded.

Table 3.4.1 Taiwan's EEWH for green building assessment, four categories with nine indicators

Category	Indicator	Evaluation Items	Max. Scores
Ecology	Biodiversity	Ecological network, biological habitat, plant diversity, soil ecosystem	9
	Greenery	CO_2 absorption (kg-CO_2/(m^2.40yr))	9
	Soil Water Content	Water infiltration and retention, storm water runoff management	9
Energy Saving	Daily Energy Conservation	Building envelope load ENVLOAD (20% higher than building regulation), and other techniques (including HVAC system, lighting, management system)	28
Waste Reduction	CO_2 Emission Reduction	CO_2 emission of building materials (kg-CO_2/m^2)	9
	Construction Waste Reduction	Waste of soil, construction, destruction, utilisation of recycled materials	9
Health	Indoor Environment	Acoustics, illumination and ventilation, interior finishing building materials	12
	Water Conservation	Water usage (L/person), grey water reuse hygienic instrument with water saving,	9
	Sewage & Waste Disposal Facility Improvement	Sewer plumbing, sanitary condition for garbage gathering, compost	6
		Total	100

Adapted from Taiwan Architecture and Building Research Institute

The scoring and rating awarded the following five grades:

- ✧ **Certified** $60 > \text{Score} \geq 50$,
- ✧ **Bronze** $70 > \text{Score} \geq 60$,
- ✧ **Silver** $80 > \text{Score} \geq 70$,
- ✧ **Gold** $90 > \text{Score} \geq 80$,
- ✧ **Diamond** $\text{Score} \geq 90$

There are two types of certification:
(i) **Green Building Candidate Certificate** for building projects prior to construction
(ii) **Green Building Label** for completed buildings
The minimum requirement for green building certification is to pass four indicators, including two prerequisites (daily energy conservation and water conservation) and two other optional indicators. The label is valid for three years and renewable.

Of note is that the EEWH is the only assessment system evaluating buildings in subtropical regions where climate is characterised by high temperature and high humidity. Again, this certification system is a government initiative and developed by the Architecture and Building Research Institute (ABRI) of the Ministry of the Interior of Taiwan, and the certifying entity of the Green Building Label is the Taiwan

Architecture & Building Center (TABC), also established by the Ministry of the Interior of Taiwan. The involvement of the government in the development of assessment and accreditation required for green buildings has paved the way for further policy implementation and institutionalisation.

Building Certification & Legislation

Though EEWH was adopted in 1999 by the Ministry of the Interior as a standard for certifying green buildings, the Green Building Label was not compulsory for buildings. Naturally, there were limited applications, evidenced by single-digit certifications issued in the years 2000 and 2001 (Figure 3.2.1). The turning point came in 2001 when EEWH accreditation became mandatory under the Green Building Promotion Program, which stipulated that all new public buildings worth over $50 million have to obtain the Green Building Candidate Certificate as a prerequisite of the issuance of construction licence. The enforcement of mandated green building design in the public sector led to a tremendous soar in the number of certifications. As shown in Figure 3.2.1, the number of certifications issued to the public sector was merely 3 in 2001 but rose to 111 in 2002 and remained high. With the public sector playing the leading and demonstrative role, the green building industry and its market was thus gradually formed. In 2004, green building regulations were officially stipulated in the Building Code, meaning that both public and private constructions are required by law to comply with green building design and construction. As shown in Figure 3.4.1, in the past decades, the majority of green buildings are mainly public buildings.

Figure 3.4.1 Green building certifications in public and private sectors (2000-2021) in Taiwan
Adapted from Data from website of Taiwan Architecture & Building Center
https://eewh.tw/information_statistics.php?statistic=type3

Tracing the factors contributing to the rapid growth of green buildings in Taiwan revealed government policy promotion and legislation as the main driver. EEWH as an assessment and accreditation system does play an important promotional role in green building development. In view of the success of such government-led promotional policy, can the same top-down strategy be duplicated in support of circular constructions? Despite determination shown and support been offered, an important element is missing, that is, an EEWH counterpart for circular buildings. **Merely using EEWH for building circularity assessment cannot suffice** as the required conditions for accreditation involve mainly energy and water conservation. Although waste and emission reduction are among the indicators, **there should be greater emphasis on circular use of materials and resources in construction**.

Moreover, in *PM Chow's* opinion, while green buildings and circular buildings have overlapping characteristics, they are also distinct from each other in certain aspects. Furthermore, circular goals cover more aspects and are harder to achieve than green goals; while circular strategies, besides being technical, also involve business models.

Without a building circularity assessment/accreditation system, practitioners involved in building projects do not know the standards required to meet or the criteria for gauging performance. More importantly, **these standards/criteria can guide and facilitate turning CE concepts into defined action plans or circular practices for implementation**. To fill the missing gap, Taiwan has to either adopt an existing building circularity assessment metrics or develop one on its own like the EEWH.

3.5 Candidate Building Circularity Assessment Metrics for Taiwan

As discussed in Section 2.4.3, existing assessment systems, though few and far from being widely adopted, are potential candidates for Taiwan to adopt. However, none of those seem suitable or sufficient to meet the needs of Taiwan. First, **the MCI developed by EMF is meant for evaluating the circularity of products and components of a building rather than the building as a whole entity**. Material circularity assessment constitutes only part of the holistic approach to building circularity assessment. Second, **most of the indicators proposed have not been validated, not to mention adopted or implemented**. Third, existing assessment systems comprise **mainly quantitative indicators involving calculations and few qualitative indicators.** Nevertheless, not everything that can be measured is important and not everything that is important can be measured. Hence, an ideal assessment system should give due consideration to both quantitative and qualitative measurements.

Most of the respondents are not familiar with the existing assessment systems. The one most heard of and sometimes adopted is the MCI. *PM Chow* also commented on Madaster, deeming it unsuitable for Taiwan. "*A good certification system needs to be open and credible. Madaster involves complex calculations requiring relevant building data, and the Madaster Platform functions as a closed system, like a black box*." A reliable Madaster CI score is only feasible for buildings whose products and materials have been fully recorded[5]. In reality, such is hard if not impossible considering the enormous amount of products and materials involved in the different life-cycle stages of a building. The required building data may be either unavailable or incomplete, thus undermining the validity of the calculations.

PM Chow's view on a prospective circularity assessment metric for Taiwan would be to adopt/adapt a current one rather than starting from scratch to develop a new one. He acknowledged the difficulty involved and highlighted that EEWH took seven years to come into being, not to mention the funding and manpower involved.

A unique human factor worthy of consideration when choosing or developing a building circularity assessment system for Taiwan is that most practitioners in Taiwan's construction industry are **familiar with indicators for green building certification.** After all, they have been following and complying with those for twenty years. Faced with the new trend for going circular, building designers and construction engineers often ask if there are equivalents of such indicators or evaluation criteria which they can refer to in planning and decision-making. Hence, it is likely that different stakeholders in the construction industry may find **green building-based circularity assessment metrics easier to understand, accept and adopt**.

With that taken into consideration, BREEAM's proposed framework of circular indicators (BREEAM-C) (Kubbinga et al., 2018), which evolved from its original green building assessment system, may be a potential candidate to meet Taiwan's need. In fact, among the current assessment metrics and indicators proposed, **BREEAM-C is the one and only one with roots in green building assessment**.

To conclude, both literature study and expert opinion pointed out a practical need for a circularity assessment metric in support of promoting circular construction in Taiwan. Now that the government has taken up the leading role, Taiwan has to consider either adopting an available circularity assessment metrics or developing a new one. The subsequent chapters contain a thorough review of a potential solution or a candidate assessment system BREEAM-C, focusing on how BREEAM incorporates material circularity indicators into its existing green assessment framework, and examining its applicability, strengths/inadequacies as well as room for improvement.

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[5] https://docs.madaster.com/files/Madaster_Circularity_Indicator_explained_v1.1.pdf

4. BREEAM Indicators for Building Circularity Assessment

This chapter aims to conduct an in-depth review of BREEAM's proposed framework of indicators for circular buildings (BREEAM-C) (Kubbinga et al., 2018) as a candidate building circularity assessment system for adoption by Taiwan, tracing its evolution from its original green building certification scheme (BREEAM-G) (4.1), focusing on how circularity indicators for material, energy and water are incorporated into the existing green building assessment framework (4.2). Finally, BREEAM-C is evaluated in terms of whether the indicators are realisable through circular strategies and whether due consideration has been given to building circularity in different impact areas, structural layers and life-cycle stages (4.3).

4.1 BREEAM-G: Green Building Assessment System

BREEAM, which stands for Building Research Establishment Environmental Assessment Method, was developed in 1990 by the Building Research Establishment of the UK. It is generally accepted as the first green building rating scheme in the world. More than 2,300,000 buildings in 93 countries have been assessed by BREEAM with around 600,000 certificates issued[6]. Needless to say, BREEAM and EEWH detailed in Section 3.4, both being performance rating schemes for green buildings, have the same goal though also share similarities and differences as they are developed for countries with different cultures and climates.

BREEAM's logo and representative icons, seen in Figure 4.1.1, show the nine categories assessed, covering a broad range from energy to ecology, external environment to internal domain, utilisation of natural resources and materials, management of building, and disposal of waste. The number of indicators, available credits and weighting of each respective category are listed in Table 4.1.1.

Figure 4.1.1 BREEAM's logo and representative icons of nine assessment categories

[6] https://www.breeam.com/ (accessed November 2021)

Table 4.1.1 BREEAM assessment categories, indicators, credits and weightings

Categories	No. of Indicators	Available credits	Weighting
Energy	8	35	20%
Health & Well-being	7	21	19%
Material	5	14	13%
Management	5	19	11%
Pollution	5	10	10%
Land use & Ecology	4	9	8%
Water	4	9	7%
Transport	5	12	6%
Waste	5	9	6%
Total	**48**	**138**	**100%**
Innovation credits			10%

Assessment by BREEAM is to be conducted at two phases in the construction process, namely the design phase and the delivery phase. In the design phase, the assessment is on the sustainability aspirations of the building while in the delivery phase, the assessment is on its actual performance in mitigating negative environmental impact. The ratings and score thresholds are shown in Table 4.1.2.

Table 4.1.2 BREEAM ratings and score thresholds

Qualification	Score threshold	Performance comparison
Pass	> 30%	Top 75% (standard good practice)
Good:	> 45%	Top 50% (intermediate good practice)
Very Good	> 55%	Top 25% (advanced good practice)
Excellent:	> 70%	Top 10% (best practice)
Outstanding:	> 85%	Top 75% (standard good practice)

Individual new buildings under construction were the original targets of BREEAM for assessing their impact on the environment. As time and needs evolve, the scope of BREEAM's assessment framework also changes. The assessment covers not only new but also existing buildings; and not merely single constructions but also industrial or commercial complexes, communities, infrastructure or development projects. Moreover, the concept of sustainability is expanded from the construction stage to include also design, in-use and refurbishment stages. To meet diverse demands from different types of constructions and at different life-cycle stages, there are different BREEAM schemes, as listed in Table 4.1.3.

Table 4.1.3 Different BREEAM schemes for different building types and life-cycle stages

Scheme	Building Type	Life-cycle Stage
BREEAM Communities	Communities	Planning
BREEAM New Construction	New Non-residential	Design Procurement
BREEAM International New Construction	New Residential & Non-residential Not in the UK (national scheme applies)	Design Procurement
Code for Sustainable Homes	Domestic buildings	Design Construction
BREEAM In-Use	Non-domestic Commercial, Industrial, Retail, Institutional	In-Use

In sum, as a green building assessment, BREEAM emphasises sustainability in terms of maximised conservation of resources as seen by more indicators and higher credits awarded to the categories of energy, material, land and water. The highest weighting of 20% given to the category of energy reveals the top sustainability goal of being energy-efficient with minimised carbon emissions or "zero-carbon". In addition to environmental protection and pollution reduction, BREEAM also stresses constructions that support healthier and happier living as well as productive working.

The worldwide trend of shifting toward CE and whole life-cycle thinking for buildings have rendered current green building assessment schemes insufficient for circularity appraisal. Criteria/indicators for building circularity have to be defined and a uniform, effective measuring framework need to be developed.

4.2 BREEAM-C: Framework of Circular Indicators

In view of such need, the operator of BREEAM NL, the Dutch Green Building Council (DGBC) in collaboration with Metabolic, SGS Search and Circle Economy put forward in 2018 "A Framework for Circular Buildings: Indicators for possible inclusion in BREEAM" (BREEAM-C).

'Roots' of BREEAM-C

Having similar goals and missions as those of EMF, Metabolic and Circle Economy, both founded in the NL, are advocates of transition toward CE for global sustainability, offering advice and providing strategies and tools for a smooth transition. Hence, the circularity principles and strategies incorporated in BREEAM-C have their roots in **Metabolic's seven pillars** for CE and **Circle Economy's eight key elements** for CE as summarised in Table 4.2.1.

Table 4.2.1 Metabolic's seven CE pillars and Circle Economy's eight key CE elements

Circular Economy	
Metabolic - 7 pillars	**Circle Economy - 8 key elements**
Materials maintained in continuous high-value cycles	Prioritize regenerative resources
Energy all based on renewable sources.	Stretch the lifetime
Water managed in a 100% circular fashion	Use waste as a resource
Biodiversity structurally supported and enhanced	Design for the future
Human society and culture preserved	Rethink the business model
Health and wellbeing of humans and other species structurally supported	Incorporate digital technology
Human activities generate value in measures beyond just financial.	Team up to create joint value
	Strengthen and advance knowledge

On one hand, the seven CE pillars are taken as the performance characteristics or the desired impacts of CE; on the other hand, seven among the eight key CE elements (with the exception of 'incorporate digital technology') are adapted to be general circular strategies, from which four specific circular building strategies are deduced, namely **Reduce, Synergies, Supply and Manage**. Applying these four strategies to the desired impacts or performance characteristics of circular building further generate sub-strategies, which form the basis of potential circularity indicators. More in-depth discussion on this will be elaborated below.

Before that, attention must be drawn to another important 'root' of BREEAM-C, i.e., **"Roadmap of Circular Land Tendering: An introduction to circular building projects"** (hereinafter Roadmap). Although the focus of this 2016 report prepared by Metabolic and SGS Search is on circular land tendering, it contains guidelines on steps that can be taken to promote and assess circular building practices and innovations. A total of 32 performance-related criteria under five categories, namely Materials, Adaptivity and Resilience, Water, Energy, Ecosystems and Biodiversity were enumerated for promoting adherence to circular principles, which in turn constitute the foundation for circular building assessment. Of note is that the criteria defined in the Roadmap follows the template in existing instruments including BREEAM and GPR Building.

To-cap on how BREEAM-C comes into being, both BREEAM-G and Roadmap play significant roles. Chronologically, there is BREEAM-G developed in 1990, which has become well-established with different localised schemes widely used. Then, the Roadmap put forward in 2016 provides a clear definition on circular buildings in terms of their adherence to CE principles and manifestation of desired impacts of CE. In addition, the Roadmap, modelling on current available schemes, suggests 32 circular indicators. With knowledge on what is to be measured or assessed in buildings qualified as circular and some initial indicators in hand, BREEAM-C put together a strategic framework hoping to answer the need for a circulatory assessment tool. Hence, BREEAM-G and Roadmap are like parents to BREEAM-C.

Appendix B presents a detailed comparison of BREEAM-C with its roots Roadmap and BREEAM-G (version 2014), showing the foundation or inspiration for the current circular indicators and pointing out new 'shoots', in the form of disparities or additions. Significant changes and additions are highlighted and discussed below.

