The Circular Economy in the Australian Built Environment:

The State of Play and a Research Agenda

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Published by Deakin University.

ISBN: 978-0-7300-0405-9

S. Shooshtarian, M.R. Hosseini, T. Kocaturk, M. Ashraf, and T. Arnel. 2021. The Circular Economy in the Australian Built Environment: The State of Play and A Research Agenda. Faculty of Science, Engineering and Built Environment, Deakin University, Geelong, Australia.

Executive summary

At the global level, the extraction of raw materials more than doubled between 1990 and 2017, and is projected to double again by 2060. In recent years, countries have demonstrated stronger interest in resource efficiency, not only to address environmental issues but also to achieve objectives such as economic growth, and employment and resource security. A transition to a more circular economy (CE) will have a significant effect on resource efficiency and the conservation of natural resources. This report presents an overview, with Australia the primary focus, of the design, practice, and implementation of a CE in the architecture, engineering and construction (AEC) industry.

The AEC industry is a major contributor to the nation's economy: the industry is estimated to generate over A$360 billion in revenue, contributing 9% of total gross domestic product (GDP). Due to the size of the industry and its adverse and unwanted impacts on Australia's environment, society and economy, this report aims to provide a platform for research on a CE, exploring its various aspects. The methodology employed is desktop research using the available secondary data, and involving a literature review, policy analysis and network analysis.

The report is structured in five sections as follows:

1. To set the context, an overview is presented of the AEC industry in Australia in terms of its size, performance, environmental impact, and contribution to the Australian economy.

2. The characteristics of a CE are explored. This includes investigating the history and definition of the CE model, the model's knowledge and theoretical foundations, and international CE policies and guidelines. The exploration is supplemented with the results of a network analysis of CE keywords and a review of the CE literature, mapping out the systemic nature of a CE and the enablers and barriers influencing CE adoption in the built environment.

3. The environment of CE application in the Australian context is described, providing an analysis of the CE policy and guideline landscape, and identifying key stakeholders.

4. The Australian research and development (R&D) ecosystem is analysed in relation to the extent that it contributes to introducing the transition to a CE in Australia.

5. Several research directions are introduced for CE design, planning and practice in the AEC industry.

The report provides a picture of the CE landscape in Australia, with discussions on the main areas (i.e. research and industry) as follows:

Research

- A surge in the number of research outputs on the CE–AEC industry is apparent from 2010–2020. China, with 139 documents, had the highest number of publications on the CE–AEC industry, followed by Spain (63) and the United Kingdom (UK) (63).
- The network analysis of major keywords referenced in CE-related literature shows that CE science is still under development, with the relevant literature aimed at introducing the basic concepts to readers.
- The CE–AEC industry priority research areas centre on durability, adaptability, waste reduction and improved waste management.
- A growing number of government-funded research institutes and hubs are researching a CE in the AEC industry, with these identified in the current study.

Industry

- The AEC industry is a significant contributor to the Australian economy; however, current industry practices negatively impact on the environment, society and the economy.
- While the history of the CE model dates to as early as 1966, the model has recently received more attention within developed and developing economies.
- A CE in the built environment is informed by seven determinants (i.e. valuing resource productivity; fostering behaviour change; sustainably managing all resources; designing out waste and pollution; creating new CE jobs; providing innovative solutions; and maintaining the value of products and materials).
- The study identifies the dominant CE-focused frameworks deemed suitable for the AEC industry.
- Also identified are around 13 ISO (International Organization for Standardization) standards that currently focus on the CE, followed by five other ISO standards that are under development.
- Several barriers to and enablers of the CE are identified through a literature review.
- Due to the systemic nature of the CE, a multidisciplinary approach is needed from the main actors to establish CE-related research/practice/policy initiatives.
- The key stakeholders in the CE–AEC industry are identified, comprising public agencies, industry associations, the research and development (R&D) sector, designers, structural engineers, builders, labourers, building (facility) managers, end-users, recyclers, and manufacturers.
- The study identifies major CE-related policies and guidelines in Australia.
- The federal government with state and territory governments are identified as providing annual funding to promote the CE in the AEC and related industries.

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List of acronyms

ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
AEC	architecture, engineering and construction
C&D	construction and demolition
C2C	cradle to cradle
CBM	circular business model
C&DW	construction demolition waste
CE	circular economy
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWE	Department of Agriculture, Water and the Environment
DfD	design for deconstruction or disassembly
DfMA	design for manufacture and assembly
DfRem	design for remanufacturing
DoW	design-out waste
EMS	environmental management system
EPA	Environmental Protection Authority
EPR	extended producer responsibility
GBCA	Green Building Council of Australia
GDP	gross domestic product
GHG	greenhouse gas (emissions)
ISO	International Organization for Standardization
LCA	life cycle assessment
LE	linear economy
MFA	material flow analysis
NSW	New South Wales
NT	Northern Territory
NWR	National Waste Report
OECD	Organisation for Economic Co-operation and Development
PS	product stewardship
PTB	product take-back
Qld	Queensland
R&D	research and development
SA	South Australia
Tas	Tasmania
Vic	Victoria
WA	Western Australia

Introduction

Resource efficiency and our responsibility

The 20th century was an age of unprecedented growth in the use of natural resources and materials. Global demand for materials grew during that century, following steady economic growth in OECD[1] countries, the industrialisation of emerging economies and a growing world population. At the global level, the extraction of raw materials more than doubled between 1990 and 2017 and is projected to double again by 2060.[2] These recent trends, however, will not be enough to counteract the rising demands and ongoing quest for higher living standards of a world population headed to more than 10 billion by 2060, of whom more than 75% are expected to live in urban areas.[3]

Three socio-economic factors generally drive the use of materials and resources. First, a growing global population and the progressive convergence in living standards across countries lead to higher consumption, thus increasing materials use. Furthermore, as economies develop, investments in construction and infrastructure increase, leading to a higher demand for materials. Second, technological improvements reduce energy consumption which can decrease the material intensity[4] of production, thus reducing the materials input required to produce a given economic good. For instance, prefabrication, as an advanced construction technology, is more resource-efficient (less waste/material intensity) and has a better economic performance than previous methods.[5] Third, with structural changes in the landscape of the overarching economy, the material intensity of the economy can be further reduced. As specified in a recent OECD report, as income levels rise, aggregate demand shifts towards less resource-intensive sectors, such as services and leisure activities.[2]

Overall, technological advancements and structural changes have the potential to counterbalance the increasing demand for materials use, partially decoupling materials use from economic growth.

In recent years, countries have demonstrated stronger interest in resource efficiency, not only to address environmental issues but also to achieve objectives such as economic growth, and employment and resource security. A transition to a more resource-efficient, circular economy (CE) – a concept that rests on a systemic approach to resource efficiency in which one looks beyond the current take-make-waste extractive industrial model – will have a significant effect on the use of resources and contribute to creating sustainability in the environment, the economy and society. Global use of primary materials may decline, while secondary materials and sectors not reliant on primary materials may see an increase, especially if overall economic activity is boosted by the transition.[6] Environmental impacts include climate change; air, land and water pollution; and the consequences for human health. The direct consequences would be reduced primary materials use and lower environmental impact per tonne of secondary materials when compared to primary materials.

