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Circular Economy in the Built Environment

Teaching & Learning Guidebook

Teaching
& Learning
Guidebook

Circular Economy *in the* Built Environment

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DISCLAIMER

This Guidebook aims to assist in the teaching and learning process of circular economy to undergraduates and postgraduate students.

ACKNOWLEDGEMENT

This Guidebook is a summary of circular economy concepts, built environment circular economy local-based case studies, and how circular economy concepts can be integrated into teaching and learning. This Guidebook is based on collaborations undertaken for a research project by five universities: RMIT University, University of Peradeniya (UoP), Arabaev Kyrgyz State University (AKSU), TERI School of Advanced Studies (TERI-SAS), and Asian Institute of Technology (AIT).

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EXECUTIVE SUMMARY

Circular economy is an evolving field of study contributing significantly to global sustainability by eliminating waste and reducing the use of virgin materials in industrial and daily activities. Circular designs and manufacturing have lowered the costs of products and provided innovative solutions for resource scarcity. Novel concepts associated with the circular economy, such as cradle-to-cradle designs, have eliminated waste generation from cradle-to-grave designs in a linear economy. Circular economy is not limited to any specific field of study but amalgamates many fields to circulate materials throughout their systems. However, we found that the availability of case studies is a gap in demonstrating its applicability to the built environment. We proposed a project on developing case studies for the built environment and sought funding through United Nations University (UNU). Our research has produced this Guidebook to support teaching and learning for built environment programs.

The Guidebook starts with a section on how best to use the content for teaching and learning. It facilitates engaging both students and teachers of circular economy to acquire a basic understanding of the concepts involved compared to a linear way of using resources. This is covered in the first section: introduction to the circular economy. Then, it exposes the user to case studies on the built environment. The case studies cover a variety of circular applications in the built environment, from buildings to roads and irrigation projects. The cases are not necessarily best practice examples, but provide insights on how various strategies for circularity may be practically applied. Furthermore, it shares our experience of teaching and learning the circular economy in different areas of study.

The Guidebook is a resource for anyone interested in the circular economy applied to the built environment. It comprises all the basic principles related to the concept. The difference between a linear economy and a circular economy is illustrated. Furthermore, the case studies give users some knowledge of using the concepts in built environment practices. Finally, users will understand the problems encountered in teaching and learning circular economy techniques under the lessons learned to help align teaching methods to specific contexts and share similar experiences from that context.

The Guidebook presents diverse circular economy applications in the built environment and promises to be an eye-opener for future applications in the built environment. The case studies promote documentation of similar cases in the future for the benefit of the built environment stakeholders, including educators. We highly recommend this guidebook to assist users with the successful application of circular economy principles to help sustain planet Earth.

INTRODUCTION

PURPOSE

This Guidebook aims to enhance understanding of the circular economy and promote its implementation in both personal and professional activities. The Guidebook provides a brief introduction to circular economy definitions, principles, and case studies to support teaching and learning, as well as to understand and apply the circular economy in practice. This Guidebook contributes to transitioning the industry and community towards a truly circular economy.

CONTEXT

The built environment is a leading sector in the use of natural resources, raw materials, greenhouse gas emissions, and waste generation. Recent data shows that the United States generated 600 million tons of construction and demolition waste (CDW) in 2018 (United States Environmental Protection Agency, 2018) while the European Union produced 374 million tons of CDW in 2016, with the exclusion of excavated soil (European Environment Agency, 2020). CDW is forecast to globally increase to 2.2 billion tons by 2050 (EMF, 2020). The increase in waste causes issues for landfill, the environment, and the climate. Although CDW has a high value in reuse and recycling, only 40% of CDW has typically been reused, recycled, and used to generate energy (waste to energy) (United States Environmental Protection Agency, 2018). In Australia, 19.0 million tonnes of CDW was generated in 2008-2009 (based on the available data in the report 2011) and 45% of CDW was disposed to landfill (Department of Climate Change, Energy, the Environment and Water, 2011). A large amount of CDW ends up in landfill and negatively impacts the environment.