4.3 Circularity Goals Integrated with Green Focuses

'Shoots' of BREEAM-C

Table 4.3.1 Summary of number of strategies and indicators under BREEAM-C

CIRCULAR BUILDING			
Desired Impact Areas	No. of Strategies	No. of Sub-Strategies	No. of Indicators
Material Cycle	4	13	32
Energy Cycle	4	5	9
Water Cycle	3	5	6
Biodiversity & Ecology	4	5	-*
Human Culture & Society	3	3	- *
Health & Wellbeing	3	6	2
Multiple Values	2	2	-

* the same indicators in BREEAM-G were adopted for use in BREEAM-C

Table 4.3.1 summarises the number of strategies, sub-strategies and indicators under each impact area in BREEAM-C. As can be seen, the proposed circular indicators are mainly under the Material, Energy and Water Cycles, which will be the focus of discussion below. The discussion aims to examine the CE principles behind these indicators, what new CE features are considered in the indicators, and how their inclusion would serve the purpose of enhancing building circularity

Material Cycle

Merely looking at the number of sub-strategies (13) and indicators (32) related to the material cycle, one can see the importance of materials in building circularity. Indeed, the concept of buildings as 'Material Banks' forms the backbone of circular transitions. There is even a project called BAMB - **Buildings As Material Banks** (BAMB, 2019) with 15 partners in 7 countries working together for a systematic shift to a circular construction industry. With buildings seen as repositories or stockpiles of valuable, high-quality materials, a circular approach with zero-waste objective is to enable materials to be easily taken apart, recovered, and reused. Hence, emphases are on **material use reduction, flexible building design, environmental impact**

minimization, use of secondary/reused/renewable materials, and knowledge/information sharing.

To facilitate sharing knowledge/information and to put CE into practice, **Material Passport**, also called Product Passport, Circularity Passport or C2C Passport, is a tool specified for keeping stock of the materials 'deposited' in the building and keeping track of material flows. Such information is not only monitored and managed but also shared among stakeholders. The material inventory should contain latest data on components, materials and products used during construction, present during use as well as generated during deconstruction. Documenting locations and flows of materials facilitates possible reuse/reutilization. In this way, the life cycle of materials not only becomes longer but also more useful. Knowing what is in hand prevents loss, registering what is in the building helps reduce depreciation and retain value. A comprehensive and detailed inventory that allows traceability of materials is of use to the developer in the construction and demolition stages as well as the users in the in-use and refurbishment stages. It is also of particular importance at the end-of-life stage so as to enable effective reuse/reutilization and to facilitate disassembly and reassembly. Digital technology and data accessibility are influential factors on whether material passports can become everyday practice. Hence, the CE element of 'incorporate digital technology' is after all embedded in the knowledge/information sharing practice.

Under **Optimization of Material Use**, BREEAM-C incorporates a new perspective on achieving CE, **M1.1 Accountability and substantiation of building volume**. Indicators under this criterion highlights the need and practice of minimising the possibility for new construction, minimising construction area and total material mass, going beyond BREEAM-G's focus on minimising environmental impact of materials. Instead, material usage and building area should be reduced to what is nominally required. Keeping total mass and area to the minimum would also contribute to mitigate the possible negative impacts of the building on the environment

Among the new indicators, **M1.3.2 under Design for resilience** aims at making buildings more durable by minimising the risks of crucial functions being damaged/destroyed when situated in vulnerable locations of buildings. The same objective is echoed in **M1.3.3** with extra protection for parts of buildings under high risk of damage. Maintaining and enhancing the resilience of buildings through anticipating and avoiding threats contributes to reducing materials used for repair or reconstruction. Circular strategies for meeting this criterion not only have the benefit of optimising material use, the construction and use of buildings can be more cost-efficient.

Both **M1.4.1** and **M1.4.2 under Design for reassembly** are new additions as reassembly at end-of-life stage is a new circularity concept not present in BREEAM-G. Again going beyond design for disassembly, which aims at material recovery and value retention, BREEAM-C takes one step further to ensure meaningful reuse of parts and components after deconstruction. In other words, the target is more than facilitating material removal or minimising demolition waste but to ensure closure of material cycle through reinjecting disassembled materials into the loop for next use, giving an afterlife to the used materials. The same stress on reutilization of components, elements and products whether previously used or from demolition, is echoed in new indicators **M2.2.2 under Maximize amount of reused components, M2.3.1** and **M2.3.3 under Maximize amount of reused elements, M2.4.1** and **M2.4.4 under Future use.** To maximize reuse potential and increase reuse options, flexibility and convertibility of whole building design are the keys.

In sum, new material-related indicators in BREEAM-C are added **to ensure and enhance building circularity through extending the life cycle of materials in being reutilized and prolonging the lifespan of buildings in being able to stand the test of time and challenges from manmade and natural disasters**. The tool used in BREEAM-C for assessing material reutilization is the EMF's MCI, a previously discussed building circularity assessment tool at the product level (Section 2.4.2).

Energy Cycle

With respect to energy consumption, in addition to the emphasis of BREEAM-G on energy-efficiency during the in-use stage only **(E1.1.1)**, BREAM-C stresses also minimal energy consumption during the construction phase **(E1.1.2)** and even during the design phase **(E1.1.4)** through selecting elements, components and/or materials with least embodied energy. Hence, BREEAM-C has given due attention to energy uses in different life-cycle stages. While the same strategy for reducing energy consumption is adopted, BREEAM-G gives priority to lower greenhouse or carbon emission while BREEAM-C targets **natural resource conservation and preservation through avoiding waste**. Note that environmental impact of energy use has not been left out in BREEAM-C as seen in indicator **E3.1.1** under **Minimize environmental impact on energy source,** with energy required for construction and use of building originates from sources with minimum environmental impact**.** Application of renewable energy is also stressed with an additional requirement of being 'localised".

To enhance efficient use of energy at different stages, knowledge and information sharing among users is again emphasised, as in material cycle. Good performance in both **E1.1.3** (information sharing systems) & **E4.1.2** (publicly available data) is not only indicative of effective energy management but also easy accessibility of knowledge/information on energy use for all stakeholders for the ultimate goal of usage reduction. Another way to achieve reduced consumption is smarter energy use facilitated by **E2.1.1** under **Optimization of Energy Demand** through **Energy matching**. In BREEAM-G, the emphasis is on monitoring with sub-metering, which serves the purpose of documenting energy use, but not necessarily managing it better. Instead, BREEAM-C focuses **energy matching through storage and/or management systems, aiming to avoid mismatch and hence prevent waste**.

Water Cycle

With respect to water consumption, usage reduction and recycling can be considered the two pillar strategies. There is another aspect in **W.2.3.1** under **Resource/nutrient recovery which promotes recovery besides water**. This is in line with the 'no-waste' attitude that whatever can be recovered should be recovered and reinjected as inputs into the cycle. The same emphasis of minimal water used (saving and water-free) is entrenched in design, construction and use phases, in addition to recycling through water cascading (**W2**). More efficient or smarter water use is realised through better water management (**W3.1.1**) Again, knowledge/information sharing regarding water use is highlighted by (**W1.1.2**) of BREEAM-C, which goes beyond the focus of BREEAM-G on using water meters to assess water used/saved.

In sum, indicators of the material cycle constitute the largest number and are given due consideration and top priority in BREEAM-C. This echoes Pauliuk (2018) that material cycles in terms of "natural resource depletion, in-use stock growth, and the useful service lifetime of materials" should constitute the core CE indicators.

With respect to the **Material Cycle**, the main advancement of BREEAM-C over its predecessor BREEAM-G is due consideration to the full lifespan of materials used and the building besides minimising environmental impact. In particular, there should be **end-of-life plans with guides drawn up on demolition, recovery of renewables for reassembly, reuse, and buy-back, with emphasis on future use**. Moreover, in addition to preferred use of recyclable and bio-based materials with least negative externalities, there is also the emphasis on **local sourcing**. Innovative circularity concepts such as **Material passport (M4.1), LCA (M1.5) and MCI (M2.1.1.), C2C material ban list (HW1.1.1)** are all introduced to improve over the original BREEAM-G. Similarly, for the **Energy Cycle**, BREEAM-C considers **energy consumption of BOTH construction and in-use phases (E1)**, with the addition of **new energy management & storage as assessment items (E2)**. Moreover, not only renewable but also **localized energy sources with least environmental impact (E3)** are given due credit

Circularity in Green Economy Context

Figure 4.3.1 is a simplified illustration of the relationship between CE and green economy and their focuses. As shown, CE focuses are grouped under Waste management (WM), Waste prevention (WP) and Resource efficiency (RE). Waste prevention is also referred to as source reduction and waste minimization. In terms of the R-imperatives, WP involves Refuse/Rethink/Reduce while WM involves Reuse/Repair/Refurbish/Remanufacture/Repurpose/Recycle/Recover, all aiming to design out waste and becoming resource-efficient in order for the ecosystem to sustain and for humankind to enjoy health and well-being. Obviously, **CE is embedded in the green economy context**. Hence, BREEAM's attempt in using a green building assessment as the foundation for building circularity assessment is a fitting approach.

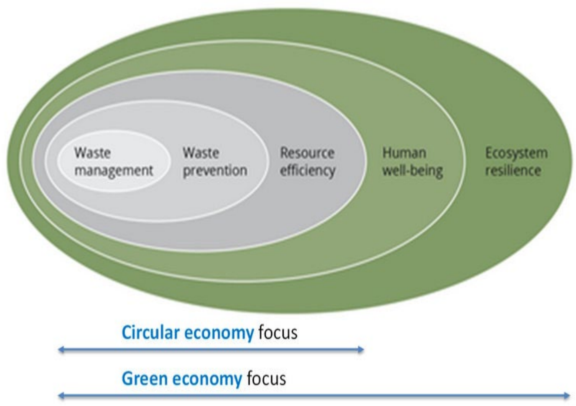

Figure 4.3.1 Circular economy in the context of green economy.
Adapted from D'Adamo, Idiano. (2019). Adopting a Circular Economy: Current Practices and Future Perspectives. Social Sciences. 8. 328. 10.3390/socsci8120328.

Table 4.3.2 summarises BREEAM-C indicators in relation to the CE principles in which they are rooted (Table 4.2.1). As can be seen, each of BREEAM-C indicators has its root in the key circular elements, with the majority of indicators rooted in the "**Use waste as a resource**" principle, justifying these indicators as valid criteria for circularity assessment. Moreover, these principles and strategies behind these indicators are applicable through R-imperatives (Figure 2.2.4) to specific layers (Figure 2.3.4) and at the suitable life-cycle stages (Table 2.5.1) of buildings. For better clarity and simplicity, the 10 R-imperatives listed in Figure 2.2.4 are condensed into 5R, which is the most utilised in CE-related literature (Reike et al., 2018). For practitioners intended or required to implement CE in their building projects, the current analysis illustrates the feasibility of realising CE goals through the different R-imperatives applied to the different building layers discussed in Section 2.3.2 and at different life-cycle stages discussed in Section 2.5. Hence, it can be concluded that **BREEAM-C with indicators on materials and resources incorporated into green building assessment is a valid framework well-grounded in CE principles and covers building circularity realisable through R-imperatives applied to building layers and life-cycle stages of buildings.**

Table 4.3.2 BREEAM-C indicators of Material, Energy and Water Cycles in relation to CE principles that can be realised through applying R-imperatives to specific layers and life-cycle stages of buildings

Life-cycle stages are **D**esign, **M**anufacture **& S**upply, **C**onstruction, **I**n use **& R**efurbishment and **E**nd **o**f **L**ife

Material Cycle

Indicator	**CE Principles**	**R-imperatives**					**Building Layers**						**Life-cycle Stages**				
		Rethink	**Reduce**	**Reuse**	**Repair**	**Recycle**	**Stuff**	**Space Plan**	**Services**	**Skin**	**Structure**	**Site**	**D**	**M & S**	**C**	**I & R**	**EoL**
M1.1.1	Stretch lifetime																
M1.1.2	Reduce consumption																
M1.1.3																	
M1.2.1	Design for future																
M1.3.1																	
M1.3.2	Stretch lifetime																
M1.3.3																	
M1.4.1	Design for future																
M1.4.2																	
M1.4.3																	
M1.5.1	Reduce impact on environment																
M1.5.2																	
M2.1.1	Use waste as a resource																
M2.1.2																	
M2.2.1																	
M2.2.2																	
M2.3.1																	
M2.3.2																	
M2.3.3																	
M2.4.1	Rethink business model																
M2.4.2																	
M2.4.3																	
M2.4.4																	
M3.1.1																	

M3.1.2	Prioritize regenerative resources																
M3.2.1	Reduce consumption																
M3.2.2																	
M3.3.1																	
M3.3.2																	
M4.1.1	Strengthen & advance knowledge																
M4.1.2																	
M4.1.3	Design for future																

Energy Cycle

Indicator	**CE Principles**	**R-imperatives**					**Building Layers**						**Life-cycle Stages**				
		Rethink	Reduce	Reuse	Repair	Recycle	Stuff	Space Plan	Services	Skin	Structure	Site	D	M & S	C	I & R	EoL
E1.1.1	Reduce consumption																
E1.1.2																	
E1.1.3	Incorporate digital technology																
E1.1.4	Reduce impact on environment																
E2.1.1	Incorporate digital technology																
E3.1.1	Reduce impact on environment																
E4.1.1	Incorporate digital technology																
E4.1.2																	
E4.2.1																	

Water Cycle

Indicator	CE Principles	R-imperatives					Building Layers						Life-cycle Stages				
		Rethink	Reduce	Reuse	Repair	Recycle	Stuff	Space Plan	Services	Skin	Structure	Site	D	M & S	C	I & R	EoL
W1.1.1	Reduce consumption																
W1.1.2	Incorporate digital technology																
W.2.1.1																	
W2.2.1	Use waste as a resource																
W2.3.1																	
W3.1.1	Incorporate digital technology																

5. Applicability of BREEAM for Building Circularity Assessment

To the knowledge of the author and till the time the thesis research was carried out, the proposed BREEAM-C indicators have not been applied or validated. This chapter reviews the applicability of BREEAM-C to building circularity assessment using a two-pronged approach. First, BREEAM-C indicators are matched against prevalent circular practices (5.1). In actual application, these indicators when playing the role of assessment criteria should have the capacity of identifying circular practices if implemented; or when serving as pointers for circularity goals should inspire circular practices to be adopted. Second, cross-case analysis is performed using BREEAM-C indicators to assess two CE-focused building projects to demonstrate and evaluate its application in a real-life context (5.2).

5.1 BREEAM-C Indicators & Prevalent Circular Practices

There exists a plethora of strategies and practices related to CE, most of which are qualitatively deduced from systematic literature review (Adams et al., 2017; Munaro et al., 2020). These circular practices often overlap with other approaches such as cleaner production and Industrial Ecology (Schroeder et al., 2019); and are applied in diverse fields including manufacturing, waste and energy management, and of course, construction. Moreover, these practices show variations in countries and localities owing to social, cultural and climatic conditions. For example, insulation of buildings is considered important in European countries but not so in tropical and subtropical regions.

In a recent article entitled "The Key Strategies to Implement Circular Economy in Building Projects—A Case Study of Taiwan" (Tserng et al., 2021), 30 circular practices are identified from five CE-focused pilot building projects, three from the Netherlands and two from Taiwan. Located respectively in Europe and Asia, the two localities chosen reflect different concerns in constructions. The three Dutch pilot projects are Park 20 | 20 (Zwart, 2018), Venlo City Hall (VCH) (Eurbanlab, 2015), ABN AMRO CIRCL (Circle Economy & ABN AMRO, 2017); and the two Taiwanese pilot projects are TaiSugar's Circular Village (TCV, also known as Shalun Circular Housing) and Nangang Public Housing (Tserng et al., 2021). Among these, VCH and TCV are further explored in the cross-case analysis.

Table 5.1.1. lists the 30 circular practices identified from the above-mentioned CE-focused pilot building projects (hereinafter CE-30) (Table 7 of Tserng et al., 2021) categorised in terms of their status of development and extent of implementation and whether they are covered by BREEAM-C indicators or not.