Governments worldwide are aware of the environmental issues related to resource use and have already started to enact policies to address these issues. Several countries have established national strategies for the use of resources and materials to ensure a sustainable environment, society and economy.

Consequently, CE roadmaps were introduced in China in 2013; the European Union in 2015[7]; Finland, France, the Netherlands, and Scotland in 2016; and Slovenia and Portugal in 2017.[3]

Built environment status in Australia: Economic impact and need for the circular economy

Architecture, engineering and construction

The architecture, engineering, and construction (AEC) industry is a large contributor to Australia's gross domestic product (GDP).[8] It is estimated that the industry generates over A$360 billion in revenue, contributes a 9% share of the country's total GDP and features a projected 2.4% growth rate in the next five years.[9] Below is an overview of the different types of services and work provided by each AEC industry sector and its performance in Australia.

Architecture

Architectural services firms provide architectural design and drafting services, landscape design services and town planning services. Industry operators provide consultation on land zoning and building code regulations. Commercial and industrial construction represents a large market for industry firms, as developers and engineers often require architectural and design services before construction activity. This market includes demand for buildings such as offices, hotels, shopping centres, factories, and warehouses.

The sector revenue was expected to fall at an annual 3.2% over the five years to 2020–2021 to A$5.6 billion. It is then expected to fall by 6.7% in 2020–2021, largely due to the continued effects of the COVID-19 pandemic. Contract documentation (32.8%) and contract administration (28%) are the two largest contributors to the sector.[10] Over the past five years, architects have faced growing competition from vertically integrated firms, such as large building construction and engineering consulting firms.

Some large firms have expanded into overseas markets to counter this trend and capture new revenue streams.[10] Rising environmental awareness has increased pressure to incorporate environmentally sustainable elements into new and existing buildings. This trend has provided new opportunities for architects to diversify their services over the past five years. Green architecture is a specialised area of architecture that designs buildings and structures to minimise harm to the environment, ecological systems and human health. Green architecture includes the incorporation of eco-friendly materials and construction practices in designs and largely contributes to a circular economy (CE) in the Australian built environment.

Construction

The construction sector includes firms that primarily construct buildings, roads, railroads, harbour or river works, transmission lines, pipelines and oil refineries. These firms are also involved in civil engineering and irrigation projects and construct water, gas, electricity and sewerage infrastructure. Some construction firms carry out repairs and renovations, prepare mine sites, install utilities and undertake demolition and excavation.[11] The key external drivers are private non-residential construction capital expenditure, capital expenditure on private dwellings, capital expenditure by the public sector, the 10-year bond rate, the population and residential housing loan rates. For much of the past five years, favourable trends in Australia's population growth and record low interest rates have supported the sector's expansion of operation.

However, demand conditions have deteriorated in the heavy and civil engineering construction subdivision due to reduced investment in resource developments and weaker government spending on public infrastructure, such as power generation capacity and water supply resources.
The construction sector has benefited from investment in the National Broadband Network (NBN) roll-out and in landmark road and rail infrastructure projects. In recent years, the pressure for ecological accountability has driven regulatory changes influencing the sector. For example, concerns over energy consumption led to the establishment of the Green Building Council of Australia (GBCA) which lobbies for initiatives to eliminate unsustainable practices. The GBCA promotes the improvement of building practices in terms of energy consumption, environmental impact and the circular economy (CE).[11]

Engineering

The estimated value of total engineering construction work in December 2020 was A$21,306.5 million, comprising A$13,150.7 million and A$8,155.8 million in the Australian private and public sectors, respectively.[12] Unlike the other two sectors, these figures for the engineering sector of the AEC industry show a declining trend. Engineers Australia reported the same trend for the sector's economic performance between 2008 and 2018.[13] That report indicated this sector's highest level of involvement in public projects was linked with road construction, followed by railway construction and telecommunications. In private projects, the increasing trends were noted to be electricity and telecommunications.

Seasonally adjusted work done in 2020 fell 4.8%, with this decline for the private and public sectors being 1.8% and 9.4%, respectively. However, the trend varied among Australian states and territories. While positive figures were reported for New South Wales (NSW) at 3.6%; South Australia (SA) at 9%; Western Australia (WA) at 9.8%; and Australian Capital Territory (ACT) at 3.6%, lower engineering construction work rates compared to the previous year were reported by Victoria (Vic) at -3.7%; Queensland (Qld) at -1.7%; Tasmania (Tas) at -6.2%; and Northern Territory (NT) at -16.4%. This could be related to the negative impact of the COVID-19 pandemic on the industry in the latter states and territory.

Environmental impact of the AEC industry

The AEC industry is generally low in resource efficiency worldwide. As documented in the literature, this poor performance has resulted in serious negative environmental impacts caused by the high rate of construction and demolition (C&D) waste generation, greenhouse gas (GHG) emissions, air and water pollution, and forest degradation. The construction industry is estimated to be responsible for approximately 40% of energy consumption, 30% of CO_2 emissions and 40% of total solid production waste globally.[14]

An analysis of government and industry reports shows that the Australian AEC industry suffers from low resource efficiency to an extent exceeding the global average. The National Waste Report (NWR) 2020[15] indicates that Australia generates 27 megatonnes (mt) of C&D waste annually, a 61% increase on the figures recorded in 2006–2007. Currently, this waste stream, with more than 44% and 47% generated and recycled, respectively, is the largest source of waste in Australia. Furthermore, GHG emissions in the AEC industry have been quoted as being higher than in most other regions of the world.[16] In Australia, GHG emissions per capita are estimated to be three times the global average; Australia is constantly reported as the worst-performing country on climate policy.[17] To address these issues, one avenue for Australia is to move towards a CE that supports a sustainable AEC industry. Indeed, across the Australian landscape, the drivers for a CE have gained ground with the increasing consciousness of the fundamental importance of environmental sustainability in uninterrupted growth.

The circular economy

Introduction

In 2015, the Ellen McArthur Foundation[18] formulated a diagram (Figure 1) built on the concept of the flow of materials. This diagram involves two interacting loops: the technical and biological resource cycles. In the latter cycle, renewable and plant-based resources are consumed, regenerated, and safely taken back to the biosphere.[19] Within the former cycle, manufactured products are designed in a way that, at the end of their service life (when repair and reuse for their original purpose are no longer possible), their components are recovered, reused or repurposed into new materials. This loop results in waste landfill avoidance and a closed-loop cycle.