Circular economy in the built environment has received greater attention from scholars and practitioners due to the economic focus for resource conservation and the opportunity for more effective use of natural materials (Oluleye et al., 2022). CE focuses on the flow of materials and products across their life cycle and aims to reduce the pressure on natural materials and reduce carbon footprints. For the built environment, EMF (2021) highlighted global carbon emissions will be reduced by 2.1 billion tonnes by 2050 due to CE strategies implemented in this sector and assist in achieving net zero by that year. However, circular economy in the built environment still remains on the ‘lower order’ R strategies of “reduce, reuse and recycle” which can hinder wider applications of circular economy in various phases of a material flow and product life cycle.

This Guidebook is developed to advance the understanding of circular economy through both theoretical and practical lenses. It also shares lessons from the first delivery of circular economy teaching across the partner universities and highlights the changes in circular economy understanding post-course attendance. This book also provides recommendations to improve the next cycle of teaching and learning.

HOW TO USE THIS GUIDEBOOK

The Guidebook can be used flexibly in different climate and cultural contexts of construction projects and is dependent on the user’s perspective.

- If you are a **teacher**, this Guidebook can be considered as a reference to develop your teaching materials related to circular economy as well as circular economy in the built environment. Teaching staff can develop local case studies based on their context and analyse case studies similar to the approach developed in this book to demonstrate how and why circular economy can be implemented in different construction projects.
- If you are a **student**, this Guidebook can be considered a reference to enrich your knowledge and experience on circular economy generally and how circular economy may be implemented in construction projects. The Guidebook is developed based on an easy-to-absorb approach so you will gain an in-depth understanding of what a circular economy is, its principles, and its strategies.
- As a **user,** you can situate this knowledge to design and develop a model/ strategy for circular economy applications for your particular context.

CONTENTS

CHAPTER 1

INTRODUCTION TO CIRCULAR ECONOMY

1.1. DEFINITIONS OF CIRCULAR ECONOMY

The construction sector is the largest consumer of raw materials, and accounts for 25-40% of global carbon dioxide emissions (Forbes, 2021). Most of the built environment projects commonly follow a “take-make-dispose” approach and this linear approach ultimately increases resource burden. The additional impacts could also lead to depletion of ecosystems and their services in the long term, as the waste generated results in increased landfill sites and deposits. The transition to a circular economy in the built environment can be a key to achieving a resource efficient society.

Circular Economy is defined as “an economic system that uses a systemic approach to maintain a circular flow of resources by recovering, retaining or adding to their value while contributing to sustainable development”.

(ISO/DIS 59004, 2021)

Another definition of Circular economy is “economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles” BS 8001: 2017 standard (British Standards Institution, 2017).

According to Kirchherr et al. (2017), circular economy is a system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim of achieving sustainable development, thus simultaneously dealing with environmental quality, economic prosperity, and social equity, for the benefit of current and future generations.

As per National Institute of Standards and Technology (NIST) – US Department of Commerce, a circular economic model preserves natural resources, reduces the need for landfills, and advances social and environmental justice while creating value and new business opportunities (NIST, 2023). The circular economy is a systems solution framework that tackles global challenges such as climate change, biodiversity loss, waste, and pollution (Ellen MacArthur Foundation, 2023a).