Table 5.1.1. 30 circular practices identified from selected CE-focused pilot building projects covered (✓) and not covered (**X**) by BREEAM-C indicators

Circular Practices		**BREEAM-C**	
Well-developed & widely implemented Total: 11 practices ✓ : 9 practices **X** : 2 practices	Passive (energy) / green / bio-architectural design	✓	
	Natural lighting system	✓	
	Solar energy system	✓	
	Heat recovery system	✓	
	Water recycle system	✓	
	Urban agriculture	✓	
	Zero waste / zero energy consumption	✓	
	Reusing green and healthy materials	✓	
	Using renewable or recycled materials	✓	
	Leftover recycle system		**X**
	Construction waste recycling system		**X**
Innovative & eagerly adopted Total: 8 practices ✓: 3 practices **X** : 5 practices	Lightweight structure	✓	
	Closed loops (e.g., on-site resource circular flows)	✓	
	Lifespan extension (smart maintenance / repair /renewal)	✓	
	People-oriented design (e.g., good indoor environment)		**X**
	CE-related certification (products/materials/ organisation)		**X**
	Prefabrication system		**X**
	Sharing space (e.g., co-working space)		**X**
	Exchange platform (e.g., used goods, agricultural products)		**X**
Pioneering with room for further development & use promotion Total: 11 practices ✓: 5 practices **X** : 6 practices	Innovative business model (e.g., material ownership by supplier)	✓	
	Flexible unit (e.g., design for disassembly & reassembly)	✓	
	Building materials / equipment tracking (e.g., QR code)	✓	
	Product as a service (e.g., lighting, elevator, furniture appliance)	✓	
	Material passport	✓	
	Innovative financial model (e.g., flexible taxation)		**X**
	Modular unit (e.g., Modular partition/exterior wall)		**X**
	3D printing		**X**
	Sharing ownership (e.g., appliance, vehicle)		**X**
	Quantifying residual value of materials		**X**
	Material bank		**X**
	Total number of circular practices:	17	13

In contrast to those theoretically characterised from literature review (Table 4, Benachio et al., 2020), CE-30 listed above have been practically applied to actual building projects designed and implemented with CE as the guiding principle. It can be said that they are of greater relevance to achieving CE in the built environment; their applicability has been demonstrated, and they can be adopted/adapted by other CE-focused construction projects. In view of these, CE-30 makes a good starting point for matching against the BREEAM-C indicators.

Such matching serves the following purposes. First, it validates the applicability of BREEAM-C indicators in terms of their capacity in recognizing known/implemented circular practices. Second, it reveals what known circular practices are left out and why, implying whether there is room for further improvement in BREEAM-C so that circular practices can be acknowledged, contributing to the recognition/certification of the building/project as circular. Third, relevant to achieving CE in the built environment, what other circular practices in addition to CE-30 the indicators are looking for.

5.1.1 Circular Practices Identified by BREEAM-C Indicators

Table 5.1.2 lists the CE-30 covered by BREEAM-C indicators according to the respective impact areas and those not covered by this circularity assessment framework. As can be seen, BREEAM-C indicators can recognize more than half of the 30 identified circular practices.

On one hand, the same circular practice, such as ‘Using renewable or recycled materials’ and ‘Water recycle system’ can be recognised by more than one indicator, revealing its significance and contribution to circularity. Indeed, recycling or reinjecting reusable materials into the cycle so as to close the loop and minimise waste is a distinct feature of particular emphasis in CE. Hence, buildings/projects implementing such practices should certainly be recognised as circular. Take the practice ‘Water recycle system’ for further examination, the five different indicators associated with such practice reflect different means or strategies to realise such practice. In other words, these indicators serve as useful references for putting water recycling into practice. On the other hand, more than one circular practices can be recognised by the same indicator, such as M2.4.1 ‘Circular business models used could possibly encourage return & reutilization of products’. Again, return and reutilization is emphasised, which echoes recycling and is in line with the CE focus. Of note is that this indicator encourages new thinking and new approaches to ensure future use of materials.

Among those practices being recognised, the majority are well-developed and widely implemented, especially those related to the Energy and Water cycles, Biodiversity and Ecology, Health & Well-being. It can be said that these practices are both green and circular, such as water recycling, solar energy and natural lighting. The same is true for practices involving material reuse/recycle and waste minimization. Nevertheless, there are several innovative material-related approaches eagerly put to practice by the construction industry for achieving circularity, including use of lightweight structure, lifespan extension, and resource circular flow. Pioneering practices acknowledged by BREEAM-C indicators but with room for further development are product as service / material ownership by supplier, modular construction and flexible unit, and material passport. The benefits of these practices are yet to be validated and advocated to different stakeholders of the building. The fact that these practices are recognised and given due credits by BREEAM assessment would promote their adoption and implementation.

Table 5.1.2 Matching between BREEAM-C indicators and circular practices

	CE-30 covered by BREEAM-C indicators		CE-30 NOT covered by BREEAM-C indicators
Material Cycle	M1.1.3	Lightweight structure	Construction waste recycling system Prefabrication system Modular unit 3D printing Material bank Quantifying residual value of materials
	M1.2.1	Flexible unit	
	M1.3.3		
	M1.4.1	Lifespan extension	
	M1.4.2		
	M1.4.3		
	M2.1.1	Reusing green and healthy materials	
	M2.1.1		
	M2.2.1	Using renewable or recycled materials	
	M2.3.1		
	M2.3.1		
	M2.4.1	Innovative business model Closed loop Zero waste	
	M2.4.3	Product as a service / Material ownership by supplier	
	M3.1.1	Using renewable or recycled materials	
	M3.1.2		
	M4.1.1	Material Passport	
	M4.1.2		
Energy Cycle	E.1.1.1	Passive (energy) architectural design	
	E.3.1.1	Solar energy system Heat recovery system	
Water Cycle	W1.1.1	Water recycle system	
	W1.1.2		
	W2.1.1		
	W2.2.1		
	W3.1.1		
Biodiversity & Ecology	BE2.2	Bio-architectural design Urban agriculture	
Health & Wellbeing	HW2.2	Natural lighting system	People-oriented design
			Leftover recycle system Sharing space Exchange platform Other CE-related certification Sharing ownership Innovative financial model
No. of circular practices		**17**	**13**

5.1.2 Circular Practices NOT Covered by BREEAM-C Indicators

As seen in Table 5.1.2, of the CE-30 circular practices, 13 are without corresponding BREEAM-C indicators. However, a closer look at these practices reveals that they are not totally neglected or left out. Analysing why these are seemingly left out provide useful references on how BREEAM-C can be improved. **Through increasing the current seven impact areas and extending their coverage would enable more practices to be acknowledged. Certain indicators would have to be made more specific so as to focus on aspects worthy of due recognition**.

Among the six practices under Material Cycle, 'Construction waste recycling system' has already been included in BREEAM-G under WST 1 'Waste management on the construction site'. Under M2 Reutilization of materials, components and elements, the reuse of construction waste should have been included though not specifically mentioned. Three other practices, 'Modular unit' (e.g., modular partition/exterior), 'Prefabrication system' and '3D printing' share the advantages of enabling or facilitating reuse/repair of materials and minimising material use/waste, which contribute to prolong the lifespan of building materials. It is thus suggested that under M1.2 Design for flexibility or M1.4 Design for reassembly, a 'Design for Manufacture and Assembly' sub-strategy should be added to recognize modularity practice as well as prefabricated or 3D-printed materials in construction.

As mentioned in Section 4.3, the concept of buildings as "Material Banks' forms the backbone of circular transitions with emphasis on reuse/recycle. Practices such as 'Material Passport' documenting the inventory and flow of materials used, M1.2 Design for flexibility with the objective of enabling materials to be easily taken apart, recovered and reused as well as M2.4 Future use are all related to this. Thus, it can be said that the concept of 'Material bank' has been embedded in several circular practices. As for the last practice of 'Quantifying residual value of materials', understanding the total use cost of a whole building life-cycle can provide better economic estimation for building materials to be reused. Hence, this should be specified as a required information item in the Material Passport.

Noted also in Section 4.1 is that indicators of Biodiversity & Ecology, Human Culture & Society and Health & Well-being are directly adopted from BREEAM-G for green building assessment and hence scarcely associated with circular practices. Of the three practices classified under these impact areas, 'Natural lighting system' is originally under BREEAM-G HEA 6 Light control and now under Health & Wellbeing. However, this practice also serves the purpose of reducing energy consumed for illumination. Thus, it is suggested to be considered under sub-strategy E1.1 Minimal energy used & contained in building design. Two human-related impact areas in BREEAM-C are Culture & Society as well as Health & Well-being, the practice of

‘People-oriented design’ serves to bring attention and due emphasis to these two impact areas. Building design with the objectives of improving the health of users and providing a user-friendly working environment can enhance work efficiency and reduce costs.

Finally, of the six circular practices not classified under any of the impact areas, ‘Leftover recycle system’ refers mainly to organic leftovers is related to WST 5 ‘Compost’ in BREEAM-G. Practices including ‘Sharing space’ in residences and workplaces, ‘Sharing ownership’ of vehicles and appliances, and ‘Exchange platform’ of used goods and agricultural products, all aim for maximum resource efficiency and waste reduction are certainly CE-related especially during the in-use/operation phase but do not fall under any of the impact areas of BREEAM-C. Similarly, other CE-related certifications such as C2C for product circularity and BS8001 for organisation circularity, though not currently included in BREEAM-C should be given due credits for their contribution to overall circularity of the building.

An in-depth analysis and discussion on possible improvements and expansions of current BREEAM-C and will be covered in Section 6.2.

5.1.3 BREEAM-C Indicators Without Matching Circular Practices

Although there are some known circular practices that BREEAM-C indicators fail to give recognition, the CE-30 list is neither exhaustive nor comprehensive. There are potential circular practices suggested by BREEAM-C with no matching practices mentioned in CE-30. It can be viewed that the proposed BREEAM-C indicators can serve to inspire and encourage commendable CE-related practice so as to realise higher circularity. The following discusses examples of some of the BREEAM-C indicators not attended by CE-30.

- ✧ **M1.1: Accountability and substantiation of building volume** – This sub-strategy should be realised through very early design efforts for **‘Refurbishment rather than new development’ (M1.1.1)** and **‘Minimizing construction/renovation space’**, **(M1.1.2)**, not just for buildings alone but also community planning. Then from manufacture through construction and use phases, **‘Minimizing total mass of material usage’ (M.1.1.3)** is an important practice to adhere to as a core circular practice.
- ✧ **M2: Reutilization** – This gives much emphasis to local supply of reused materials/elements and components. Indeed, **‘Local sourcing of materials’**, **(M2.1.2)** whether reused or not, should be given greater priority as that would involve less transport, thus incurring lower carbon footprint and environmental impact.

- ✧ **M3.2: Minimize use of scare/critical materials** – In line with the C2C emphasis of not using critical materials, the sub-strategy aims to curb further resource depletion. The construction industry should step up to **'Keep use of scare/critical materials to the minimum' (M3.2.1)**, and **'Proper documentation of their use and flow' (M3.2.2) in 'Material Passport'** (already a CE-30 practice) would contribute to avoid misuse/waste.

- ✧ **M4.1: Availability of Information** – A specific and significant end-of-life practice is **'Disassembly guidelines' (M4.1.3)**. Advanced planning and directives for demolition should be part and parcel of all circular constructions so as to ensure recovery of useful materials as inputs of the building cycle, thus realising the essence of being circular. However, this has been neglected at the design stage because end-of-life phase at that time point seems too distant to make preparations for. Due consideration to the eventual demolition, though remote, helps put things into perspective and would influence the choice of materials to use and modes of construction to adopt. Hence, this practice should fittingly be acknowledged and credited.

- ✧ **E4.2: Possibility of optimization during use phase** – **'Performance-based contracting' (E4.2.1)** highlighted in this sub-strategy should be made applicable to all contracts involved for the construction and throughout different life-cycle stages and not just the use phase.

- ✧ **E4.1 & W3.1: Availability of Information** – **'Open access to use of energy and water'** should also be put to practice as free flow of information would get all stakeholders involved in realising the common goal of reducing consumption for resource preservation.

To conclude, the matching of BREEAM-C indicators against prevalent circular practices detailed above illustrate the following. First, **BREEAM-C, as an extension of BREEAM-G, does include new and innovative CE-focused indicators as required for serving its purpose of building circularity assessment**. As shown in Table 5.1.1, many innovative and pioneering CE practices currently implemented are already covered by BREEAM-C indicators. Moreover, indicators discussed in Section 5.1.3 are without corresponding established practices in the construction industry. They are CE innovations which can serve to guide CE transition. Nevertheless, whether these indicators are practical and whether related practicable strategies can be devised are yet to be seen. In sum, BREEAM-C indicators have shown ability to identify circular practices when implemented; thus demonstrating its applicability as a circularity assessment metrics.

5.2 Cross-case Analysis of Venlo City Hall and TaiSugar's Circular Village

To further evaluate and illustrate the applicability of BREEAM-C to building circularity assessment, two showcase CE-focused construction projects, namely Venlo City Hall (VCH) and TaiSugar's Circular Village (TCV) are studied and compared. VCH is chosen as BREEAM-C is put forward by the Dutch Green Building Society in collaboration with Metabolic, SGS Search and Circle Economy, all from NL. Moreover, one of the 'parents' of the proposed framework is the roadmap of circular land tendering in NL. Hence, it is natural and logical to include a Dutch case for more in-depth study. Taiwan and NL are similar in size and economy; and both look to CE as a route to self-sufficiency and sustainability. Being new to the field, Taiwan takes NL as an exemplary model and TCV is often deemed VCH's Asian counterpart. Hence, the cross-case analysis would reveal whether there are variations in performance when BREEAM-C indicators are applied to **constructions of different types, for different functions, in different global regions and climate zones**.

As mentioned in the beginning of this chapter, the proposed BREEAM-C indicators have not been applied to constructions for circularity assessment. Neither have VCH and TCV been assessed using circularity metrics. Hence, this cross-case analysis performed is on one hand **a 'mock' validation of BREEAM-C in terms of its capacity for building circularity assessment in a real-life context**; and on the other hand, **a 'maiden' assessment of VCH and TCV in terms of its circularity performance, testifying whether they really live up to its name as circular constructions**.

Moreover, insights gained from comparing the circular practices implemented at VCH and TCV in the light of BREEAM-C indicators would reveal **BREEAM-C's strengths and inadequacies as well as room for improvement and expansion**. In particular, the applicability of BREEAM-C to circularity assessment of TCV would also shed light on the **potential of BREEAM-C being adopted as an assessment metrics for certifying circular buildings in Taiwan**.

Diverse data of the respective cases are collected from related literature, publications and official websites. Table 5.2.1 lists comparative features of VCH and TCV and Table 5.2.2 compares circular features of VCH and TCV under Material, Energy and Water Cycles against BREEAM-C indicators. Detailed case information of VCH and TCV with illustrations depicting circular features and characteristics is provided in Appendices C and D, respectively.

Table 5.2.1 Comparative features of VCH and TCV

VCH	TCV
Project Owner	
Venlo City government with business sector	Taiwan Sugar Corporation, state-owned enterprise
Year of Completion	
Completed in 2015; Open for use since 2016	Completed in July 2022, just open for use
Awards	
Greenest city of Europe (2003) Cradle to Cradle Frontrunner Award (2013)	EEWH Gold Candidate Certificate Honourable mention in Public Construction Golden Safety Award (2020) FIABCI-Taiwan Prix D'Excellence Awards Planning & Design Excellence Award (2019) Shortlisted for World Architecture Festival Awards (Residential – Future Project category (2018).
Achievements	
Sign of excellent service to residents and businesses with an image of being open, transparent and accessible	
Location & Climate	
Situated in south-eastern NL with temperate climate	Located in south Taiwan within tropical climate zone
Project Description	
City Hall office building	Residential use to meet accommodation needs of stationed staff at the Science City
Three-storey underground parking garage, providing 400 parking spaces	429 rental units: Studio, 1- to 3-bedroom apartments
Total office floor space of 13,500 m^2 for 620 workplaces that can accommodate 900 employees	Site area: ~ 14,000 m^2 Gross floor area: 28,580 m^2.
Design Goals	
Emphasise providing comfortable & healthy working environment with innovative sustainability.	Smart city that co-develops with nature, People-oriented community with green life system
	Three Zeros – Zero Waste, Zero Emission and Zero Accident
	Sustainable, co-sharing, homely & healthy living environment
Financial Savings	
Applying C2C principles within a CE business model would save 16.8 million Euro over the use time of the building for its initial investment of 3.4 million Euro.	Unknown as just open for use
Procurement of C2C furniture alone leads to an 18% cost saving	
Energy cost reduced from 600 Euro/yr to 140 Euro/yr	

<u>Circularity Performance of VCH and TCV</u>

As shown in Table 5.2.2, over 90% of the indicators have matching circular practices implemented in the two building projects. Alternatively, characteristic features deemed compliant with CE principles by both VCH and TCV are also recognised as such according to the BREEAM-C indicators. Hence, it can be said that **BREEAM's proposed framework does fulfil its purpose of gauging implemented**

circular features and pointing out potential ones for consideration by the construction industry in future planning to meet such criteria. In addition, when assessed by BREEAM-C indicators, VCH and TCV indeed have good circularity performance and uphold CE principles in their construction. **True to VCH's initial goal and TCV's name, both building projects can be deemed circular constructions designed and built in accordance with CE principles**.