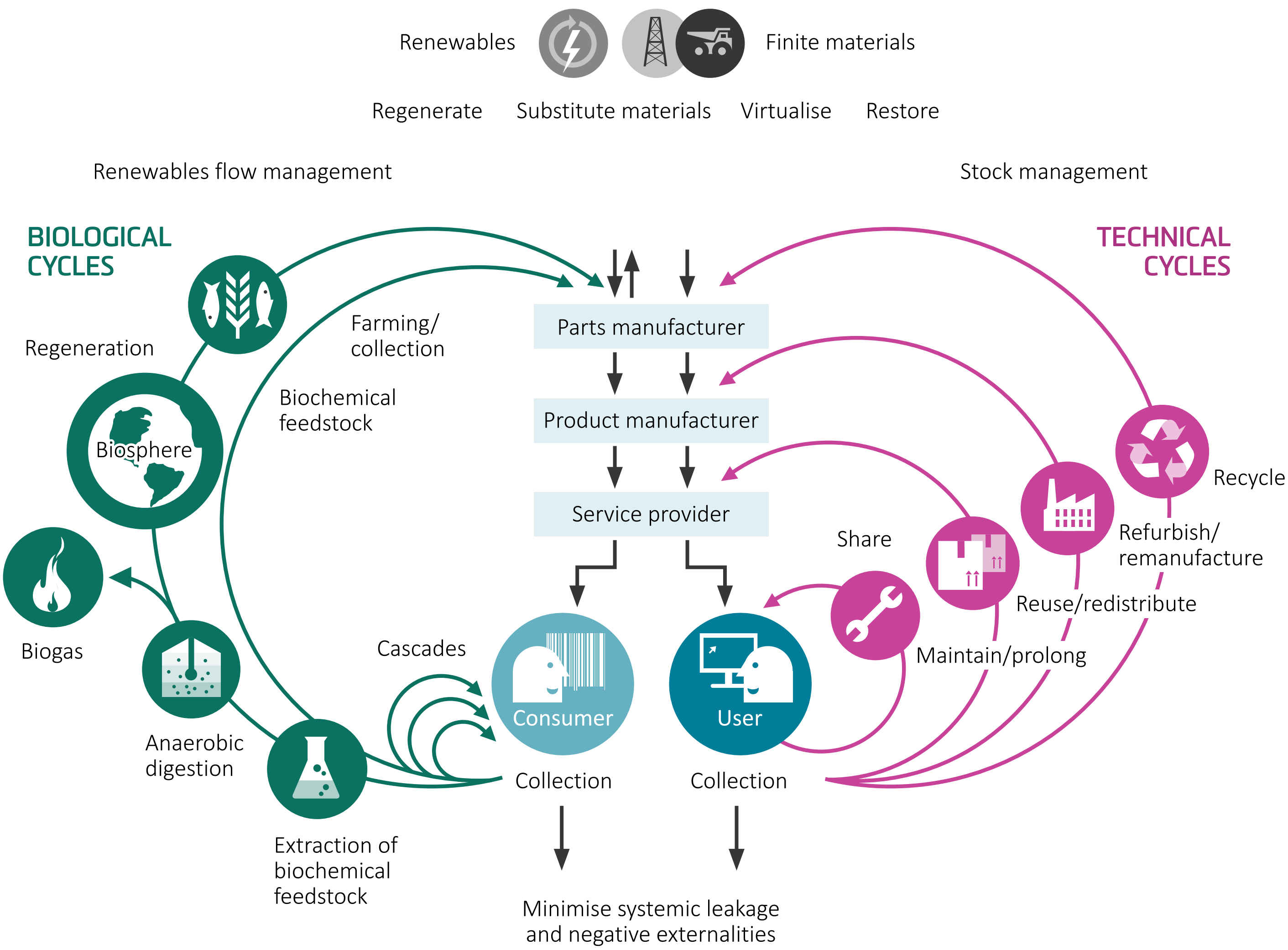

Figure 1. Conceptual model of the circular economy (CE) in the built environment

Source: Arup (2016)[18]

The circular economy (CE) model, as a comprehensive strategy for sustainable development, has already spread throughout the world. This model has been conceptualised as a system that is restorative by design with a core strategic focus on reframing and reorganising materials, and information and energy flows to achieve greater resource efficiency by the reuse, remanufacture and recycling of materials. Its key premise is that waste minimisation can act as a new source of value for the business.[20] Fundamentally, the concept of the CE model encapsulates the tension between limits and growth, advocating for a shift from linear to circular patterns of resource use and management. Long-established sustainability principles, such as cradle to cradle (C2C) are being reconfigured through this lens.[21] The growing prominence of CE frameworks and their associated discourses represent increasing interest in the more specific guiding principles of maintaining sustainable economic systems through retaining, for as long as possible, the added value in products.[22]

History and definition

No single definition has been universally agreed upon for the term “circular economy”. The Ellen MacArthur Foundation’s definition of the CE as “an industrial economy that is restorative or regenerative by intention” is, however, widely accepted and used by the scholarly community, industry experts and government officials.[17] The idea of a circular flow for materials and energy is not new, appearing as early as 1966 in a book by Kenneth E. Boulding[23] in which he explained that we should be in a “cyclical” system of production. The term “circular economy” appeared for the first time in 1988 in an article by Allen V. Kneese titled “The Economics of Natural Resources”.[24] This notion was developed further following three major events: the explosion of raw material prices between 2000 and 2010; the Chinese embargo on rare earth materials; and the arrival of the 2008–2009 Global Financial Crisis (GFC).[25]

One answer to these challenges is the CE model. Thus, new modes of production and consumption are emerging with the main objective being to generate billions of dollars while controlling and reducing environmental consequences. The CE model has its roots in concepts dating back to the 1970s, including the Club of Rome’s “Limits to Growth” theory; biomimicry; Braungart and McDonough’s C2C model; Lyle’s regenerative design model; and Stahel’s performance economy. The approach has gained attention more recently thanks to the Ellen MacArthur Foundation, a charity dedicated to promoting the global transition to the circular economy (CE).[26]

Knowledge and theoretical foundation and circular business models

Several sources provide principles for the CE that underpin organisational decision making and planning.[27,28] While having some general overlaps, such as waste recycling, the various CE principles are differently defined. As depicted in Figure 2, a CE is underpinned by principles that comprise 'sustainable management of all resources'; 'valuing resource productivity'; 'designing out waste and pollution'; 'maintaining the value of products and materials'; 'innovating new solutions for resource efficiency'; 'creating new CE jobs'; and 'fostering behavioural change through education and engagement'.[26]

More specific guidelines with a focus on the adoption of a CE in the AEC industry, however, provide a clearer picture.

For instance, the European Commission[27] listed eight CE principles for building design with a suite of key actions to implement each principle. These principles comprise: (1) applicability of CE design principles to all actors across the value chain; (2) consideration of total life cycle costs when planning for sustainable choices; (3) development of a viable business model for each economic operator across the value chain; (4) application of the principles to be accompanied by a cost–benefit analysis; (5) knowledge improvement in construction techniques (i.e. improvements in deconstruction, durability and adaptability of buildings); (6) improvement in design and performance of construction products and information sharing; (7) prevention of premature building demolition through developing a new design culture; and (8) designing products for ease of reusing, repairing, recycling and recovery.