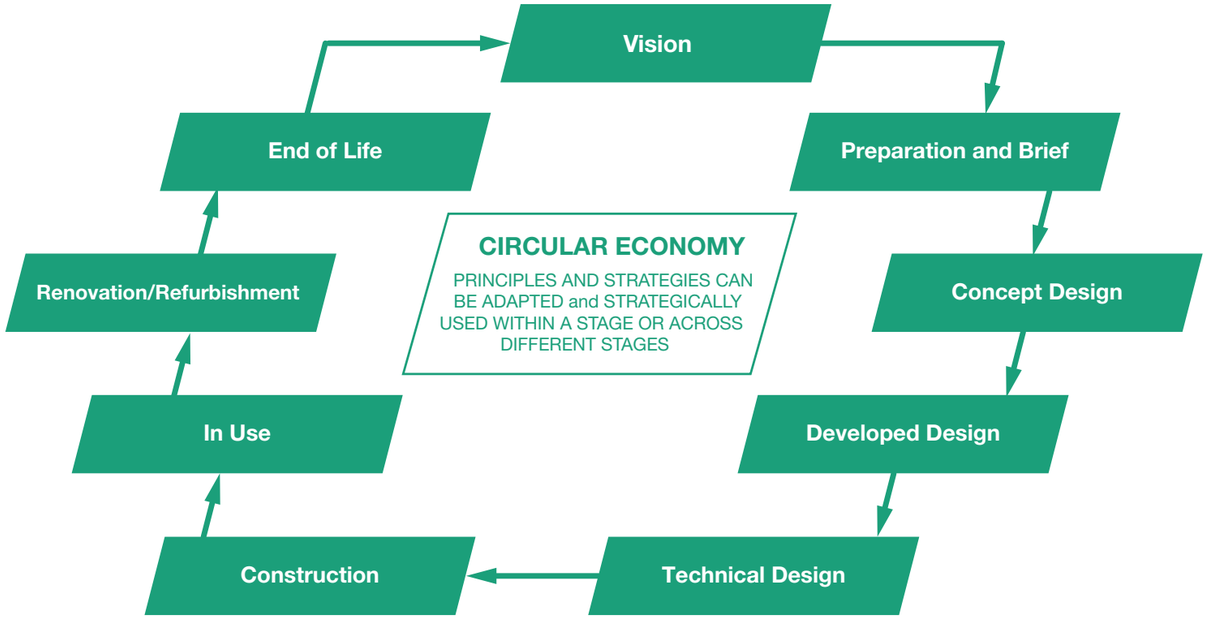


Figure 1.
A Conceptual Model for Circular Economy in the Built Environment (Authors)

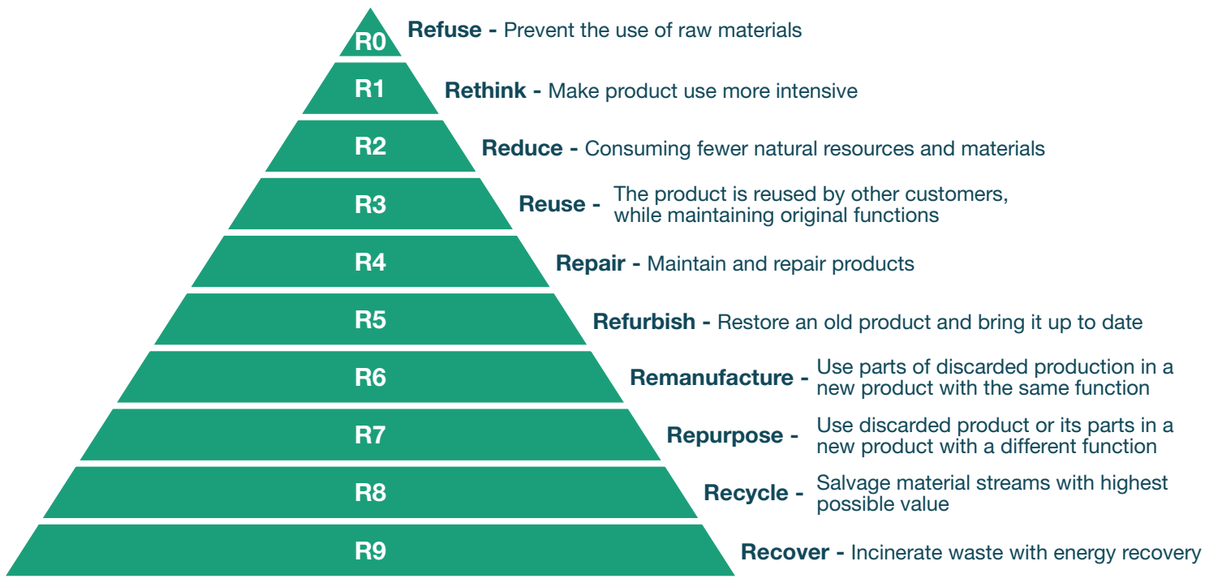


Figure 2.
R Strategies (Adapted from Potting et al., 2017, Cramer, 2022)

1.2.

CIRCULAR ECONOMY PRINCIPLES

The transition to a circular economy from a linear economy requires adopting some principles. The circular economy is based on three principles (Ellen MacArthur Foundation, 2023b).