Of note and interest is that the same CE strategies in BREEAM-C have similar and different manifestations in VCH and TCV. The following discussion will present both comparable and also distinct practices adopted for realising the same CE principles and explore the reasons behind.

<u>*Material Cycle*</u>

SAME/SIMILAR

- For **M2.1.2 and M2.2.2**, **local sourcing of reusable materials** has been achieved in the two cases. Both VCH and TCV put circularity to practice in maximising reused materials, components and elements.

DIFFERENT

- **M1.3.1 Good to excellent thermal comfort ensured** is about temperature regulation for living comfort.
  For **VCH**, the concern is provision of **'heating'** with heat exchangers and air wells installed for temperature regulation. In addition to comfort, energy consumption is reduced through capturing solar heat to create thermals for air circulation.
  For **TCV**, the focus is on enhanced efficiency of the **'air-conditioning'** system through waste heat recovery.
  Their dissimilar emphases and approaches are attributed to their **different geographical location as well as geological and climatic conditions**; VCH in Europe with temperate climate while TCV in central Taiwan with tropical climate.
- **M2.4 Future use** is a completely new addition to the original BREEAM-G. It is also a new CE concept for the construction industry with focus on the later life-cycle stages of a building.
  To ensure **the perpetual flow of materials and products,**
  VCH uses mainly **C2C certified products and buy-back scheme** while
  TCV realises such through **appliance rental and 'product as a service'.**
- To meet **M3.1.2** in using **Bio-based materials used in biological cycle**,
  VCH maintains a **green façade** while
  TCV sustains **landscaping** and **urban farming** with compost from kitchen waste
- **M4.1 Availability of information** has been realised in both cases via documentation of material storage and flows.
  VCH is designed to serve as a material bank. The use of a digital **Material passport** with details on 'what' the material constituents of the building components are

and 'how' to disassemble them for return to the manufacturer for reuse and recycling is aimed not only to enable and promote material circularity, but also help recoup original investment from the residual material value. In particular, the '**green demolition plan**' with clear directives on proper disassembly would enable and facilitate maximal retrieval of residual materials for future use.

TCV uses instead a **BIM-based documentation** method more for better management of construction materials throughout the life cycle of the building without emphasising the residual monetary value of key materials at a later or the end-of -life stage.

Energy Cycle

SAME/SIMILAR

- **Open access to energy consumption information** is achieved in both **VCH** and **TCV** through systems set up in building **(E1.13)** to monitor and document energy use and the information is made accessible **(E.4.1.1 and E4.1.2)** to users with the goal of reducing energy use.

DIFFERENT

- **E3.1** emphasises that energy required for construction and use of building originates from sources with minimum environmental impact. Both VCH and TCV use solar energy, which is renewable and poses least impact on the environment.
  VCH has solar energy heat exchanger for indoor heating needed for the cold climate of NL; while
  TCV uses biogas from food waste, which is regularly collected from households in Taiwan for feeding livestock and making fertilisers.
- Besides the construction and use of buildings, means of transport at **TCV** also use **renewable energy sources**. In addition to facilities providing easy charging electric cars and scooters, they are made available for shared use by the residents, a realisation of the '**sharing economy**'.

Water Cycle

SAME/SIMILAR

- For both **VCH** and **TCV**, **water consumption information** is monitored and managed with feedback made available **(W1.1.1, E1.1.2 and W3.1.1)** to users with the goal of minimising water use**.**

DIFFERENT

- **Grey water (W2.1.1),** used water from wash basins and pantries is filtered by helophyte and then reused for **toilet flushing at VCH** and **urban farming at TCV.**
- **Rainwater collected (W2.2.1)** is used for **watering the green roof and façade at VCH** and for **urban farming at TCV**

Table 5.2.2 Circular features under (a) Material Cycle, (b) Energy Cycle and (c) Water Cycle of Venlo City Hall and TaiSugar's Circular Village matched against BREEAM-C indicators

(a) Material Cycle

Indicator	CE Principles`	Venlo City Hall	TaiSugar's Circular Village
M1.1.1	Stretch lifetime	VCH is a new development because the structural layout of the old building cannot accommodate spatial and functional transformations in line with C2C principles. Of note is that VCH catalyses renovation of an old neighbourhood factory which now contains living accommodation	
M1.1.2	Reduce consumption		
M1.1.3			
M1.2.1	Design for future		Flexible floor design for housing and community centre
M1.3.1	Design for future	Solar chimneys installed to capture solar heat and create thermals for air circulation. Heat exchangers and air wells installed for temperature regulation	Air-conditioning system combined with waste energy recovery
M1.3.2	Stretch lifetime		
M1.3.3			
M1.4.1	Design for future		Modular design for more efficient instalment and reassembly process. Prefab process in construction
M1.4.2			
M1.4.3			
M1.5.1	Reduce impact on environment		
M1.5.2			
M2.1.1	Use waste as a resource	C2C-certified products made from reused materials are procured	
M2.1.2		Local sourcing of reusable green and healthy raw materials	Local and reusable material for the urban farming area. (steel and hardwood from old rail tracks)
M2.2.1		C2C-certified products made from reused components are procured	
M2.2.2		Local sourcing of reusable green and healthy components	Local and reusable components for the urban farming area. (steel and hardwood from old rail tracks)
M2.3.1		C2C-certified products are procured	
M2.3.2		Significant share of total material consumption attributed to numerous C2C-certified products used	
M2.3.3		Local sourcing of reusable green and healthy elements	

M2.4.1	Rethink business model	Guaranteed takeback systems to preserve residual values reutilized Material ownership by supplier / Innovative business model / Closed loop	Product as a service is implemented in lighting, furniture, appliance, bath, elevator, food waste machine.
M2.4.2		C2C-certified products are procured to enhance material reutilization / recycling	
M2.4.3		'Buy and buyback' scheme for selling recovered materials back to manufacturers for reuse Retain residual value of materials used	
M2.4.4	Prioritize regenerative resources	C2C-certified products procured to enhance product reutilization	
M3.1.1		C2C ensures perpetual flow of materials in technical cycle	
M3.1.2		C2C ensures perpetual flow of materials in biological cycle	Aquaponics and composting
M3.2.1	Reduce consumption		No critical material being used for health reasons
M3.2.2		Material passport documenting types and flows of materials used	
M3.3.1			
M3.3.2			
M4.1.1	Strengthen & advance knowledge	Material passport	Material bank, BIM-based material flow documentation BAMB concept
M4.1.2		Material passport	
M4.1.3	Design for future	'Green demolition' plan providing directives on how to disassemble the building to create continuous cycles and to use the maximal potential of the building as a material bank.	

(b) <u>Energy Cycle</u>

Indicator	**CE Strategies**	**Venlo City Hall**	**TaiSugar's Circular Village**
E1.1.1	Reduce consumption	Solar chimneys installed to capture solar heat and create thermals for air circulation. Heat exchangers and air wells installed for temperature regulation	Air-conditioning system combined with waste energy recovery
E1.1.2		Open access to energy consumption information	Open access to energy consumption information
E1.1.3	Incorporate digital technology	Open access to energy consumption information	Open access to energy consumption information

E1.1.4	Reduce impact on environment		
E2.1.1	Incorporate digital technology		
E3.1.1	Reduce impact on environment	Solar energy-fuelled electricity & heating system Solar panels installed on the south façade	On-site solar panels Biogas from food waste Electric cars and scooters sharing and charging
E4.1.1	Incorporate digital technology	Open access to energy consumption information	Open access to energy consumption information
E4.1.2		Open access to energy consumption information	Open access to energy consumption information
E4.2.1			

(c) <u>Water Cycle</u>

Indicator	**CE Strategies**	**Venlo City Hall**	**TaiSugar's Circular Village**
W1.1.1	Reduce consumption	Open access to water consumption information	Open access to water consumption information
W1.1.2	Incorporate digital technology	Open access to water consumption information	Open access to water consumption information
W.2.1.1	Use waste as a resource	Grey water filtered and used for toilet flushing	Use grey water in urban farming
W2.2.1		Rain water collected from the roof to water the green wall	Use rainwater collection in urban farming
W2.3.1		Nutrients extracted from waste water	Water reused in urban farming
W3.1.1	Incorporate digital technology	Open access to water consumption information	Open access to water consumption information

Seen also in Table 5.2.2 are indicators without corresponding circular practices in either case. For example, **M1.1.2** and **M1.13** are abou**t feasibility study on minimising building area and total material mass**. While the concept of both area and material minimization echoes waste reduction at the source, it is **hard** if not impossible **to set a baseline for comparison in the case of the whole building**. **M1.3.2 and M.1.3** concern **building for resilience**; yet, these aspects should have been **given due attention in consideration for safety and protection rather than material circularity**. Similarly, considerations for **M1.5.1 and M1.5.2**, which are about **environmental impact minimization**, are so entrenched in green-focused building projects that they need no particular circular practice. Same for **E.2.1.1** and **E4.2.1** on **energy matching** and **optimization**, which are also much **emphasised in green buildings**. Then for **M3.3.1** and **3.3.2** on **use of scarce and critical materials and elements**, the construction industry is less likely to use them not so much for circularity concern but rather **financial consideration** as scarce and critical materials tend to be more expensive, posing a burden to the construction budget.

Worth mentioning here are features commendable in both cases but the impact areas of Material, Energy and Water have no indicators corresponding to those. These practices are more related to ecosystems and biodiversity. For VCH, one of the design focuses is on **Air Quality**, aiming for enhancing the overall well-being of its users. Installed at the rooftop is a greenhouse that serves as the green lung of the building. **BE2.1** under Biodiversity and Ecology gives credit to the inclusion of ecosystem elements to provide biodiversity and building functions. The living green north façade comprising over 100 plant varieties is not only an eye-catching feature but also creates a habitat for birds and insects, demonstrating integration of ecosystem service to **Strengthen local diversity** as indicated by **BE3.1**. In fact, this feature embodies the visions of good air quality both indoor and outdoor with a purifying, smog-reducing function. Not only does it filter particulate matter from the air and convert carbon dioxide into oxygen, it also regulates temperature and reduces sound. It absorbs 30% of sulphur and nitrogen oxides in the air in the vicinity of the building, offsetting the emissions of particulate matter from local traffic. An interior green wall helps to add moisture to the air inside the building. A vide structure from ground floor to rooftop provides a natural ventilation flow. The design of VCH is to bring as much daylight and greenery into the interior as possible. These **people-oriented designs** with positive externalities contribute to provide a comfortable environment to stay and work, relieve stress and help boost work productivity.

For TCV, **farm plots on the rooftop** aim to build a community where residents can gather and be engaged in something related to nature. Design of the circular village targets to promote a **people-oriented community** and the demo house is meant for promoting circular and green lifestyles. This is particularly for TCV as it would be an exemplary building project that demonstrates how building circularity can actually be realised. Its success would stimulate construction with CE focuses. As it has been completed only recently, it takes time to see whether it does serve what it is designed to achieve.

To conclude, **when matched against prevalent circular practices, BREEAM-C indicators fulfil its role as assessment criteria for identifying circular practices implemented**; and **when applied to assess CE-focused constructions, BREEAM-C indicators also serve as benchmarks testifying that CE principles/strategies have been put to use or incorporated in the design, construction, operation and management of the buildings**. Nevertheless, the case analyses also reveal inadequacies and room for improvement or expansion of the proposed indicators, which will be further elaborated in the next chapter. In the case of TCV, BREEAM-C has proven to be applicable as a circularity assessment metrics, thus signifying its potential for use in Taiwan. However, **the comparative case review also highlights the need for the indicators to be adapted or localised due to differences in function and location, culture and climate**.

6. Potentials of Using BREEAM for Building Circularity Assessment in Taiwan

To answer the main research question on whether BREEAM-C can be adopted to support building circularity assessment in Taiwan, this chapter discusses first the potential of BREEAM being used as a building circularity assessment metrics in Taiwan (6.1). Then BREEAM's inadequacies and room for improvement/expansion as revealed in the evaluation done in previous chapters are detailed, focusing on how BREEAM will be adopted for use (6.2) and what Taiwan can learn from BREEAM's attempt to incorporate material/resource circularity indicators into an existing green building assessment system for building circularity assessment (6.3). The chapter ends with presenting the stakeholders' expectations of circularity assessment for Taiwan (6.4) for reference when choosing or developing a metrics for certifying circular building.

6.1 Potential of BREEAM-C to be Adopted/Adapted for Taiwan

With its applicability for circularity assessment proven and its application to assessing TCV, the showcase CE-focused construction in Taiwan, demonstrated, BREEAM-C should be deemed a building circularity assessment metrics suitable for adoption by Taiwan. This conclusion on **BREEAM-C being feasible and valid for circular building assessment and apt for use in Taiwan** is echoed by the commonly shared positive appraisal of BREEAM-C by the respondents. That is, all respondents agreed that BREEAM-C can be applied to circular building assessment in Taiwan.

Of note is that the respondents have not reviewed BREEAM-C in great detail, unlike the thorough evaluation done in this thesis research. In fact, *Dir Hsieh*, representative of the construction industry did not know much about BREEAM before receiving the related materials prior to the interview, implying that many practitioners are not fully abreast of available but 'foreign' assessment metrics. Nevertheless, they considered **BREEAM's use of their green building assessment as the basis and expanding it with circular indicators a sound and appropriate approach that would most likely succeed and be adopted for use** as a circularity assessment metric in Taiwan. Again, their familiarity with EEWH explains why they favour the prospective circularity assessment metrics to bear resemblance with the green building certification scheme that they have been using for years.

Despite applicable, the respondents considered **adaptation or localisation a must** for the proposed circular indicators. *Chang*: "*In Taiwan, cases with BREEAM certification are few and the construction industry is not familiar with BREEAM; hence, for it to be adopted, it needs to be "localised*." This is also in line with findings in the cross-case analysis that indicators must be adapted in accordance with local social, cultural and climatic conditions.

Indeed, a 'localised' assessment system is not only better adapted to the local social, cultural and climatic conditions, but also **more aligned with** and can be more easily updated according to **local legislations and regulations**. In addition to being an **effective assessment system for the local context**, country-specific systems using local language and implemented with local assessors can also serve as **a pragmatic marketing tool for promoting circular construction practices**.

The common view of the respondents is **adoption of BREEAM-C for reference and not for direct application**. BREEAM-C can be taken as a guide for Taiwan to develop its own building circularity assessment metrics. That is, BREEAM's attempt would be like a role model for EEWH. What *PM Chow* considered desirable and feasible is the **'transplant' of BREEAM's approach to develop a framework of circular indicators on the basis of EEWH**. Currently, EEWH has evaluation manual for different types of constructions including EEWH-BC (Basic Construction), EEWH-EC (Ecological Community), EEWH-GF (Green Factory), EEWH-RS (Residential Buildings), EEWH-RN (Renovation) and EEWH-OS (Overseas Scenarios). A potential and practical development would be **a new evaluation manual EEWH-CB (Circular Buildings)**. *Chang* shared similar thoughts and suggested **incorporating circularity assessment under Waste Reduction of EEWH**. Recall that the construction industry is known to be conservative and slow in embracing new ideas. Hence, instead of introducing a brand new assessment metrics, adding an extra type of construction or a sub-category to the widely applied EEWH would make it more acceptable.