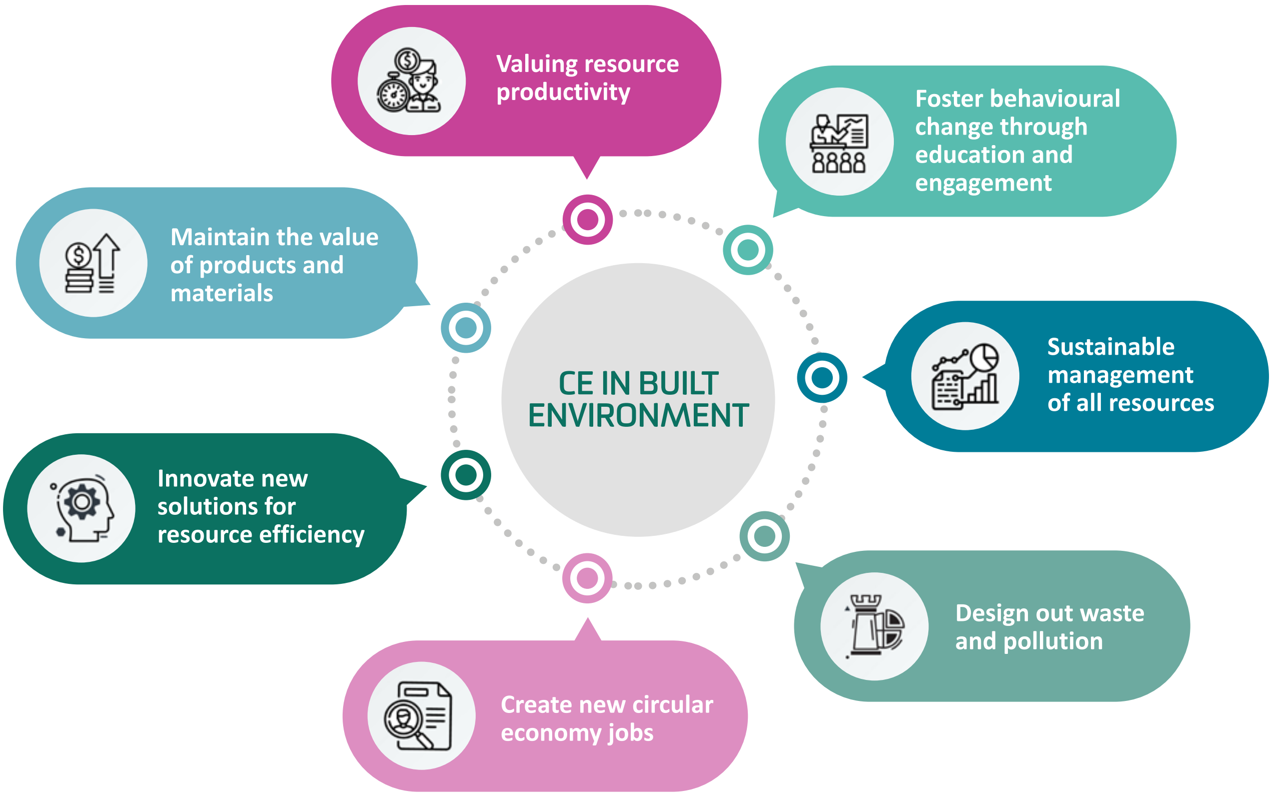

Figure 2. Major components of a CE in the AEC industry

Source: NSW Government (2019)[26]

Drawing on Figure 2, the above-mentioned CE areas and other literature[29], this section identifies how the application of a CE can achieve value for the AEC industry. Table 1 presents the identified CE priority practices during five stages of a construction project life cycle. These practices contribute to resource and energy efficiency, reuse of materials, efficient use of spaces and reduced quantity of C&D waste.

Table 1. Circular economy (CE) practices for the AEC industry

Life cycle stage	Circular economy (CE) practices
Project Design	• Design and use of modular buildings • Design for disassembly of building structures • Design for adaptability of existing buildings • Use of a scale to analyse the level of implementation of CE practices in the company • Use of a simulation in a Building Information Modelling (BIM) model early in the project to analyse the reuse potential of the materials in different types of designs • Use of life cycle analysis to find the benefits of reusing different types of materials in the design stage • Use of materials stock data to help with the reuse of materials in a new building • Anticipation of changes in requirements
Manufacture	• Change of use of materials, by giving ownership to manufacturers to reuse materials after the end of life of the first building • Reuse of secondary materials in the production of building materials • Development of material passports
Construction	• Reuse of building materials in a new construction • Waste reduction • Off-site construction • Prescribing in procurement contracts that waste should be separated on site to facilitate recycling • Favouring of construction systems that incorporate CE thinking • Conserving, updating and sharing information so it can remain valid and relevant during the whole life cycle of the building
Operation	• Use of a tool to evaluate the state of materials during the life span and end of life of a building • Use of water management practices • Minimising recuperative maintenance through preventive maintenance
End of Life	• Analysis of the potential for reuse or recycling of existing materials and whether their use is feasible compared to using new materials • Management of demolition waste • Use of a circularity tool to evaluate existing buildings, thus giving the best possible solutions to refurbishment • Deconstruction of building structures and parts • Requesting detailed information from providers and designers on products, materials and building design

Source: Adopted from Benachio et al. (2020)

Need for circular business models

Evidence from the AEC industry indicates that stakeholders across the supply chain of construction projects perceive that the disposal of resources is more cost effective and convenient compared to going through the procedure of reusing them.[30] Therefore, circular models will not be adopted on a broad scale without intervention.[31,32] To be specific, the roadmap towards widespread adoption of the CE in the AEC industry lies in reducing costs and offering good value in the reuse of resources.[33] New business models are needed to enhance the delivery of value in adopting a CE, and to associate CE adoption with a winning value proposition alongside wider benefits in social and environmental aspects.[29,31,32,34]

The adoption of a CE model – as with adopting any new industrial paradigm – requires AEC companies to adapt their business models to those designed for a circular economy (CE).[33] As the first step towards circular business models (CBMs), the proactive cooperation of stakeholders is needed to enable a co-innovation process towards circularity.[35] Several major modifications are also required for companies to undertake CBM adoption. Chief among all is a set of return flows – from end-users to producers – to be facilitated through information sharing and a higher degree of collaboration among actors in the supply chain.[33,36] To offer added value from new business models, circular supply chains rely on the integration of the supply chain, fostering collaboration among all stakeholders and making required information readily available.[31]

These factors predicate the achievement of the aims of any business model designed for a CE[37], where providing additional value in adopting a CE strongly relies on making essential information available and establishing collaboration among stakeholders – across the project supply chain.[38,39,40,41] The flow of information and collaboration hence play a crucial role in creating value from CE adoption.[29,36,42]

Changing a company's business model into a circular one is challenging, with support essential in the transition process from linear business models to circular ones.[31,43] Furthermore, merely establishing CBMs is inadequate; companies must rethink their supply chains and modify the way in which they create and deliver value in such business models.[41] Successful value creation from a CBM depends on resource optimisation, for which a key competence is access to information to ensure the capability of keeping track of products, components and materials data.[42,44] In addition, CBMs need efficiency, enabled by collaboration between stakeholders, where building trusted partnerships and long-term relationships with suppliers and customers can facilitate the co-creation of value.[33,38]

With the above in mind, several frameworks and CBMs[45] have been developed to further explore opportunities in which the CE approach can be applied. These frameworks are deemed to be suitable for the AEC industry. Table 2 presents the dominant CE frameworks and CBMs, their creators and their features.