1. **Eliminate waste and pollution:** The first principle of the circular economy is to reduce waste in built environment projects, and this can be achieved with ***better planning and design*** of the project.
2. **Circulate products and materials:** Circulating products and materials at their highest value in built environment projects can help ***decrease the requirement of raw material***. This way, ***nothing becomes waste***, and the ***intrinsic value of products and materials are retained***.
3. **Regenerate nature:** Construction and demolition waste from built environment projects can be ***processed in waste processing units*** and ***converted into recycled sand and aggregates*** that have a range of uses in a variety of construction applications. Thus, we are not drawing on the use of virgin resources and can ***support the earth to regenerate***.

The use of the word “waste” itself needs to be eliminated from our vocabulary so we can always consider something ‘unwanted’ as valuable. Potting et al. (2017) identified a priority framework for a circular economy containing ‘10 R’- strategies including refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover. In circular economy language, refuse is the best option and the highest order of circularity whereas recover is the worst, where the product or material is permanently lost as waste to energy.

In practice, circular economy in the built environment implies adopting circular economy principles in projects such as the use of locally available and recycled materials and reducing construction and demolition waste to a minimum or eliminating it completely. Buildings designed with local materials having low embodied energy is another way to implement circularity in the built environment. Using passive design to reduce operational energy and integrated with renewable energy systems can also help to achieve circularity. When a product reaches the end of its life, its materials are kept within the economy wherever possible by recycling or using any of the other R-strategies. Building information modelling (BIM), life cycle assessment (LCA) and material flow analysis (MFA) are well established techniques for sustainability studies in the built environment and can be used for circular economy design, and in planning and operation of projects.

CHAPTER 2

CIRCULAR ECONOMY IN THE BUILT ENVIRONMENT

2.1.

CIRCULAR ECONOMY AND THE BUILT ENVIRONMENT

Why does the built environment need to become circular?

Figure 3.
Bosco Verticale, Milan, Italy

The built environment consumes a high volume of natural resources and generates a high level of waste and carbon footprint which significantly affects the environment and climate. Existing studies demonstrate that linear economic patterns would not be a sustainable economic model for this industry due to finite resources and increasing demands of population growth. There is an urgent need for this industry to transition towards circularity.

Circular economy in the built environment can assist in resolving various issues of construction-demolition waste, resource scarcity and environmental issues. Existing studies show that circularity can be applied through various approaches including materials selection, design solution, technology innovation and waste management. It also highlights a core role of designers and a high commitment amongst stakeholders in constructing the final product, as well as deciding what happens at the end of life.

The implementation of three R strategies “reuse, reduce and recycle” are dominant in this discipline with the focus on materials, waste reduction and waste management. It means that circular economy implementation needs to incorporate more than the end-of-pipe solutions; it needs the integration of various cyclical and mutually beneficial relationships in a supply chain to keep materials and products staying longer in the current built environment sector. Circular economy implementation in this sector is still fragmented and lacks collaboration amongst stakeholders. Therefore, improving circular economy understanding for such stakeholders in and the community at large is needed to promote more circular practices.

The following section offers local-based circular economy case studies which present practical circular economy applications to both teachers and learners. These case studies can be used as examples to underline how circular economy can be interpreted in a particular context and how it can be realised through different innovative methods/frameworks/strategies. More importantly, these case studies provide some insights of circular economy applications and benefits that can be gleaned from these applications. The case studies were developed for the built environment, but lessons gained from these case studies can be applied to other sectors.

2.2.

CIRCULAR ECONOMY CASE STUDIES

How can we practically apply circular economy in the built environment?

Let's examine several circular economy case studies.

Figure 4.
A road laid with Reconophalt™
(Downer Group, 2020)

2.2.1. Reconophalt Downer – Australia

Reconophalt™ is the first road surfacing material in Australia that contains a high volume of recycled components derived from waste streams, such as soft plastics, glass and toner. Reconophalt™ is made from both new materials and recycled materials including natural aggregates, recycled asphalt, waste toners, recycled plastic and recycled glass.

This material is either a light duty product for footpaths and recreational areas or a heavy-duty product for highways or even airports. The proportions of mixed constituents can be changed to meet technical requirements and standards of local road surfaces. Indeed, Reconophalt™436 includes four recycled components accounting for 36% of its weight while Reconophalt™886 contains eight recycled materials making up 86% of its weight.