Nevertheless, the respondents also expressed concern of whether its root in green building assessment would limit the coverage of BREEAM-C and of non-existent standard values against which circularity attained can be compared. In fact, BREEAM-C does have possible room for further improvement and expansion as revealed in the matching between its indicators and prevalent circular practices and discussed below. The discussion would be useful reference not only for BREEAM developers but also for those, like Taiwan, that deem BREEAM a candidate circularity assessment metrics for adoption/adaptation.

6.2 Possible Expansions/Improvements in Localised System

Review of CE-30 in light of BREEAM-C indicators, detailed in Chapter 5, has revealed some practices that fall outside the coverage of the BREEAM-C assessment framework. This Section attempts to characterise these deficiencies and suggest possible improvements which can be realised by both expansion of the BREEMA-C impact areas, and/or additions of more comprehensive coverage to current ones. Moreover, there are lessons learnt from VCH and TCV on building practices that contribute values beyond circularity and should be encouraged and acknowledged. The following directions are identified.

✧ **Use of Natural / Sustainable and intangible Resources**

In the Material Cycle of BREEAM-C, most of the current indicators concern 'manufactured' and 'tangible' materials, specific sub-strategies that acknowledge and encourage **efficient use of 'natural/sustainable' and 'intangible' resources** should also be added.

Take the case of VCH for example. The construction uses mainly wood, a natural/sustainable resource. In fact, timber has long been used as a building material. After the industrial revolution, steel and concrete with better cost efficiency and higher structural strength emerged to become the mainstream building materials. However, advances in processing technology as well as emphasis on sustainability and circularity have put timber back in the limelight. Being biodegradable at end-of-life and consuming less energy in production, **timber and wooden materials** are alternative circular building materials. Similarly, in Taiwan with abundant forestry reserve, both wood and bamboo has long been used for construction or as ingredients of construction materials. Hence, their use in building should be encouraged and given due recognition.

✧ **Circular Practices of In-Use/Operation Phases**

Among the different BREEAM schemes listed in Table 4.1.3, most are related to design, procurement and construction. Moreover, as mentioned in Section 4.1, assessment by BREEAM is to be conducted at the design phase and the delivery phase. Hence, circular practices acknowledged by BREEAM concerns mainly the design and construction stages. Nevertheless, CE-related concepts put to practice when the building is completed and open for use should also be aptly recognised.

For example, among the CE-30 practices, **'Sharing space'** in residences and workplaces, **'Sharing ownership'** of vehicles and appliances in the case of TCV, and **'Exchange platform' of used goods and agricultural products** are mainly implemented **during the in-use/operation phase** but are not accounted for in any of the impact areas of BREEAM-C. These practices target at maximising resource efficiency and reducing waste have been left out by BREEAM-C. For them to be duly credited, impact areas should either be increased or expanded.

✧ Do More Good in addition to Do Less Harm

Most assessment schemes stress minimising/reducing environmental impact through using materials of low environmental impact. BREEAM-C is no exception given its roots in BREEAM-G. A lesson learnt from the case study of VCH is that the building itself from inception to completion has contributed added **values in the form of benefits brought to the neighbourhood/community and society**. For example, VCH being self-sufficient in energy shares its surplus with the neighbouring communities. Another contribution is that it serves as a showcase for promoting C2C approach in construction and has attracted over 25,000 visitors with a special interest in that in less than 1.5 years after its opening.

The current proposed BREEAM-C indicators fall mainly under Materials, Energy and Water targeting at 'zero-waste' while existing BREEAM-G indicators aim at 'zero-emission', both fulfilling the purpose of doing less harm. Indicators that would encourage doing more good such as **enhancing aesthetics and biodiversity, promoting health and well-being**, should be added. In this way, CE-related efforts of designers and engineers **that do good to both humans and the environment** would gain rightful credits.

✧ Financial Circularity

In BREEAM-C M2.4, the future use of materials is being assessed. However, the financial benefit through achieving material circularity is not being addressed. CE-related practices are not only good for the environment and ecology but should also benefit the economy. Hence, there should be indicators pertaining to **monetary gain from adopting circular practices** such as TCV's product as a service or innovative business model such as VCH's buy-back scheme. In the case of VCH, their investment in applying a wide variety of circular practices within a circular economy business model, amounting to 3.4 million Euro, has created a net saving of 16.8 million Euro over the use time of the building and a positive cash flow after year 1. Not all circular practices aiming for future material use have financial positivity, especially at the beginning, but the **evaluation and quantification of residual value at end-of-life stage** should be encouraged. Hence, a circular framework should award credits for such financial circularity assessment.

✧ Flexibility and Versatility of Building Functions by Design

Buildings are designed to be used for a very long period of time. Hence, durability is often a concern to ensure usability throughout the lifespan of a building. When **buildings can last longer**, another feature, flexibility becomes significant. Buildings should be so constructed as to be **readily adaptable to changing conditions and**

serving different functions as required. With flexibility built into the design for changing the functional purpose of the building, the lifespan of a building can also be extended. **Working in a cycle, lifespan, durability and flexibility reinforce each other, all contributing to higher resource efficiency**.

Versatile functionalities may extend to include education and promotion. Both VCH and TCV are notable examples. Visitors interested in seeing how C2C can be put to practice are attracted to see VCH, 40% of which are from overseas. Hence, in addition to being a functional municipal office building, it is a life-size showroom with C2C approaches demonstrated in use, serving as an inspiration for other organisations to apply CE principles within their own context. The demo house in TCV is also meant for educating and promoting lifestyle in compliance with CE principles.

✧ **Recognition of C2C and other CE-Related Certifications**

While the assessment of building circularity is still evolving, there exists some related assessment tools developed for other purposes. For example, VCH has obtained C2C certification for many of its fixtures and appliances. As construction companies and building owners would likely get such certifications, BREEAM-C can consider recognizing these as additional credits in assessment, for example, under the Multiple Value (V) impact area.

Examples of such certifications include:

- **C2C certification**

This is a certification from a Germany foundation that assesses CE on a product level. Of all 668 C2C-certified products, 224 are related to interior design and furniture, while 214 are of building supply and materials.[7] Using C2C-certified products is generally deemed a CE practice; hence, when assessing building circularity, C2C certifications should be given due recognition.

- **BS8001**[8]

This is a certification tool developed by British Standards Institution to assess CE transition and resource management from an organisational way, focusing more on how the building is operated to achieve CE from a management point of view. Hence, such certification would make up for circular indicators related to management during the in-use/operation phase currently lacking in BREEAM-C

[7] http://www.c2c-centre.com/products

[8] https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/becoming-more-sustainable-with-standards/BS8001-Circular-Economy/

- **Circularity Facts Program**[9]

This program launched by Underwriters Laboratories ((UL) evaluates a company's efforts to move from a linear economy mind-set to a more sustainable circular approach. Specific circularity attributes of processes and products are validated in terms of recycled content and recyclability, waste minimization and zero waste to landfill. These emphases are in line also with achieving building circularity and relevant certifications obtained from such assessment should be recognised under BREEAM-C.

According to the respondents, obtaining circular building or CE-related certifications would help enhance the image of the building project and the construction company involved. A **better image** would also mean **better publicity and greater profit, thus reinforcing their commitment to circular construction**. In other words, for project owners and construction companies to invest in circular construction, there should be corresponding financial return.

With reference to the abovementioned areas of potential expansion and improvement identified, Table 6.2.1 summarises possible strategies with corresponding indicators and practices to be included in future building circularity assessment metrics.

Table 6.2.1. Summary of possible strategies with corresponding indicators and practices for addressing the inadequacies of the current BREEAM-C.

Strategy	Indicator	Example Practices
Ownership & Management	Building design comprises plans for CE practice in operation phase	Space / Workplace sharing Ownership sharing Exchange platform
Positive community influence	Building poses positive impact on promoting CE in built environment and surrounding community	Supply extra electricity generated to surrounding community Showcase CE concepts
Financial circularity	Assess financial benefits achieved through CE practice	Financial assessment
Flexible building function	Building designed for multiple functions with flexibility for transformation	Flexible design for multiple uses with ease for switch, e.g., from commercial to residential
CE-Related certifications	Obtain other CE certifications	BS8001 C2C

[9] https://www.ul.com/resources/circularity-facts-program

6.3 Lessons of BREEAM's attempt for Taiwan

As mentioned in Section 4.3, indicators of the Material Cycle constitute the largest number and are given due consideration and top priority in BREEAM-C. Hence, for EEWH to become an apt circularity assessment metrics, material circularity-related indicators should be added. Currently, **only 18% of EEWH indicators are related to material and waste**; they are listed under the **Waste Reduction category with focus on reduction of emissions and construction waste (**See Table 3.4.1). Strategies for reducing CO2 emissions include decreasing material volume, enhancing material durability, adopting lightweight structural design and utilizing reused materials; while practices for reducing construction waste involve minimising soil excavation, cutting down construction materials used, curbing air pollution through green walls around the construction site.

Table 6.3.1 lists the proposed BREEAM-C Material Cycle indicators against current EEWH material-related indicators. Of the 32 BREEAM-C indicators, 20 are new to EEWH and can be considered for possible incorporation while there are 12 related or similar ones in EEWH that may require adaptation with focus on circularity enhancement.

In brief, possible additions to EEWH inspired by BREEAM's proposed indicators concern the following aspects:

- Reduction of possible new constructions
- Greater flexibility in building design to prepare for future uses and functions
- Design for reassembly emphasising replaceable joint/connections in building design
- Local sourcing of materials
- Future use of materials
- Business model, management plan, reuse strategy, possibility of material reutilization
- No critical materials used
- Material passport documenting flows and storage of materials
- Buildings as material banks
- Disassembly guidelines with end-of-life plans
- Life cycle impact assessment

With the above aspects covered in the assessment metrics to be developed for Taiwan's circular buildings, the dual focus of 'zero emission' and 'zero waste' would be equally emphasised and given due recognition. Using the EEWH as the foundation has benefits of saving the time from developing the metrics from scratch and it would be more easily accepted by local practitioners given their familiarity of the existing green assessment EEWH, thus facilitating the promotion of circular construction in Taiwan.

Table 6.3.1 BREEAM-C Material Cycle indicators versus current EEWH material-related indicators
Indicators in ☐ boxes are new additions to be considered for possible incorporation; and
indicators in ☐ boxes are related / similar ones in current EEWH that may require adaptation.

BREEAM-C (MATERIAL CYCLE)		**EEWH**
M1	**Optimization of Material Use**	
M1.1	**Accountability and substantiation of building volume**	
M1.1.1	Feasibility study performed on possibilities of building refurbishment, possibly excluding the option of new development	
M1.1.2	Feasibility study performed on possibilities of minimizing square meters of development (both new construction & renovation) within specified requirements.	**Building shape coefficient:** The more diverse and unregularly shape, the more CO2 emission is assumed to be embedded.
M1.1.3	Feasibility study performed on possibilities of minimizing total material mass used within specified requirements and square meter surface of development.	**Light weight design coefficient**
M1.2	**Design for flexibility**	
M1.2.1	Score calculated by Building Flexibility ≥ X.	
M1.3	**Design for resilience**	
M1.3.1	Good to excellent thermal comfort ensured	Heating not needed in Taiwan,
M1.3.2	Crucial functions not situated in vulnerable locations of building.	**Durability coefficient:** Assessing building material that can be repaired
M1.3.3	Parts of building with high risk of damages supplied with extra protection measures.	**Durability coefficient:** Assessing building durability design
M1.4	**Design reassembly**	
M1.4.1	De-/remountable connections used when placing/installing product in its direct surrounding, of which preservation of similar quality can be guaranteed	
M1.4.2	Product assembled through de-/remountable connections, of which preservation of similar quality can be guaranteed.	
M1.4.3	Connections used for placing/installing the product in its (direct) environment are accessible.	
M1.5	**Checks and balances on environmental impact (prerequisite)**	
M1.5.1	LCA calculation made both during design & post-construction stages. Resulting environmental impact compared with best practice results of similar buildings.	LCA studies or environmental impact of buildings not required in EEWH or Taiwan
M1.5.2	Construction materials chosen evaluated on environmental impact based on LCA calculation of total building and material option(s) with lowest or net-positive environmental impact considered.	

M2	**Reutilization**	
M2.1	**M2.1 Maximize amount of reused materials**	
M2.1.1	Score calculated by Material Circularity Indicator >x	
M2.1.2	Search for local supply of reusable/second-hand materials for materialization	Indicators for reusable materials
M2.2	**M2.2 Maximize amount of reused components**	
M2.2.1	Search for renewable components	Indicators for reusable materials
M2.2.2	Search for local supply of reusable components	
M2.3	**M2.3 Maximize amount of reused elements**	
M2.3.1	Mention use of recycled products in tender to stimulate reutilization during design phase	Indicators for reusable materials
M2.3.2	Search for renewable elements, preferably with a significant share in total material consumption	
M2.3.3	Search for local supply of reusable elements	
M2.4	**Future use**	
M2.4.1	Circular business models used could possibly encourage return & reutilization of products	
M2.4.2	Elements chosen proven to be able for reutilization / recycling in material cycle for future (similar) products	
M2.4.3	Managed service contracting with building suppliers to guarantee building product performance	
M2.4.4	Feasibility study performed on possibilities of product reutilization	
M3	**Circular Materials**	
M3.1	**Maximize amount of renewable materials**	
M3.1.1	Recyclable materials used in technical cycle	Indicators for reusable materials
M3.1.2	Bio-based materials used in biological cycle	
M3.2	**Minimize use of scarce/critical materials**	
M3.2.1	Building not made of critical materials	
M3.2.2	Document critical materials if used.	
M3.3	**Minimize use of scarce/critical elements**	
M3.3.1	Environmental impact of used materials lower than reference value	
M3.3.2	Minimum of X volume % of used materials with substantiated / responsible origin.	
M4	**Knowledge Development & Sharing**	
M4.1	**Availability of information (element, component, material)**	
M4.1.1	Building material passport composed & maintained during use cycle of building regarding material cycles	
M4.1.2	Building material passport available for every building stakeholder	
M4.1.3	Building upon completion delivered with demolition specifications / disassembly guidelines	

6.4 Stakeholders' Expectations of Circularity Assessment Metrics for Taiwan

Besides commenting on BREEAM-C suitability for building circularity assessment in Taiwan, the respondents, representing stakeholders with different concerns, expressed their expectations of a building circularity assessment metrics for Taiwan.

- It should be clear and not too complicated. The goals and standards should be objective and well-defined. As circular building and building circularity are emerging concepts, still new to many in the construction industry, there should be clear definitions. *(PM Chou)*
- The calculation basis and approaches should also be clear, well-defined and objective. *(PA Lin)*
- To promote implementation, there must be support from the government with economic incentives; and to foster compliance, there must be related legislations enacted. *(PA Lin)*
- At the initial stage, three grades should suffice to avoid too detailed grading. *(PM Chou)*
- Innovations should be encouraged with higher scores or weights given. *(PM Chou)*
- There should be follow-up after the certification as a building has a long life cycle to ensure that circular goals are adhered to and circular strategies are applied even at the later life-cycle stages. *(Dir Hsieh)*

Whether adopting or adapting a currently available building circularity metrics, the above stakeholders' views and insights can provide useful references. As mentioned in Chapter 3 and echoed by the respondents, a building circularity assessment metrics is considered a must for supporting the promotion of circular construction. Other contributing factors expressed by the respondents include the following.