Table 2. Dominant CE-focused frameworks for the AEC industry

Framework	Organisation creatures	Features
ReSOLVE framework	McKinsey Center for Business and Environment[46]	The framework translates the three principles of the CE into six business actions that can support the development of circular technical and business models: re-generate, share, optimise, loop, virtualise and exchange
Design for demand	Forum for the Future and Novelis[47]	A platform that takes users in five steps through the design process: introduction of a CE, materials, solutions (introducing six design strategies), strategies (proposing three design-business model archetypes) and the "design brief generator"
Speedcycle	Goldsworthy (2017)[48]	The Speedcycle supports design for different speeds within a product's life cycle based on four parameters: materials, production, use and recovery. Several archetypes are introduced as examples
BECE framework	Mendoza et al. (2017)	The BECE framework offers a 10-step circular guide for business innovations: it links business model planning – through back-casting and the business model canvas – with an (eco)design using the ReSOLVE checklist
C3 Business model canvas	Hofmann et al. (2017)[49]	A business model canvas that situates the economic dimension (eight components of the business model canvas) within the social dimension (key stakeholders) within the ecological dimension (i.e. environmental inputs, output, impact)
Value Hill	Achterberg et al. (2016)[50]	A canvas on which activities, partners and products are placed based on the life cycle phase of a product. Designers can select from several circular designs, and supply chain and business model strategies to develop their design
Products that last (framework)	Bakker et al. (2014)[51]	A framework that links circular business model archetypes and circular design strategies, offering some examples
Guided choices towards a circular business model	Joustra et al. (2013)[52]	A practical guide to developing a circular business model comprising five steps: introduction of a CE, review of partners, product (re)design, service (re)design and business model calculation
Collaborative consumption	Choi et al. (1998)[53]	Rental or sharing of products between members of the public or businesses, often through peer-to-peer networks
Performance/ service system	Tukker et al. (2004)[54]	Providing a service based on delivering the performance outputs of a product where the manufacturer retains ownership, has greater control over the production of a product and, therefore, has more interest in producing a product that lasts

International circular economy (CE)-related guidelines and standards

Several guidelines and standards have recently been developed at the global level to guide CE adoption in the AEC and other industries. For instance, in 2020, the European Union (EU) released *Circular Economy – Principles for Building Design*[26], a document which aims to inform and support actors along the construction value chain, and which provides principles for the circular design of buildings. This document inspired several national CE policies in the EU and other countries. Furthermore, the International Organization for Standardization (ISO), a standard-setting body consisting of representatives from various national standards organisations, has released several CE-related standards (Table 3). Currently 14 ISO standards are directly or indirectly related to the CE, with five other standards specifically being designed for the circular economy (CE). Depending on the type and method of CE principles to be applied, several environmental and sustainable standards might become relevant. The ISO standards are leading several aspects of sustainable and environmental innovation, with ISO 14000 standards widely recognised and applied internationally.

For instance, ISO 14001:2015 *Environmental management systems – Requirements with guidance for use* provides a certification scheme for any organisation that applies effective environmental management systems, regardless of the size, type and nature of the organisation. Similarly, ISO 14007:2019 *Environmental management – Guidelines for determining environmental costs and benefits* applies an anthropocentric perspective, generating a guideline for organisations on determining the environmental cost and benefits associated with their environmental aspects. Furthermore, ISO 14009:2020 *Environmental management systems – Guidelines for incorporating material circulation in design and development* is a guideline for establishing, documenting, maintaining and continuously improving material(s) circulation inside organisations, using an environmental management system (EMS) framework in accordance with ISO 14001.

Table 3. Current and future international CE-related standards

Current ISO standards

Standard code	Title of the standard
ISO 14009:2020	Environmental management systems – Guidelines for incorporating material circulation in design and development
ISO 15392:2019	Sustainability in buildings and civil engineering works – General principles
ISO 21931-2:2019	Sustainability in buildings and civil engineering works – Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment – Part 2: Civil engineering works
ISO 14007:2019	Environmental management – Guidelines for determining environmental costs and benefits
BSI 8001-2017	Framework for implementing the principles of the circular economy in organisations – Guide
ISO 21930:2017	Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services
ISO 14021:2016	Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling)
ISO 14001:2015	Environmental management systems – Requirements with guidance for use
ISO 21931-1:2010	Sustainability in building construction – Framework for methods of assessment of the environmental performance of construction works – Part 1: Buildings
ISO/TR 21932:2013	Sustainability in buildings and civil engineering works – A review of terminology
ISO 14025:2006	Environmental labels and declarations – Type III environmental declarations – Principles and procedures
ISO 14040:2006	Environmental management – Life cycle assessment – Principles and framework
ISO 14044:2006	Environmental management – Life cycle assessment – Requirements and guidelines
ISO 14020:2000	Environmental labels and declarations – General principles

ISO standards under development

Standard code	Title of the standard
ISO/WD 59004	Circular Economy – Framework and principles for implementation
ISO/WD 59010	Circular Economy – Guidelines on business models and value chains
ISO/WD 59020.2	Circular Economy – Measuring circularity framework
ISO/CD TR 59031	Circular Economy – Performance-based approach – Analysis of case studies
ISO/DTR 59032	Circular Economy – Review of business model implementation

Barriers to and enablers of the circular economy

This section reviews the major barriers to, and enablers of, the uptake of a CE model in the built environment. The analysis of multiple sources shows that many barriers hinder the application of a CE in built environment projects. Table 4 summarises the studies that investigate challenges in promoting the CE in the AEC industry.

Table 4. Key barriers to a CE in the AEC industry

Reference	Major barriers
Charef et al. (2021)[55]	Economic aspects: Profit-seeking attitude (short-term vision); high costs of recycled C&D waste products; low landfill costs; labour-intensive efforts; less manpower and more mechanisation; estimation of deconstruction; lack or poor market performance for recycled materials; lack of demand for recycled materials; lack of marketing plan; low cost of demolition; and additional cost for sustainable C&D waste practices. Social aspects: Consumer culture and perceptions regarding reclaimed materials; bad image of salvaged components (poor quality); lack of awareness and demand; cultural and false beliefs; lack of trust and acceptance of reclaimed components; unfavourable business culture/quick return on investment (ROI); construction industry scepticism and tradition; and natural resistance to change and innovation
Bilal et al. (2020)[56]	Lack of environmental regulations and laws; lack of customer/public awareness; lack of support/backing from public institutions; and inadequate financial resources
Gallego-Schmid et al. (2020)[57]	High initial costs; limited information and public awareness about benefits and expenses; and limited political support for circular economy (CE)
Adams et al. (2017)[80]	Lack of an incentive to design for end-of-life issues for construction products; lack of market mechanisms to aid greater materials recovery; low value of products at end of life and an unclear financial case; and the construction industry's structure with its fragmented supply chain
Hart et al. (2019)[58]	Cultural barriers (lack of interest, lack of knowledge/skills and engagement throughout the value chain); delivering CE projects in a linear economy (LE); lack of collaboration between businesses (lack of collaboration between business functions); regulatory barriers (lack of a consistent regulatory framework, and obstructing laws and regulations); financial barriers (high upfront investment costs, low virgin materials prices, poor business case, unconvincing case studies and limited funding); and sectoral barriers (lack of bandwidth compounded by an absence of a coherent vision for the industry, complexity/confused incentives, long product life cycles, technical challenges regarding materials recovery, lack of standardisation, and insufficient use or development of CE-focused design and collaboration tools, information and metrics)
Nußholz et al. (2019)[59]	Unclear financial cases; low amount and quality of materials at end of life; and lack of mechanisms for materials recovery