In 2020, Downer laid over 77,000 tonnes on roads in six Australian states and territories, using 46.1 million plastic bags and packaging equivalents, 1.3 million used toner cartridges, 11.5 million glass bottle equivalents and 20,500 tonnes of reclaimed asphalt.

(Downer Group, 2020)

Reconophalt™ brings no increased environmental risk while providing considerable sustainability and performance benefits with the inclusion of fatigue life increase and deformation resistance improvement.

Figure 5.
Eco-bricks

2.2.2. Eco-bricks – Thailand

This eco brick-making process from Thailand can be simply executed by laypeople without the requirement of any construction or engineering background. Unrecyclable plastic trash such as plastic bags, snack bags, candy wrapper plastic, and straws that can be easily found in the community are cleaned, dried, and cut into small pieces, then compressed in a plastic bottle; and used as a replacement for concrete bricks (Short Recap, 2019).

The project has contributed to the community's-built environment which has been expanded from building walls and stairs to the school buildings, library, and houses for marginalized people. In addition, it has caused a big country-wise collaboration in plastic waste collection and segregation for the eco brick-making process which leads to awareness-raising among Thai people. Significantly, rethink and remanufacturing concepts contributed to sustainable community development through construction and also created opportunities to access education and health care for remote and marginalized people in the area, not to mention creating employment.

2.2.3. Mahaweli Water Security Investment Program – Sri Lanka

With the key focus on reduce, repurpose, and remanufacture strategies, the Mahaweli Water Security Investment Program aims to provide sufficient water for targeting irrigable areas in this province in Sri Lanka. The target is to transfer about 130 MCM (1 MCM= 1000 cubic meters) annually to North-western Province Canal, and to reduce virgin material use and waste dumps as much as possible while fulfilling the primary aim of the built environment.

The program's speciality is based on the fact that most of the earth filling material are being extracted from the inundated area on site so that virgin materials will not be used for backfilling. Therefore, this will help in reducing the cost of virgin materials as well as the transportation cost to site indirectly reducing energy usage as much as possible.

As supplementary achievements, a reduction of virgin material usage is noted by reusing ballast and excavated materials. Management of construction and demolition waste through the re-using of materials is noted and culverts have been repaired and remanufactured.

Nevertheless, identifying possible materials for repurposing at the design stage along the tunnel stretches, incorporating quantities in bidding documents, and sharing profits between stakeholders, whether the Ministry of Irrigation – the project client, Tractebel Engineering Pvt Ltd – the consultant firm, contractors, material suppliers, and especially farmers, are still being considered for the future.

Figure 6.
Repurpose soil and tunnel mucking material to use for infrastructure projects

2.2.4. Butterflies building – India

Butterflies NGO building in Delhi, India designed by Ashok B Lall Architects is an example of the adaptability of circular economy principles in building design and construction. The building serves as a child resilience centre and is multifunctional with administration, offices, training centres, and residential areas for children. It combines the organisation's vision of a cost saving sustainable building with green building design elements and strategies from the architects.

The building reused materials from previous construction, re-manufactured excavated soil (for building materials), refurbished wooden doors and windows, incorporated passive design techniques, and also used circular economy principles in operation of the building. It combines the rethink, reduce, reuse, refurbish, remanufacture, and recycle principles from the 10R's strategy.

Therefore, the project successfully contributes to the re-manufacturing of all the excavated soil into compressed blocks to be used in the walls of the building and re-purposing the discarded doors and windows in the whole building.

Figure 7.
Corridor in Butterflies building with remanufactured brick walls. (Butterfly NGO)

Figure 8.
Biogas

2.2.5. Rural waste recycling – Kyrgyzstan

A case study on conducting research on heating buildings with biogas from livestock waste in Naryn region in Kyrgyzstan is explored. The case study application of biogas technology model for rural areas introduced a cost-effective green technology that delivers concrete renewable energy solutions, reducing environmental pollution and providing safe livelihoods. The research demonstrates reuse, waste recycling, creating a new product in the form of biogas, without negative impacts on the environment. In remote rural areas of the country, the case study can be applied by local people for home heating and improving wellbeing. The main benefits identified are reduce the impact towards the environment, improve safety and wellbeing of local population, recycle waste to give new ‘life’ to the waste, reduce costs and lower carbon emissions.