- There should be more choices and greater supply of renewable construction materials. It would be desirable for Taiwan to develop a certification system for renewable construction materials, similar to the C2C certification for products and materials. *(Chang)*
- More can be done at the government level; for example, changes in procurement regulations. *(Dir Hsieh)*

Recalling the interview exchanges brings up in my mind the parable of "The Blind Men and an Elephant". Indeed, the responses from the interviewees are representative of the involvement and experience in the related field. It also reflects the prevailing situation in Taiwan is that the government and stakeholders have different concerns, interests and focuses and there is the lack of coherent vision for development in circular construction. As pointed out by *PA Lin*: "*Taiwan's self-established circular building assessment/accreditation system can serve as a roadmap for common development among different stakeholders*."

Furthermore, *PA Lin* saw as himself like a missionary tasked to educate and propagate the new concept of circular construction to fellow stakeholders and downstream workers involved in building projects and the assessment/accreditation metrics would function as the "commandments" for providing directions and guidance and a tool for communication.

To conclude this chapter, while BREEAM-C has potential to be adopted for building circularity assessment in Taiwan, **adaptation or localised is necessary** and the inadequacies and room for expansion/improvement provide useful references. Expert opinions incline towards adapting Taiwan's green building certification for circularity assessment. The advantages are as follows: (i) it saves time; (ii) the current EEWH being well developed and in use for decades constitute a solid and valid basis; (iii) practitioners are familiar with EEWH, thus facilitating their acceptance and implementation of the future circularity metrics developed from EEWH.

7. Conclusions

7.1 Summary of Results

This thesis targets to address the question of whether the framework of circular indicators proposed by BREEAM can be adopted for building circularity assessment in Taiwan. The key results as described in this thesis in accordance with the sub-questions and main research questions are as follows.

1. *How can CE principles guide building circularity assessment?*

   Review of related literature, detailed in Chapter 2, shows that CE principles provide the bases for generating circular strategies so as to reach CE goals. The CE aspects for different life-cycle stages, as listed in Table 2.5.1, offers guidelines for circular practices to be developed and implemented. These building circularity targets can serve as the benchmarks for assessment or criteria to be met for being recognised as circular building.

2. *Which kind of system would Taiwan need for building circularity assessment?*

   Tracing the development history of Taiwan's green building assessment system, the EEWH reveals its contribution to promoting green construction while analysing expert opinion of Taiwan's need for building circularity assessment indicates their preference for the prospective circularity assessment metrics to bear resemblance with EEWH which they have been using for years though insufficient for circularity appraisal due to its green focuses. BREEAM's proposed framework of circular indicators which evolved from its original green building assessment system is a potential candidate to meet Taiwan's need.

3. *How does BREEAM incorporate material circularity indicators into its existing green assessment framework?*

   When incorporating material circularity indicators into its existing green assessment framework, BREEAM stresses value retention, viewing the building as a repository of materials and natural resources and gives due consideration to the full lifespan of materials. Indicators thus developed emphasise end-of-life plans with guides drawn up on demolition, recovery of renewables for reassembly, reuse, and buy-back, future use and local sourcing. Innovative circularity concepts such as Material passport, LCA, MCI and C2C are also integrated in the indicators.

4. *What is the applicability of BREEAM for building circularity assessment?*

   When matched against a set of implemented circular building practices, BREEAM-C indicators have shown ability to identify them with good coverage of building circularity targets. When applied in a real-life context for assessment of two circular building projects, BREEAM indicators also serve its purpose in recognising the circular features. Expert opinions also echo the positive appraisal of BREEAM's applicability for circularity assessment and see its potential for use in Taiwan.

5. *What are the strengths and inadequacies of BREEAM?*

   As a potential metrics for building circularity assessment to be adopted /adapted by Taiwan, BREEAM has strengths of its root in the green assessment system which bear similarities with EEWH, a green building certification scheme familiar to domestic practitioners and stakeholders, thus facilitating their acceptance and implementation of the future circularity metrics developed from EEWH. Besides the need of localisation in consideration of Taiwan's different concerns, there are inadequacies or room for expansion with indicators to be included for operation and functionalities during in-use phase of the buildings, with emphasis on the less tangible values on the financial, social and human aspects, and do-more-good in addition make-less-harm.

6. What lessons can Taiwan learn from BREEAM's attempt in incorporating material/resource circularity indicators into an existing green building assessment system for building circularity assessment?

   Faced with the new worldwide trend for going circular, Taiwan's construction industry needs clear goals and well-defined criteria for achieving a circular construction economy. Green building rating schemes, which have been intensely developed and widely adopted in the past decades offer an excellent platform for equivalent assessment schemes for circular buildings to be established. Not only is such approach time-efficient, the two emphases, 'zero emission' for green buildings and 'zero waste' for circular buildings, can both be catered for by the assessment indicators.

Can BREEAM-C be adopted for building circularity assessment to promote circular construction in Taiwan?

Results from literature review and cross-case analysis, echoed by the experts' opinion, showed that BREEAM-C being feasible, practical and applicable and can be adopted for building circularity assessment in Taiwan though not without adaptation or localisation considering different concerns with respect to climate and safety. To practitioners and stakeholders of the construction industry in Taiwan, BREEAM-C with its basis in green building assessment and its similarity with EEWH which they are familiar with and have complied with for decades would make the new circular indicators easier to accept and follow.

7.2 Potential Uses of Findings

Findings of this thesis may be of interest and use to the following.

Construction Industry

- Proven applicable, BREEAM's proposed framework would be an answer to the existing need of project owners and stakeholders for a circular building assessment metrics to gauge the performance of CE strategies put to practice.
- Innovative practices implemented in the representative case studies of CE-focused building projects offer inspirations and visions for enhancing circularity in construction and promoting circular construction economy.
- The objective, scientific, third-party evaluation of building circularity provides support for promoting the achievement of circular goals in construction and the application of CE principles in the industry and the built environment.

Government and Policy-Makers

- BREEAM-C with its strengths and limitations as well as my suggested room for improvement offers useful references for the government and policy-makers when formulating requirements and standards for future circular buildings.
- Innovative CE practices examined and exemplary practices applied in the case studies shed light on developing concepts and actions that need more support and attention from the government and policy-makers.

Assessment Metrics Developers

- BREEAM-C's attempt to integrate circularity goals with green focuses offers useful lessons for encompassing material/resource circularity indicators into an existing green building assessment system so as to achieve the dual goal of zero waste and zero emissions for a sustainable built environment.
- BREEAM-C is the only qualitative circularity assessment developed so far, its strengths and inadequacies can be useful references for other qualitative metrics developers.
- Proven practicable, BREEAM's proposed framework could be a candidate metrics for assessing/accrediting circular buildings.

Taiwan

- Taiwan's current situation of CE transition in the construction industry and the cross-case analysis with BREEAM-C indicators applied in real-life context would provide additional information on circular construction development in the Asia Pacific area and in its application to different types of constructions built for different purposes in different parts of the world with different climates.

- BREEAM’s efforts in expanding its green building assessment system with circular indicators incorporated can offer practical guidance for Taiwan should it consider to follow suit in developing its current EEWH into a circular building assessment/accreditation system.

7.3 Limitations of Research

A major limitation in this study is the small sample of interviewees. CE is an emerging concept in Taiwan. The construction industry is yet to learn more about CE and how to put it to practice. There are only a few CE-focused building projects in Taiwan, implying that there are not too many practitioners and stakeholders with sufficient experience of circular construction to share opinions and comments. While there are only four respondents, their insight does reflect those who actually KNOW about this aspect in Taiwan. Hence, what they share is of value to the discussion of the related research issues.

Discussion on TCV remains at its circular design. Unlike VCH which has been in operation for some years, the construction of TCV has just been completed. The comparative study would be of greater breadth and depth after TCV has been operated for some time and updated statistics on its in-use phase and with feedback from users available for analysis.

7.4 Future Research Directions

Following the discussion in Section 6.2, there is much room of research and development in formulating revisions or customizations of BREEAM’s circular framework in adding new impact areas or refinements to the existing ones; in particular, on social and cultural values, human engagement, knowledge sharing, ownership and business models, local diversity in ambient conditions, ecosystem and biodiversity. In addition, research efforts devoted to refining and quantifying appropriate parameters for BREEAM circular indicators are desirable.

It is hoped that this work contributes to identifying a practical evaluation framework for building circularity to meet the need of a metrics for assessing and accrediting circular buildings. In particular, for Taiwan, the availability of such assessment/accrediting system, whether through adopting/adapting BREEAM-C or adding a new category of EEWH-circular building in the light of BREEAM’s attempt in developing circular indicators, would be necessary for promoting circular construction and facilitating the CE transition in the construction industry.

8. Appendices

Appendix A – Questionnaire used in Semi-Structured Interview

Original Chinese version

循環建築標章訪問問卷

訪問對象：
單位：
職稱：

訪問題綱：

一、 以下的描述是推動台灣循環建築的主要挑戰 (Hart et al.,2019) **(圈選)**

1. 營建產業比較保守 **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**
2. 建築系統的複雜性 **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**
3. 建築長生命週期的特性 **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**
4. 缺乏科技 **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**
5. 缺乏標準化 **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**
6. 缺乏循環建築整體發展方向 **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**
7. 缺乏循環建築評估認證 **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**

針對「缺乏循環建築評估認證」是否為主要挑戰，請詳細描述原因? **(口述)**

你認為推動台灣循環建築還沒有沒其他挑戰? 或需要哪些誘因? **(口述)**

二、 你認為綠建築與循環建築的差異或關係為何? **(口述)**

三、 BREEAM-C (以英國綠建築標章發展出來的循環標章)
可以適當評估循環建築? **(圈選)** **(非常同意, 同意 , 無意見, 不同意, 非常不同意)**

為什麼? **(口述)**

四、 BREEAM-C 可以適用於台灣的循環建築評估?**(圈選)**

(非常同意, 同意 , 無意見, 不同意, 非常不同意)

為什麼? **(口述)**

五、 若有以 EEWH (台灣綠建築標章)為本發展的循環標章，

可以推動台灣循環建築的發展? **(圈選)**

(非常同意, 同意 , 無意見, 不同意, 非常不同意)

為什麼? **(口述)**

六、 以你在建築產業的角色，循環建築標章對你有什麼意義? **(口述)**

七、 你對於循環建築標章有什麼期待? **(口述)**

==================問卷結束，多謝受訪======================

Translated English version

Questionnaire on Circular Building Certification

Name of Interviewee:
Affiliation:
Job Questions:

Interview Questions

1. **(Please CIRCLE)**
   How much you agree that the following are main challenges (Hart et al.,2019) for promoting circular construction in Taiwan

   (i) Construction industry being conservative
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (ii) Building system being complex and complicated
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (iii) Long product life cycles for both buildings and materials
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (iv) Lacking technology
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (v) Lacking standardization
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (vi) Lacking coherent vision for development in circular construction
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (vii) Lacking assessment metrics for circular construction certification
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (Please TELL)
   Why or why not "Lacking assessment metrics for circular construction certification" is the main challenge.
   (Please TELL)
   Do you think there are other challenges for promoting circular construction in Taiwan?
   What do you think would help promote circular construction in Taiwan?

2. **(Please TELL)**
   What are the differences between green and circular buildings? Or how are they related?

3. **(Please CIRCLE)**

BREEAM-C (a proposed framework of circular indicators) aptly assess circular constructions
(Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

(Please TELL) Why?

4. **(Please CIRCLE)**
   BREEAM-C can be applied to circular building assessment in Taiwan
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (Please TELL) Why?

5. **(Please CIRCLE)**
   A circular building assessment system developed from EEWH (Taiwan's green building certification system) can help promote the development of circular construction in Taiwan
   (Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree)

   (Please TELL) Why?

6. **(Please TELL)**
   What does a circular building assessment system scheme mean to you with respect to your role in the construction industry?

7. **(Please TELL)**
   What are your expectations of circular building assessment system?

=================End of Questionnaire === THANK YOU=====================

Appendix B – Roots of BREEAM-C Indicators

Comparison of BREEAM-C with its roots Roadmap and BREEAM-G (version 2014), showing the foundation or inspiration for the current circular indicators and pointing out new 'shoots', in the form of disparities or additions

For easy reference in the discussion, indicators in boxes are new additions; notes shown in and boxes denote their similarities while notes in boxes highlight their differences.

Appendix Table A1 Summary of Material Cycle impact area of BREEAM-C illustrating evolution from BREEAM-G and Roadmap

BREEAM-C		Roadmap	BREEAM-G 2014
MATERIAL CYCLE			
M1	**Optimization of Material Use**		
M1.1	**Accountability and substantiation of building volume**		
M1.1.1	Feasibility study performed on possibilities of building refurbishment, possibly excluding the option of new development		MAN 6 Consultation
			BREEAM-G: Involve local stakeholder
M1.1.2	Feasibility study performed on possibilities of minimizing square meters of development (both new construction & renovation) within specified requirements.		MAT 1 Building materials / MAN 6 Consultation
			BREEAM-G: Size of area not assessed
M1.1.3	Feasibility study performed on possibilities of minimizing total material mass used within specified requirements and square meter surface of development.	M (1) Reduce material use during lifespan	MAT 1 Building materials
		Roadmap: Consider whole lifespan **BREEAM-C**: Minimize total mass only	**BREEAM-G**: Minimize total environmental impact **BREEAM-C**: Minimize total mass
M1.2	**Design for flexibility**		
M1.2.1	Score calculated by Building Flexibility ≥ X.	A&R (4) Flexible, redundant & adaptive design	MAT 8 Building flexibility
		Roadmap & **BREEAM-C**: both reference **BREEAM-G** MAT 8 Building flexibility	
M1.3	**Design for resilience**		
M1.3.1	Good to excellent thermal comfort ensured		HEA 10 Thermal comfort
			BREEAM-C: same as **BREEAM-G**
M1.3.2	Crucial functions not situated in vulnerable locations of buildings.		
M1.3.3	Parts of buildings with high risk of damages supplied with extra protection measures.		MAT 7 Robust design
			BREEAM-C: same as **BREEAM-G**
M1.4	**Design for reassembly**		
M1.4.1		M (3) Design for disassembly (DfD)	

	De-/remountable connections used when placing/installing product in its direct surrounding, of which preservation of similar quality can be guaranteed	**Roadmap:** Focus on disassembly **BREEAM-C:** Focus on reassembly	
M1.4.2	Product assembled through de-/remountable connections, of which preservation of similar quality can be guaranteed.		
M1.4.3	Connections used for placing/installing the product in its (direct) environment are accessible.		
M1.5	**Checks and balances on environmental impact (prerequisite)**		
M1.5.1	LCA calculation made both during design & post-construction stages. Resulting environmental impact compared with best practice results of similar buildings.	M (2) Reduce environmental impact of materials **Roadmap**: Focus on material passport information **BREEAM-C:** Focus on LCA	MAT 1 Building materials **BREEAM-C:** Add LCA comparison with other buildings
M1.5.2	Construction materials chosen evaluated on environmental impact based on LCA calculation of total building and material option(s) with lowest or net-positive environmental impact considered.	M (2) Reduce environmental impact of materials **Roadmap**: Focus on material passport information **BREEAM-C:** Focus on LCA	MAT 1 Building materials **BREEAM-C**: Add LCA on material environmental impact

BREEAM-C		Roadmap	BREEAM-G 2014
M2	**Reutilization**		
M2.1	**M2.1 Maximize amount of reused materials**		
M2.1.1	Score calculated by Material Circularity Indicator <X.		MAT 1 Building materials / WST 2 Use of recycled material **BREEAM-C**: Add MCI calculation
M2.1.2	Search for local supply of reusable/second-hand materials for materialization	M (5) Use of secondary materials for building (SM) **BREEAM-C**: Emphasise local supply. **BREEAM-C, Roadmap & BREEAM-G**: All have similar indicators for usage of secondary materials	WST/ 2 Use of recycled material
M2.2	**M2.2 Maximize amount of reused components**		
M2.2.1	Search for renewable components		MAT 1 Building materials **BREEAM-C**: Add building flexibility score
M2.2.2	Search for local supply of reusable components		
M2.3	**Maximize amount of reused elements**		
M2.3.1	Mention use of recycled products in tender to stimulate reutilization during design phase		
M2.3.2	Search for renewable elements, preferably with a significant share in total material consumption	M (10) Use of renewable materials (BBM) **BREEAM-C & Roadmap**: Same focus on renewable material consumption	MAT 1 Building materials **BREEAM-C**: Consider renewable elements to reduce environmental impact.
M2.3.3	Search for local supply of reusable elements		
M2.4	**Future use**		