While it was found that barriers can be viewed differently by different stakeholders or different parts of the value chain within the built environment, the review focused on studies that are recent, highly cited and took a more inclusive approach to consider perceptions of key stakeholders. Table 5 presents the main enablers for promoting the CE paradigm in the built environment, as identified in the relevant literature.

Table 5. Key enablers of a CE in the AEC industry

Reference	Major enablers
Pomponi and Moncaster (2017)[60]	Interdisciplinary research, education, tools and techniques to explore opportunities for expansion of the CE in the AEC industry; technological advancements in manufacturing and operations; partnerships and collaboration in building projects and a wider engagement with all involved stakeholders; networks for resource sharing and reuse; and a different approach to building design
Hart et al. (2019)[57]	Cultural enablers (leadership, sustainability/environmental drivers, value chain engagement activities, forming longer-term relationships and partnerships, systems thinking); regulatory enablers (policy support and public procurement regulatory reform, fiscal support, producer responsibility); financial barriers (whole-life costing, taking the easy win when it is difficult to find support for a CE business case, scale of the economy); and sectoral enablers (providing a better evidence base for policy makers, a clearer vision for the CE within the built environment, collaboration and design tools and strategies, R&D and innovation, development of standards/ assurance schemes and development of a reverse logistics infrastructure)
ARUP (2016)[18]	Regenerate (regenerating and restoring natural capital, safeguarding, restoring and increasing the resilience of ecosystems, returning valuable biological nutrients safely to the biosphere); share (maximising asset utilisation, pooling the usage of assets, reusing assets, optimising system performance, prolonging an asset's life, decreasing resource usage, implementing reverse logistics); loop (keeping products and materials in cycles, prioritising inner loops, remanufacturing and refurbishing products and components, recycling materials); virtualise (displacing resource use with virtual use); replacing (replacing physical products and services with virtual services, replacing physical with virtual locations, delivering services remotely); and exchange (selecting resources and technology wisely, replacing with renewable energy and materials sources, using alternative materials inputs, replacing traditional solutions with advanced technology, replacing product-centric delivery models with new service-centric ones)
Joensuu et al. (2020)[61]	Commitment, capability and interoperability; evaluation of the CE benefits; development of a database that comprises an interconnected and continuously supplemented set of best practices; developing consumption systems towards a commonly shared vision of the waste hierarchy; expansion of service life through practices of adaptive reuse; design-for-disassembly (DfD), design-for-repair and remanufacturing (DfRem); and extended producer responsibility (EPR) of the building industry to establish a virtual building materials bank as a marketplace for reusable building components

A systemic approach to exploring collaboration opportunities among circular economy (CE) actors

As a CE is systemic in nature, the main actors need to approach CE-related research/ practice/policy initiatives from a systemic perspective; otherwise, success is unlikely. A CE in the built environment therefore requires an interdisciplinary approach as the different and, at times, optional CE solutions to be applied in the built environment are large in number and growing at accelerating speed, highlighting the complex nature of the field. Pomponi and Moncaster (2017)[60] highlighted the multidisciplinary nature of the CE in the built environment, noting that it expands different dimensions of building research.

Consequently, several institutes and researchers have attempted to systematise these dimensions through the development of integrated frameworks that best manage interrelationships between different stakeholders, decisions and mechanisms. A list of these frameworks is provided in Table 2, with a core part of these frameworks being the engagement of all stakeholders. Following is a brief review of the relevant literature on different aspects of stakeholder engagement in a CE environment in the AEC industry.

Although the level of awareness about the CE within the AEC industry appears to be good (Benachio et al. 2020)[28], human aspects are the most pressing barriers to transitioning towards the CE (Eberhardt et al. 2019[62]; Govindan & Hasanagic 2018[63]; Kirchherr et al. 2018[64]; Mahpour 2018[65]; Adams et al. 2017[66]), especially the stakeholder aspects (Maerckx et al. 2019[67]).

The lack of clarification about the CE among stakeholders in the construction value chain is a significant problem in introducing CE practices into the AEC industry (Munaro et al. 2020[68]). As most stakeholders do not understand the practical implementation, introducing the CE concept is apparently progressing slowly in the construction industry (Adams et al. 2017; Eberhardt, Birgisdottir & Birkved 2019[61]).

Similarly, Eberhardt et al. (2019) emphasised the lack of knowledge on how to apply the CE in the AEC industry, with the reason being the complexity of the supply chain and the short-term aims of most corporations, which do not provide the end-of-life phase with the required attention. Even if it were highly possible to apply the CE in the AEC industry, it would demand greater endeavour and originality from stakeholders (Maerckx et al. 2019).

As an example, the connectivity of stakeholders is a crucial factor in enabling the use of a CE in waste management innovation (Boxall et al. 2019[69]). Notably, with various stakeholders with varied purposes having different positions in C&D waste management (Udawatta et al. 2015a[70]), this can lead to diverse behaviours and influence the outcomes of C&D waste management in practice (Kulatunga et al. 2006[71]). By meaningfully involving concerned stakeholders, waste management strategies can achieve success (Alamgir et al. 2012[72]). Even though different organisations have different responsibilities in AEC projects, it is generally accepted that, for successful C&D waste management, it is necessary to effectively engage and collaborate with key stakeholders (Li et al. 2015; Udawatta et al. 2015b[73]).

Many studies in the literature have indicated the need, to some extent, to consider and guide stakeholders when introducing the CE in the AEC industry. These strategies include analysis of stakeholders (López Ruiz et al. 2020[74]); raising the awareness of stakeholders (Anastasiades et al. 2020[75]; Munaro et al. 2020); facilitating the collaboration of stakeholders (e.g., Munaro et al. 2019; Leising et al. 2018[76]); clarifying relationships between stakeholders; and defining responsibilities of stakeholders (Munaro et al. 2020).

In this context, C&D waste management requires a method and agreement that involves and binds stakeholders in a closed-loop AEC industry (Ghaffar et al. 2020). Stakeholder engagement is ideal for this role. In addition to involving single stakeholders, stakeholder engagement processes can promote changes and act as accelerators in transition (Salvioni and Almici 2020b).