What are circular economy principles and strategies applied in these case studies? How can circular economy concepts be elucidated and conveyed through these case studies?

CHAPTER 3

CIRCULAR ECONOMY EDUCATION

3.1.

CIRCULAR ECONOMY EDUCATION

How to educate the circular economy?

The concepts of circular economy were introduced to students in the five partner universities involved in this project. These included circular economy definitions, principles, and strategies. Different definitions and theories of circular economy were highlighted to assist students in gaining an in-depth understanding of circular economy and its interpretation from different perspectives, while also considering the different values associated in different cycles in a supply chain.

Local-based case studies have been used to demonstrate how the circular economy is implemented in different scenarios of various countries. R-strategies are a particular focus to underline that circular economy has not been fully understood yet. Most circular economy case studies represent the low order of R strategies and have been applied focusing on “recycle, reuse and reduce”. The higher order R-strategies need to be encouraged including ‘’refuse and rethink”. Ultimately, regeneration to support ongoing human life on the planet needs to be considered. These higher order circular strategies can enable holistic thinking in circular economy implementation rather than focusing on one stage or one stakeholder in the life cycle.

In-class exercises are designed to encourage students to analyse case studies based on their background and experience. Many students were able to demonstrate the application of circular economy principles in different applications in the case studies such as *recycled materials use, waste management, water solutions, renewable energy and technological support*. Students highlighted its importance and the critical role/s that key stakeholders play for circular economy implementation in a project.

The research demonstrates that circular economy knowledge has been improved post course attendance. Students have critical skills that can be applied in different aspects of circular economy in a real-world context with different circular solutions. A significant change shown is their thinking, when they can consider circular economy as an approach to resolve different issues such as material scarcity, energy efficiency, carbon emission as well as climate change.

3.2.

LESSONS LEARNED FOR CIRCULAR ECONOMY EDUCATION

How does this knowledge help?

This section aims to share lessons learned from the results of interviews with lecturing staff and surveys with students on the circular economy course or circular economy integration into different courses. This part of the Guidebook is presented in three main sections: circular economy understanding, content, delivery and case studies.

3.2.1. Circular economy understanding

Generally, circular economy education provides a broad understanding but also provides an understanding across sectors.The results of the interviews and surveys demonstrate that students have gained an understanding of circular economy concepts including its definitions, core principles underpinning circular economy, R strategies, circular business models, and its practices. Some students obtained an advanced understanding of circular economy by being able to articulate material flows with a holistic view. They were able to recommend how to apply circularity in their personal and professional activities.

More than 70% of students state that they have a clear or very clear understanding of circular economy post-course attendance.

3.2.2. Circular economy content

Circular economy content in general has met the requirements and expectations of the course, teaching staff and students. No part of the content needs to be removed or changed. More than 70% of students noted that circular economy concepts were clearly or extremely clearly explained in the class. The circular economy content covered primary concepts including the explanation of moving away from linear economy patterns to lessons learned from other industries when implementing circular economy.