M2.4.1	Circular business models used could possibly encourage return & reutilization of products		
M2.4.2	Elements chosen proven to be able for reutilization / recycling in material cycle for future (similar) products	M (4) Reusability of materials/components **BREEAM-C & Roadmap**: Same focus on elements that can be reused	MAT 1 Building materials **BREEAM-C** Material recycling potential
M2.4.3	Managed service contracting with building suppliers to guarantee building product performance	M (7) Policy on circular contracting **BREEAM-C & Roadmap**: "Contract" and "suppliers" in material management	
M2.4.4	Feasibility study performed on possibilities of product reutilization		
BREEAM-C		**Roadmap**	**BREEAM-G 2014**
M3	**Circular Materials**		
M3.1	**Maximize amount of renewable materials**		
M3.1.1	Recyclable materials used in technical cycle	M (10) Use of renewable materials (BBM) **BREEAM-C & Roadmap**: Same focus on using renewable materials	MAT 1 Building materials **BREEAM-C**: Consider recyclable materials to reduce environmental impact
M3.1.2	Bio-based materials used in biological cycle		MAT 1 Building materials **BREEAM-C**: Consider bio-based materials to reduce environmental impact
M3.2	**Minimize use of scarce/critical materials**		
M3.2.1	Building not made of critical materials		MAT 1 Building materials **BREEAM-C**: Consider critical material usage when assessing environmental impact
M3.2.2	Document critical materials if used.		MAT 1 Building materials **BREEAM-C**: Consider critical material usage when assessing environmental impact
M3.3	**Minimize use of scarce/critical elements**		
M3.3.1	Environmental impact of used materials lower than reference value		MAT 1 Building materials **BREEAM-C**: same as **BREEAM-G**
M3.3.2	Minimum of X volume % of used materials with substantiated / responsible origin.	M (8) Certification of materials **BREEAM-C & Roadmap**: Same focus on responsible origin of materials M (9) Use and capture of scarce & critical materials **BREEAM-C & Roadmap**: Same focus on minimizing % of critical materials	MAT 5 Substantiated origin of materials **BREEAM-C**: same as **BREEAM-G**
M4	**Knowledge Development & Sharing**		
M4.1	**Availability of information (element, component, material)**		

M4.1.1	Building material passport composed & maintained during use cycle of building regarding material cycles	M (11) Material passport **BREEAM-C & Roadmap**: Same focus on material passport	MAT 1 Building materials **BREEAM-C**: Require material passport & demolition guideline Reference from MAN 11, MAT 1, MAT 5 & WST 1, WST 2 but none of the credits above can be identified as a complete material passport.
M4.1.2	Building material passport available for every building stakeholder	A &R (5) Information management systems **BREEAM-C & Roadmap**: Same focus on material information for stakeholder	
M4.1.3	Building upon completion delivered with demolition specifications / disassembly guidelines		

BREEAM-C		Roadmap	BREEAM-G 2014
ENERGY CYCLE			
E1	**Minimization of Energy Consumption**		
E1.1	**Minimal energy used & contained in building design**		
E1.1.1	Minimal energy consumed by building during use phase		ENE 1 Energy efficiency
			BREEAM-C: same as **BREEAM-G**
E1.1.2	Energy consumed by building during construction & use phases	E (1) Energy efficiency	ENE 1 Energy efficiency
		Roadmap: Focus on energy demand during use phase **BREEAM-C:** Focus on energy demand during construction & use phases	**BREEAM-C**: Add energy consumption during construction phase
E1.1.3	Building equipped with information sharing systems for increasing knowledge of users on energy consumption aiming for energy reduction		ENE 2 Sub-metering energy use
			BREEAM-C : Add information sharing system
E1.1.4	Elements, components and/or materials with least embodied energy selected during design phase		MAT 1 Building materials
			BREEAM-C: Consider embodied energy part of environmental impact
E2	**Optimization of Energy Demand**		
E2.1	**Energy matching (space and time)**		
E2.1.1	Building equipped with storage and/or management systems as part of energy matching	E (5) Energy matching	ENE 2 Sub-metering energy use
		BREEAM-C & Roadmap: Same goal	**BREEAM-C**: Add energy storage & management system
E3	**Sustainable & Local Energy**		
E3.1	**Minimize environmental impact on energy source**		
E3.1.1	Energy required for construction & use of building originates from sources with minimum environmental impact	E (4) Renewable energy	ENE 5 Application of renewable energy
		BREEAM-C: Add requirement of "localized" renewable energy	**BREEAM-C:** Focus on energy with lowest environmental impact instead of just using renewable energy
E4	**Knowledge development and sharing**		
E4.1	**Availability of information (energy) for building stakeholders**		
E4.1.1	All data on energy consumption to, in and out of building measured	E(6) Performance feedback	ENE 2 Sub-metering energy use
		Roadmap & **BREEAM-C**: both reference **BREEAM-G** ENE2 on documenting energy consumption	
E4.1.2	All data on energy consumption to, in and out of building publicly available		ENE 2 Sub-metering energy use
			BREEAM-C: Data need to be publicly available
E4.2	**Possibility of optimization during use phase**		

E4.2.1	Energy systems installed with performance-based contracting		

BREEAM-C		Roadmap	BREEAM-G 2014
WATER CYCLE			
W1	**Minimization of Water Consumption**		
W1.1	**Minimal water used & contained in building design**		
W1.1.1	Building equipped with water saving / water free facilities	W (1) Reduction of water demand	WAT 1 Water consumption / WAT 2 Water meter
		BREEAM-C same as **Roadmap**	**BREEAM-C**: same as **BREEAM-G**
W1.1.2	Building equipped with information sharing systems for increasing knowledge of users on water consumption aiming for water reduction	W (5) Existence of water management system: monitoring and feedback	WAT 1 Water consumption
		BREEAM-C same as **Roadmap**	**BREEAM-C** : Added information sharing system
W2	**Water Cascading**		
W2.1	**Grey water system**		
W2.1.1	Building equipped with grey water system to cascade grey water produced	W (2) Recovery of grey water and rainwater	WAT 5 Recycling of water
		BREEAM-C same as **Roadmap**	**BREEAM-C**: same as **BREEAM-G**
W2.2	**Rainwater collection system**		
W2.2.1	Building equipped with rainwater collection system to cascade rainwater	W (2) Recovery of grey water and rainwater	WAT 5 Recycling of water
		BREEAM-C same as **Roadmap**	**BREEAM-C**: same as **BREEAM-G**
W2.3	**Resource / nutrient recovery**		
W2.3.1	Possible recovery of resources & nutrients when cascading grey water and/or rainwater	W (3) Recovery of resources from wastewater	
		BREEAM-C same as **Roadmap**	
W3	**Knowledge Development & Sharing**		
W3.1	**Availability of information (water) for building stakeholders**		
W3.1.1	Building equipped with water management system to monitor and give feedback on water consumption	W (5) Existence of water management system: monitoring and feedback	WAT 2 Water meter
		BREEAM-C same as **Roadmap**	**BREEAM-C**: same as **BREEAM-G**

BREEAM-C		Roadmap	BREEAM-G 2014
BIODIVERSITY & ECOLOGY			
BE1	**Avoidance of Loss of Biodiversity**		
BE1.1	**Minimize loss of biodiversity through considering use-phase ecosystem impacts in building design**		
		B (1) Reduce embodied biodiversity impacts **BREEAM-C** same as **Roadmap**	LE 1 Reuse of land / LE 2 Contaminated soil
BE2	**Integration of Ecosystem Services**		
BE2.1	**Include ecosystem elements to provide biodiversity and building functions**		
		B (2) Ecosystem services **BREEAM-C** same as **Roadmap**	LE 2 Contaminated soil / LE 3 Plants & animals present on construction site LE 4 Plants & animals as co-users of plan area
BE3	**Integration of Ecosystem Services**		
BE3.1	**Strengthen local diversity, especially for rare species in building design**		
		B (3) Enhancement of local biodiversity **BREEAM-C** same as **Roadmap**	LE 2 Contaminated soil / LE 3 Plants & animals present on construction site LE 4 Plants & animals as co-users of plan area
BE4	**Knowledge Development & Sharing**		
BE4.1	**Long-term preservation of biodiversity & ecology**		
			LE 6 Long-term sustainable shared use of plants & animals
BE4.2	**Availability / accessibility of biodiversity information**		
			LE 6 Long-term sustainable shared use of plants & animals

(a) Human Culture & Society

BREEAM-C		Roadmap	BREEAM-G 2014
HUMAN CULTURE & SOCIETY			
HS1	**Integration of Ecosystem Services**		
HS1.1	**Minimize social shortfall and loss of cultures through considering use-phase impacts in building design**		
			LE 1 Reuse of land / MAT 5 Substantiated origin of materials
HS2	**Facilitation of Shared Amenities & Services**		
HS2.1	**Provide cohesion and impact reduction through functional shared amenities & services**		
			MAN 6 Consultation
HS3	**Knowledge Development & Sharing**		
HS3.1	**Availability / accessibility of social information**		
			MAN 9 Knowledge transfer

(c) Health & Well-Being

BREEAM-C	Roadmap	BREEAM-G 2014

Health & Wellbeing			
HW1	**Avoidance of Toxic Materials & Pollution**		
HW1.1	**Building design embodies no or minimal toxicity**		
HW1.1.1	No materials from C2C Banned List of Chemical Materials used		MAT 1 Building materials
			BREEAM-C: Add C2C material ban list
HW1.1.2	Building products have no or minimal VOC emissions		HEA 9 Volatile Organic Compounds / MAT 1 Building materials
			BREEAM-C: same as **BREEAM-G** (HEA 8 Internal air quality)
HW1.2	**Prevent pollution during construction, use and deconstruction phases**		
			HEA 9 Volatile Organic Compounds / MAT 1 Building materials
HW2	**Quality of Life Ensured with Optimal Indoor Environment Provided**		
HW2.1	**Air quality & thermal comfort ensured**		
			HEA 8 Internal air quality / HEA 9 Volatile Organic Compounds HEA 10 Thermal comfort
HW2.2	**Light & visual comfort ensured**		
			HEA 1 Daylighting / HEA 2 View / HEA 3 preventing light nuisance / HEA 4 High-frequency lighting / HEA 5 Indoor and outdoor artificial lighting / HEA 6 Light control
HW2.3	**Optimal acoustics ensured**		
			HEA 13 Acoustics
HW3	**Knowledge Development & Sharing**		
HW3.1	**Availability / accessibility of toxicity information and environment parameters**		
			HEA 8 Internal air quality / HEA 9 Volatile Organic Compounds

(d) Multiple Values

BREEAM-C		Roadmap	BREEAM-G 2014
Multiple forms of values			
V1	**Long-term Aesthetics ensured**		
V1.1	**Aesthetic value of building does not limit its functional lifetime**		
V2	**Knowledge Development & Sharing**		
V2.1	**Availability / accessibility of value information**		
			MAN 9 Knowledge transfer

Appendix C – Case information of Venlo City Hall

Source of Information

(1) C2C inspired building: City Hall Venlo, C2C Expo Lab (C2C Expo Lab., 2014)
(2) Showcasing - Venlo City Hall, Eurbanlab, 2015 (Eurbanlab., 2015)
(3) Venlo city hall from cradle to cradle, Ellen MacArthur Foundation, 2019 (EMF, 2019)
(4) Built Positive Principles Play Key Role in Venlo City Hall's Sustainable Design Mission (Cradle to Cradle, 2017)
(5) City of Venlo, A Circular Economy Business Model Case (Zwart, 2019)
(6) https://archello.com/project/municipal-office-venlo

Background and Origin

Situated in south-eastern NL and in close proximity to Germany, Venlo is a city and municipality of population 101,984 in 2021. One among the oldest NL cities with history dating back to the Romans, Venlo is the first region in Europe to embrace C2C principles, which has been embedded in its economic activities beginning from 2006.

Both government and business sectors, represented by the city administration and the Chamber of Commerce, respectively, pursue joint efforts to transform the city and the economy. Venlo city announced plans to build a new city hall in 2007. The construction industry joined the bandwagon when it was decided that all new city buildings would be designed using C2C principles.

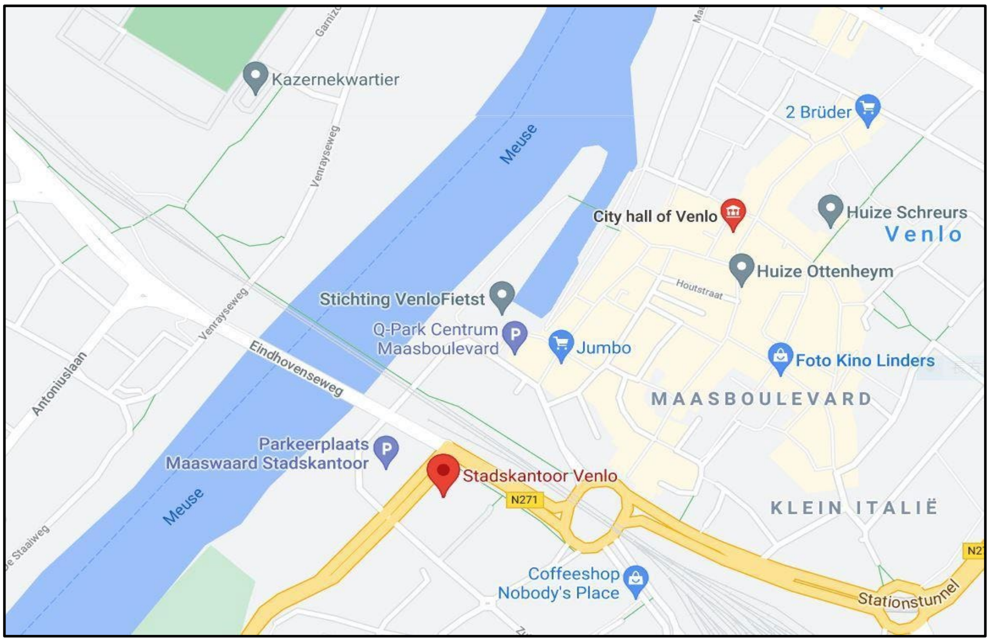

Figure C.1 Location of VCH (labelled "Stadskantoor Venlo") in Venlo city. It is about 500 m to the southwest of the Old City Hall at Venlo centre, and is situated near the banks of River Meuse.
Adapted from: Google Maps.

Hence, when the structural layout of the original city hall that required renovation did not allow for alterations of space and functions in line with these principles, another site about 500 m from the city centre along the banks of River Meuse, as depicted in Figure C.1, was chosen for a new city hall to be constructed according to the C2C standards. The design began in 2009 and the construction commenced in 2012. Finally, the new VCH was completed and opened for use in 2016. The aerial views of VCH and its surroundings are displayed in Figure C.2


(a) (b)

Figure C.2 Aerial views of VCH from (a) in front of the green façade and (b) from behind the building.
Adapted from video at: https://c2cvenlo.nl/en/city-hall-venlo/

An external view of VCH is displayed in Figure C.3(a), showing in particular its "green facade". A view from the building interior to the outside is given in Figure C.3(b). Some of the internal views are shown in Figure 5.1.4.