As an essential responsibility mechanism, stakeholder engagement allows an organisation to empower its stakeholders in discovering, understanding and replying to issues regarding sustainability, then to report, clarify and respond to stakeholders for decisions, actions and performance. This helps both the engager and engaged stakeholders in learning from this two-way contact (Leopizzi 2020[77]). Furthermore, stakeholder engagement, as a process utilised by an organisation to involve and engage relevant stakeholders, is designed with the precise aim of fulfilling agreed outcomes (Franklin 2020[78]; Leopizzi 2020). In this way, stakeholder engagement can help to enable cultural changes in organisations, while assisting the organisation to practise sustainability principles and meet expectations from the economy, society and the environment (Salvioni and Almici 2020b[79]).

A project as a temporary plan (Lundin and Soderholm 1995[80]), including AEC projects, can also be effectively influenced by stakeholder engagement. Therefore, the application of a CE in C&D waste management in AEC projects to fulfil the waste-free ideal in the AEC industry can be achieved through stakeholder engagement.

Analysis of key stakeholders

In the CE context, shifting the system involves everyone and everything (e.g., businesses, governments and individuals, cities, products and services, jobs). In the AEC industry, through designing out waste and pollution, keeping products and materials in use, and regenerating natural systems, everything can be reinvented.[18] However, the inherent complexity of the AEC industry warrants the involvement of several stakeholders who contribute to the economics of the built environment and are directly engaged with developing a CE in the industry. An analysis of existing guidelines and policies including the EU's *Circular Economy Principles for Building Design*[28] has resulted in the identification of the major players along the CE value chain. Figure 3 below presents the key stakeholders (i.e. organisations and individuals) that contribute to shaping a CE in the AEC industry.

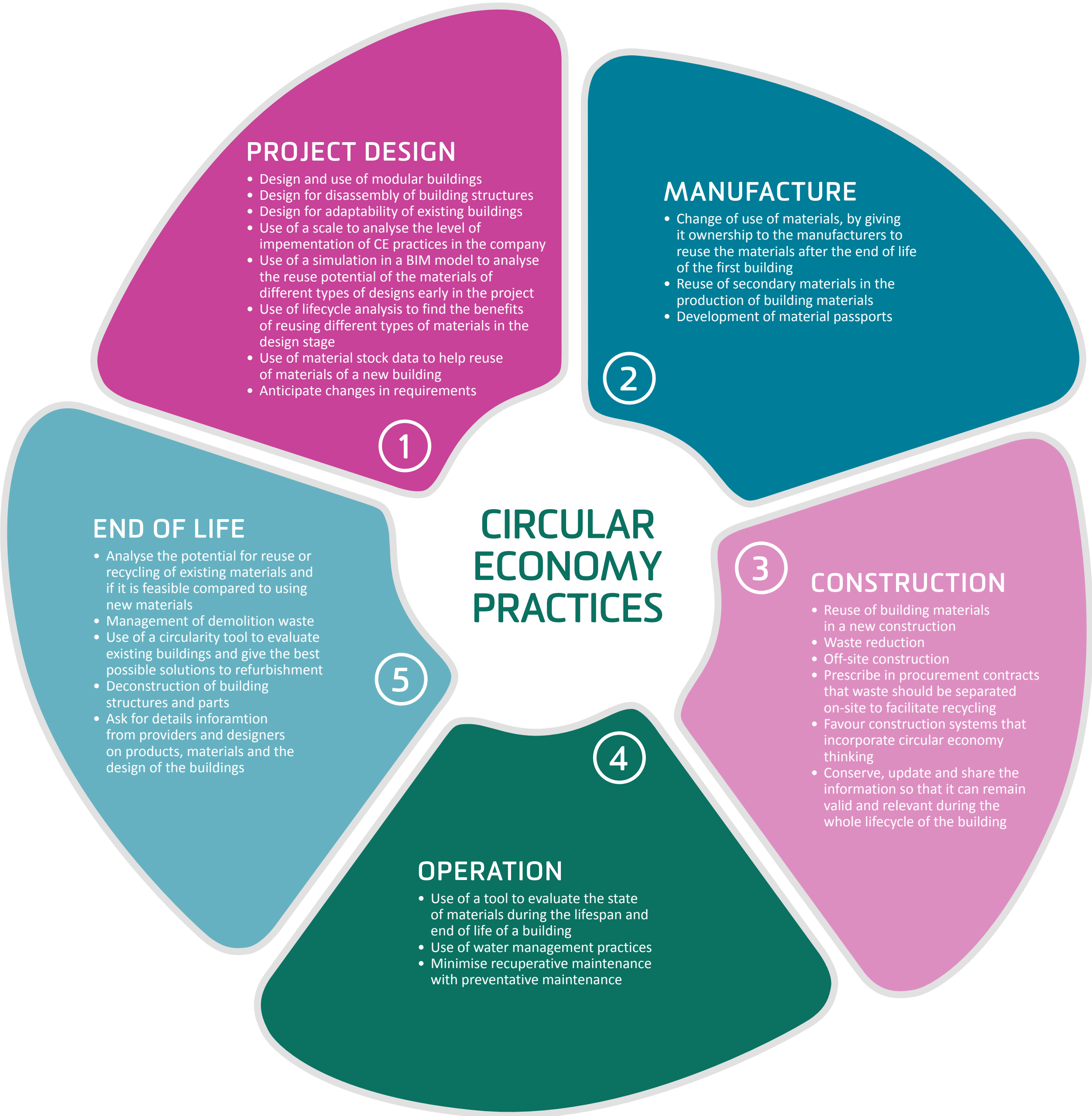

Figure 3. Circular economy (CE) practices in the AEC industry

Source: Adapted from Adams et al. (2017)[81]

Drawing on information provided in Figure 3, 12 major stakeholders of a CE in the AEC industry were identified (Figure 4). Their role in shaping a CE in the Australian AEC context is next explored.

Figure 4. Key stakeholders of a CE in the AEC industry

Designers

Designers are the key to shaping a sustainable future that includes paying greater attention to the use of benign and renewable materials, waste avoidance, reuse, repair and recycling.[82] Designers and architects play an important role in the CE's application in the built environment, notably after the introduction of new design concepts such as design out waste (DoW)[83], design for deconstruction or disassembly (DfD)[84] and design for manufacture and assembly (DfMA)[85] that focus on resource efficiency in the AEC industry. The role of a designer is to facilitate the maintenance of product integrity over multiple use cycles (e.g., through repair, refurbishment and remanufacturing), to focus on closing loops (through recycling) while, at the same time, building economically viable product–service systems.