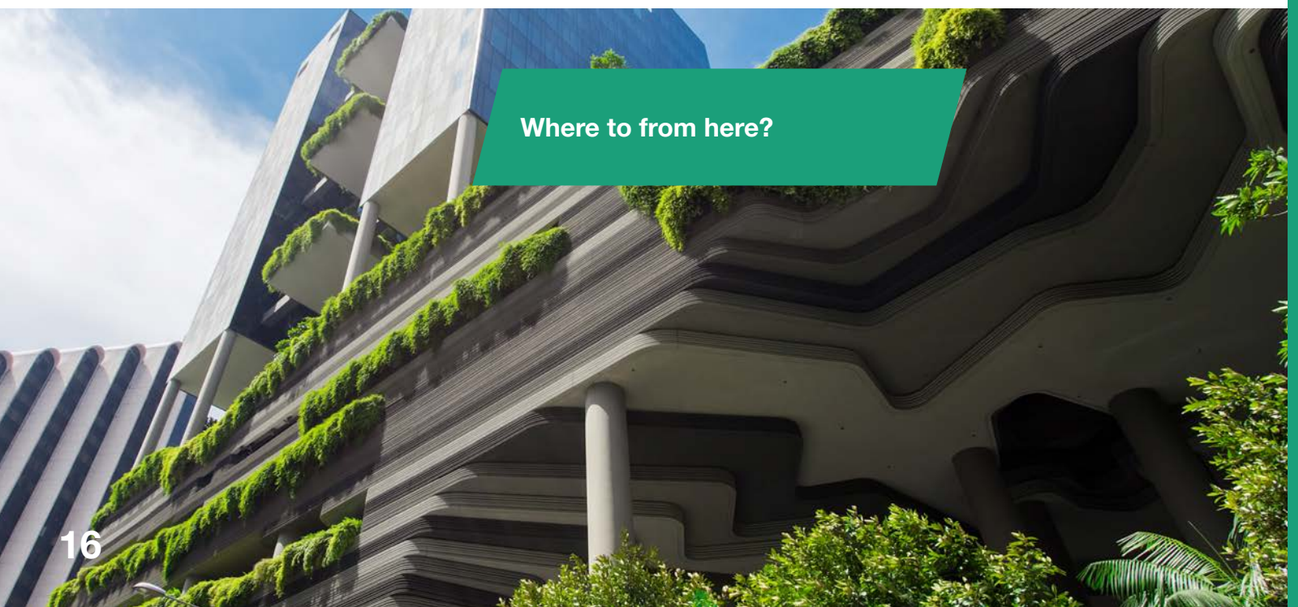
3.2.3. Circular economy course delivery

Most of the feedback from teaching staff and students was on the course delivery. Highlights include reconsidering the structure of sessions in these courses to ensure that there is enough time in each session to deliver content as some sessions were too short to deliver theory and case studies to students. The sessions need to be restructured to enhance better delivery. Technical language needs to be considered to improve the course delivery.

3.2.4. Circular economy case studies

Case studies play an important role in circular economy education as most students stated that case studies can be one of the best approaches used for them to understand concepts which are very abstract. Case studies enable honing-in circular thinking to students. The studies demonstrate how circular economy can be interpreted and implemented, and the tangible and intangible benefits that can be gained by circular considerations throughout the life cycle of products and services.

To make the best use of case studies, it is recommended to have a full set of case studies for students to understand and analyse. Along with this, short case studies or examples can be designed to explain abstract concepts such as circular tools/metrics or circular business models. The diversity of case studies needs to be improved across countries and industry sectors.



Where to from here?

CHAPTER 4

CONCLUSION

Circular economy highlights opportunities to resolve the issues of materials scarcity, global warming and climate change. It offers alternatives to the concepts of waste; and to use waste as a resource. It relies on using different cycles to keep materials/products in a loop to last longer and maintain their values. Product and services in the circular economy need to be designed in a holistic and systemic manner when considering either technical or biological cycles. Circular economy requires rethinking the whole life cycle of a product from design, manufacture, operation and to the end of life.