(a) (b)

Figure C.3 (a) External views of Venlo City Hall, showing in particular the green façade.
(b) Views from the interior of VCH to the outside.
Adapted from: http://www.c2c-centre.com/project/venlo-city-hall

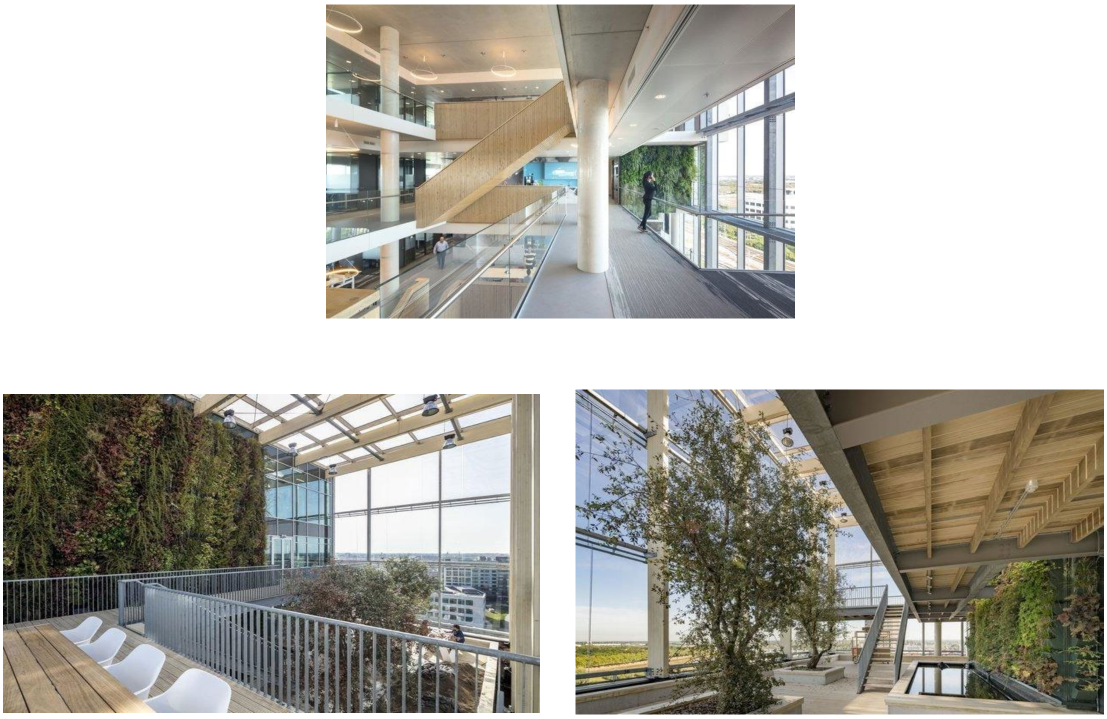

Figure C.4 Selected interior views of VCH.
Adapted from: *http://www.c2c-centre.com/project/venlo-city-hall*

To realise a 100% circular/C2C building is not yet possible; hence, it is important to focus on certain aspects. A cross-sectional schematic view of the VCH is depicted in Figure C.5, highlighting its green and circular features with their functionalities.

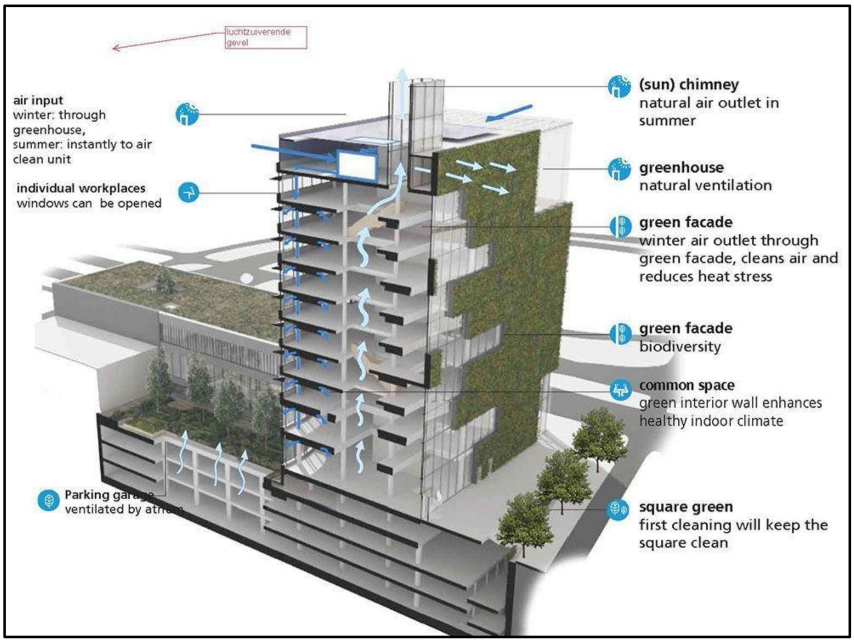

Figure C.5 Schematic figure of cross-sectional view of VCH, highlighting its green and circular features with their functionalities.
Adapted from: *https://www.royalhaskoningdhv.com/nl-nl/nederland/projecten/nieuw-stadskantoor-venlo/5931*

Displayed in Figure C.6 is an "infographics" pamphlet of the VCH with details which further showcase how its design features and functionalities would match C2C principles.

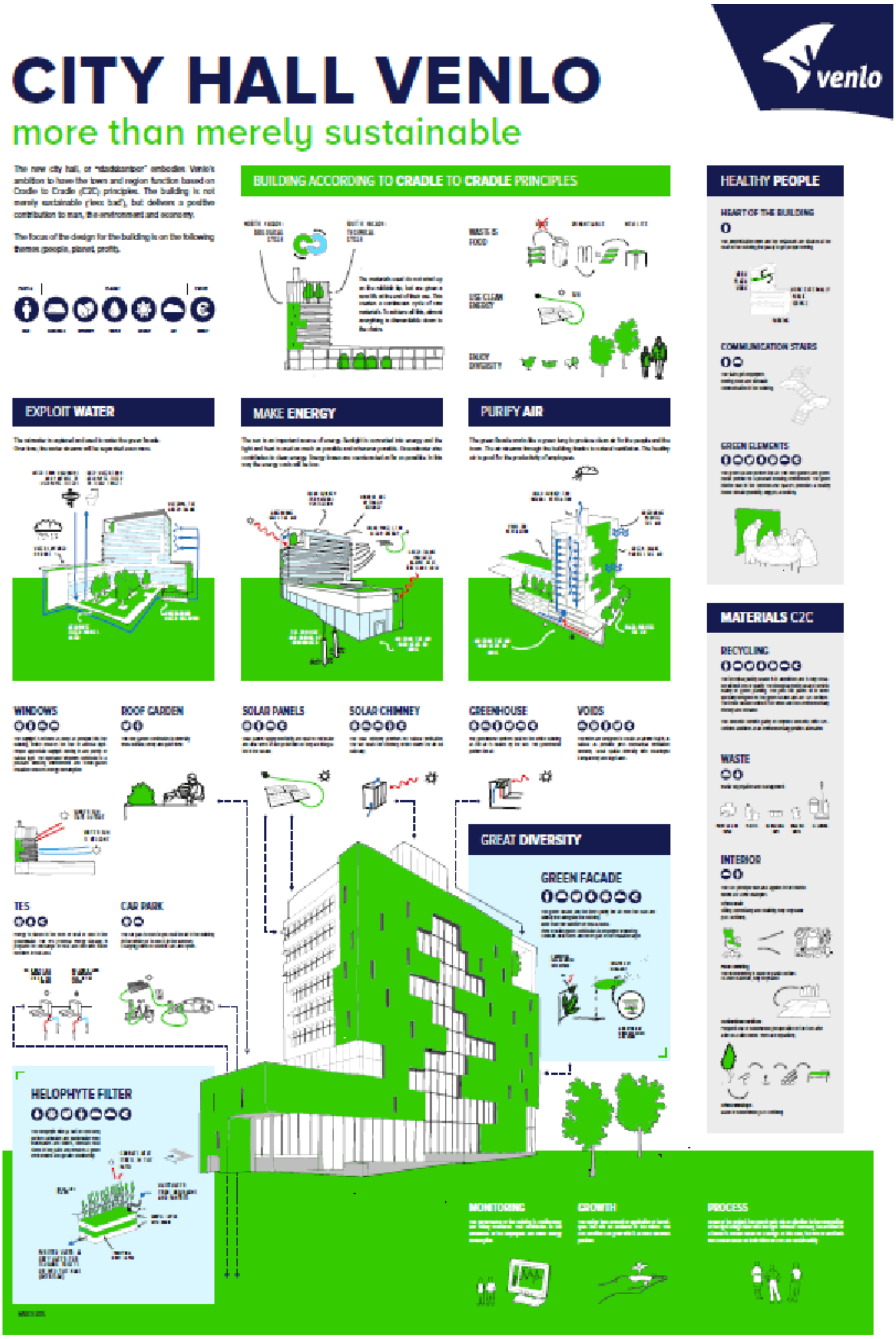

Figure C.6 An infographics pamphlet, in multilingual versions, of VCH elaborating on its features and functionalities in line with C2C principles.

Adapted from: http://www.c2c-centre.com/project/venlo-city-hall

Appendix D – Case information of TaiSugar's Circular Village

Following the 2016 President inaugural address that "… We want Taiwan to move towards the era of circular economy...", Taiwan entered the field with little or no prior experience in CE, practically in square one. The Netherlands has thus been taken as an exemplary model for Taiwan. Besides being one of the pioneering and leading countries in CE with the ambition for its economy to become 100% circular by 2050, the Netherlands and Taiwan share similarities in size and economy as well as a lack of natural resources and sense of urgency for innovative solutions to waste prevention and waste management. Both look to CE as a route to self-sufficiency and sustainability.

The Netherlands Trade and Investment Office in Taiwan (NTIO) has acted as a Social Agent for exchange. Many stakeholders from the government and the industry as well as the academia in Taiwan had also visited the Netherlands to learn from the prominent CE constructions and projects; while Dutch CE experts got invited to Taiwan to share experience and offer guidance.

Source of Information

(1) https://www.bioarch.com.tw/work/taisugar-s-circular-village
(2) https://www.taisugarcicrularvillage.com/
(3) https://www.futurarc.com/project/taisugar-circular-village/
(4) https://www.taisugar.com.tw/CSR/en/CP2.aspx?n=12329
(5) https://www.worldbuildingsdirectory.com/entries/taisugars-circular-village/
(6) https://circular-taiwan.org/en/case/taiwansugar-3/

Background and Origin

Located within the Shalun Smart Green Energy Science City, an industrial park in Gueriren District, Tainan of southern Taiwan, TCV is a residential project undertaken by the Taiwan Sugar Corporation[10] (hereinafter Taisugar) and designed by Bio-architecture Formosana[11] to meet the accommodation needs of stationed staff at the Science City. The vision is to build a smart city that co-develops with nature and to establish a people-oriented community with the necessary green life system.

[10] *https://www.taisugar.com.tw/english/index.aspx*
[11] *https://www.bioarch.com.tw/news/construction-taisugar-s-circular-village*

Figure D.1 Location of TCV in Gueriren District, Tainan.
It is situated inside the Shalun Green Energy Science City, about 500 m from Tainan High Speed Rail station in close proximity to the National Chiao Tung University Tainan campus
Adapted from: Google Maps.

Taisugar, project owner of TCV, is a state-owned enterprise and the largest agricultural producer in Taiwan. In addition, Taisugar is a leading advocacy for CE and a staunch CE practitioner committing relentless effort for promoting ‘value enhancement’ and ‘full utilisation’ of local biological resources. It has taken the initiative to launch a wide array of CE projects including organic farming, feed and fertiliser, development of renewable energy through biogas and solar power generation, cultivating mushrooms using sugar cane residue, and turning discarded oyster shells into calcium carbonate, and circular construction.

(a)

(b) (c)

Figure D.2 (a) Aerial of TCV under construction, (b) External view of a residential block, and (c) Another aerial view

Adapted from: *https://www.bioarch.com.tw/work/taisugar-s-circular-village*

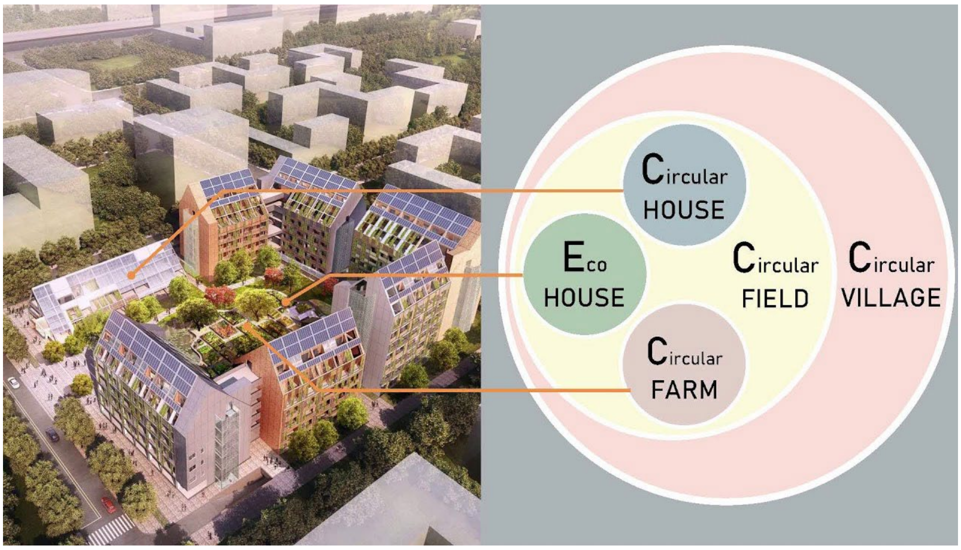

Figure D.3 Key elements in TCV: residential blocks and a circular field made up of a Circular House, an Eco House and a Circular Farm

Adapted from: *https://www.bioarch.com.tw/work/taisugar-s-circular-village*

As seen in Figure D.3, the Circular Village comprises three residential blocks where the living apartments are located and a Circular Field made up of a Circular House, an Eco House and a Circular Farm

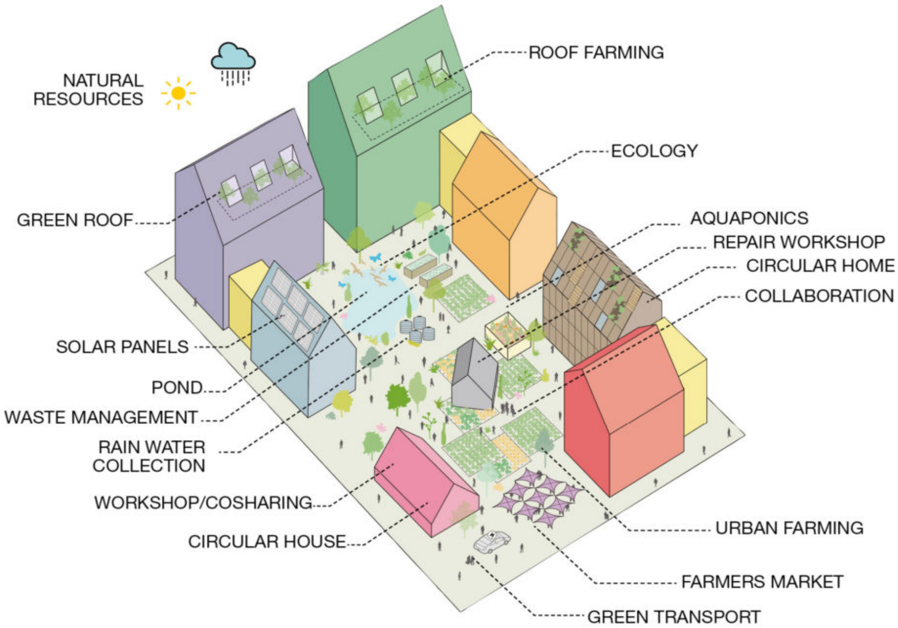

Figure D.4 Overall schematic diagram of TCV highlighting green and circular features with their functionalities.

Adapted from: *https://www.futurarc.com/project/taisugar-circular-village/*

(a)

(b)

Figure D.5 (a) Plots for roof farming and (b) solar panels for power generation at TCV

Adapted from: *https://www.taisugar.com.tw/english/index.aspx*

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