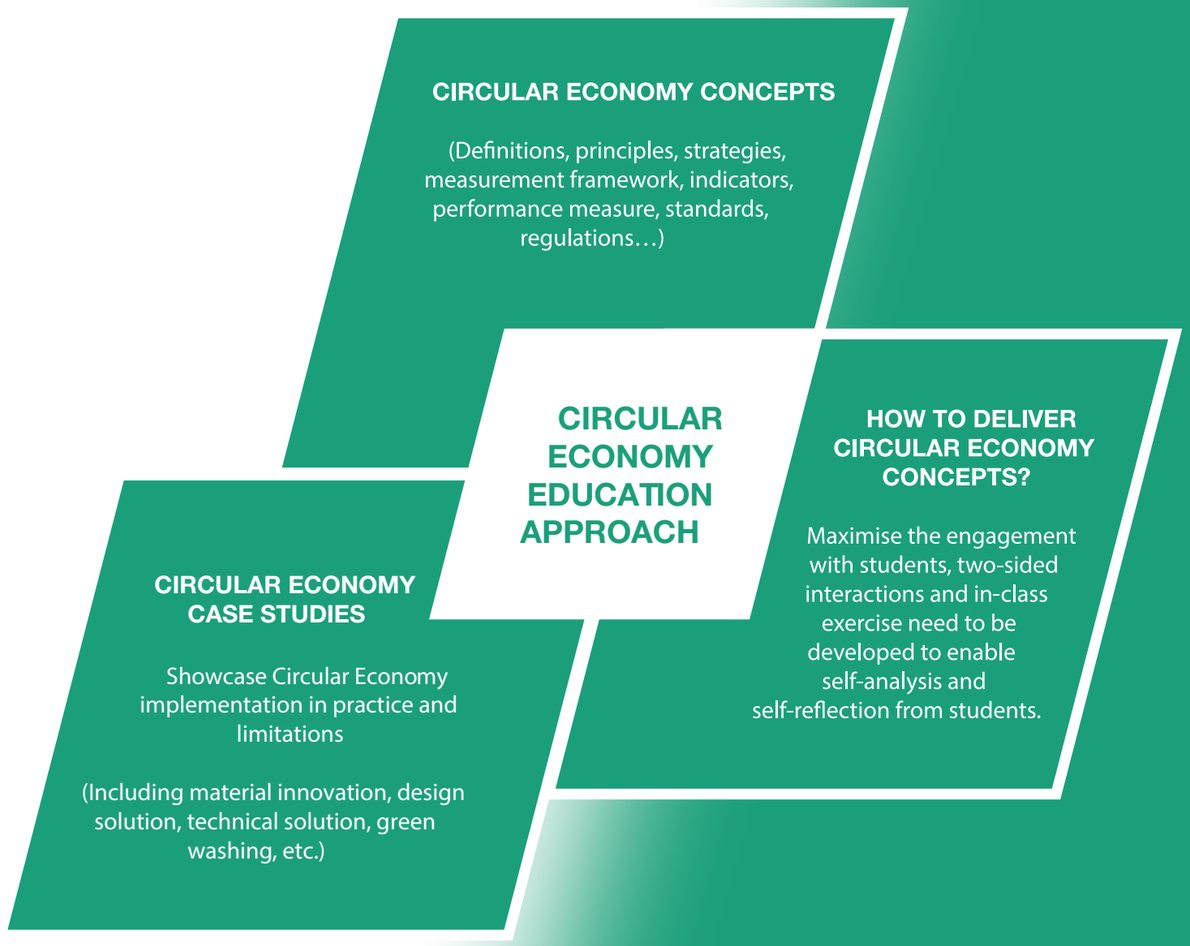
A transition from a linear to circular economy is a challenge but it creates an opportunity for the built environment to change the current system for circular adaptation. Understanding the remit of the circular economy is the key to unlocking this opportunity. This Guidebook is developed to provide CE concepts and case studies in an easy to understand and use manner to support the teaching and learning process.

The design of a circular economy education needs to include:

- Circular economy concepts including circular economy definitions and principles which can assist students in developing their personal and professional understanding of how best to apply circular principles.
- Circular economy case studies need to underline practical applications of circular economy in various construction projects. These case studies can be material innovation, design solutions, and technical solutions. They can also be infrastructure, office buildings and other types of construction projects. Presenting various case studies across various life cycles of the construction projects and the use of various R-strategies is important to enable learners to see how practically circular outcomes may be achieved in the built environment.
- How best to deliver circular economy concepts to students? Designing its content and delivery methods needs to be focused to maximise engagement with learners. Appropriate time allocation for each session and the use of a variety of technical languages will assist to better communicate with learners. Two-sided interaction and in-class exercises need to be developed to improve students' engagement.

In addition, students should be allowed to work on their own case study or analyse existing cases. This enables development of a deeper understanding and strategies where theoretical understanding can be examined in a practical context. Students should be provided opportunities to express their comprehension, engage and learn from their peers whilst also gaining knowledge from their teachers.

The lessons derived from the first delivery of circular economy education were shared in Chapter 3. These lessons were collected via interviews with fifteen lecturers and 109 surveys from students in the five partner universities. The recommendations on circular economy concepts, case studies and delivery methods are highlighted to increase the efficiency of course delivery and support circular transitions across the built environment sector regardless of the location of projects.



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