Design for a CE is an emerging, independent subfield in the design for sustainability field that requires specific competencies, methods and tools. One study[86], through semi-structured interviews with design professionals in the Netherlands, identified seven CE competencies. These comprised circular impact assessment, design for recovery, design for multiple use cycles, circular business models, circular user engagement, CE collaboration and CE communication. To educate designers in Australia about the CE, the Design Institute of Australia (DIA) has released a policy to align their designs with CE objectives.[81]

Manufacturers

Manufacturers are at the forefront in embracing a CE in the AEC industry. Suppliers of materials with minimal environmental impacts – including recycled content in the production line, producing durable materials with recyclability in mind, and employing advanced and efficient manufacturing technologies with minimal energy consumption – will contribute to a CE in the AEC industry. In Australia, the new policy setting advocates resource efficiency and urges manufacturers to share the responsibility for waste generated even after its service life through regulatory instruments such as extended producer responsibility (EPR), product stewardship (PS) and product take-back (PTB). At the level of states and territories, except for the NT, relevant primary and secondary pieces of legislation have acknowledged the need to have EPR and similar schemes in place[96] to hold materials manufacturers accountable for resources loss in the dominant linear economy (LE).

Builders

Builders can significantly improve resource efficiency in several ways. For instance, the application of efficient construction and procurement methodologies through minimised wastage of resources will facilitate a CE in the AEC industry. Furthermore, builders' knowledge and experience in dealing with recycled products are central to increasing the usage of recycled products. Builders should consider scenarios in which estimated costs for new materials, furniture and waste elimination are significantly higher than actual costs and in which certain elements could be sold for reuse and/or recycling.[27] They should also allocate specific funds for the upskilling of workers to better deal with CE principles.

Lastly, they are enablers of the adaptation and transformation of a building for better use and reuse, new ways of using it, and preparation for the end of life and future lives of the building and its components.[27]

Labourers

Labourers play an important role in avoiding waste generation during construction execution. Construction projects that employ trained and experienced employees are found to be less likely to generate excessive C&D waste.[87] One misconception is that shifting towards a CE will negatively impact on employment in the AEC industry, particularly of labourers. However, some studies have provided contrary evidence, showing that the transition is likely to lead to a net improvement in employment rates, albeit small.[88]

Structural engineers

Structural engineers have a significant responsibility in decisions on materials, applications and specifications.[89] Their knowledge of recycled materials that can be used in construction projects will be beneficial to a CE in the AEC industry. In consultation with other key stakeholders, they should favour construction systems that incorporate CE thinking. For instance, they should use systems that can be easily maintained, repaired and replaced as this will prolong the life cycle of buildings.[27] They also need to ask for detailed information from providers and designers on products, materials and the design of buildings. This information should be conserved, updated and shared so it can remain valid and relevant during the whole life cycle of the building.

Public agencies and policy makers

All public agencies have a role to play as responsible consumers. Sustainable procurement practices and the increased purchase of goods and infrastructure containing recycled materials support the transition towards a circular economy (CE). Furthermore, it helps to grow the recycling and reprocessing industry. Governments also provide funding that supports infrastructure development, waste and resource recovery management processes, and innovation.[90] Through policy making, administration and incentives, public agencies can facilitate or hinder a CE in the AEC industry.

Industry associations

As representatives of the industry, industry associations are at the forefront of informing firms and individuals about best management practices. They can also develop practice indicators and performance measures to intensify the adoption of CE thinking as a practice by firms and individuals.[91] Lastly, they can promote the understanding and use of existing standards, schemes and examples that enable a more holistic design and adjust business models to include circularity in construction.[27]

R&D sector

The R&D sector, comprising universities, research institutes and R&D groups in different organisations, explores innovative solutions and management practices towards a more CE in industry. This sector plays a primary role in propelling CE approaches into reality and, therefore, has the potential to raise the bar on sustainable performance.[92] Universities, through effective curriculum development, should train people in the industry; for instance, they can integrate deconstruction techniques into apprenticeship schemes.[27]

End-users

End-users are largely affected by the operation of a linear economy (LE) as opposed to that of a circular economy (CE). Traditionally, in the AEC industry, the costs of the LE are passed on to end-users in the form of higher costs of construction, operation of buildings (post-occupancy) and building infrastructure. Despite recent advances in the public's awareness about the negative impact of the AEC industry on the environment and society, Australians are argued to be far from fully recognising the value of a CE which is still not considered a main priority in their purchasing decisions.

Waste operators and recyclers

Waste operators and recyclers are the last link in the chain, closing the loop of resource efficiency in a circular economy (CE). Consequently, government agencies emphasise their presence in the supply chain and support them with various funding programs. From the regulatory perspective, the two major policies guiding the sector, Australia's National Waste Policy[89] and the National Waste Policy Action Plan[93], highlight the role of the CE in handling second-hand C&D materials, while encouraging waste operators and recyclers to adjust their business model to meet CE objectives and increase resource efficiency.

Overview of the circular economy concept in Australia

Introduction

This section presents an overview of CE design, policy development and implementation in the Australian context. While the CE concept has received growing attention from government, industry and academia, as well as from the general public, overall, it is in its infancy in Australia. For this reason, limited information is available on how the CE concept is being currently addressed in Australia, with most of what exists simply comprising projections of what would be achieved if CE thinking were embedded in the AEC industry's decisions, planning and practices. The following snapshot presents what is freely available in relation to a CE in the Australian AEC industry.

In the introduction of a CE in Australia, different labels – such as industrial ecology, green economy, etc. – are used but, in essence, these are the same when put into action.[94] One Australian report estimated that the adoption of a CE could deliver the benefits of significant job creation and GHG emissions reduction when compared to a 'business as usual scenario'.[95] It could create an additional 25,700 full-time equivalent jobs (21,000 by actioning material efficiency gains and 4,700 by actioning efficient and renewable energy gains). In a report developed by PricewaterhouseCoopers (PWC), the world's second-largest professional services network, it is estimated that establishing a CE in Australia would present a massive A$2 trillion opportunity.[96] The report suggests that Australia could generate A$1,860 billion in direct economic benefits over 20 years and, by 2040, could save 165 million tonnes of CO2 per year. KPMG Economics[97] estimated that in Australia in 2047–2048, the real GDP-realised benefit in the built environment sector would be A$32,302 million and A$96,806 million through compact dwellings and energy-efficient buildings, respectively.

Some organisations in both public and private sectors have recognised these benefits and are now moving towards a more circular economy (CE). For instance, manufacturers of construction materials such as bricks and concrete, carpet, gypsum, polyvinyl chloride (PVC), timber and waffle pods have developed voluntary extended producer responsibility (EPR) schemes[98] to improve end-of-life management of resources, thus contributing to a circular economy (CE).

Circular economy regulations, policies and guidelines in Australia

Australian regulatory and policy settings for a CE–AEC industry are still in their infancy, with solid policies yet to be developed by public agencies and industry associations. Only since 2018 has attention been paid to a CE in new policies: as a result, very few policies and guidelines have been established to familiarise key stakeholders and the public about a CE's benefits. Public agencies responsible for developing waste management strategy documents in the AEC industry have cited that a CE is a way to improve their waste management systems.[99] Most of these policies have emphasised the necessity of collaboration between the involved parties, led by the federal, state and territory governments, to promote a circular economy (CE). States, such as WA and Vic, have developed specific policies on a CE that advocate a shift towards resource efficiency in the AEC industry, as well as in business decisions and practices. Table 6 provides a summary of policies, guidelines and regulations, with a particular focus on a CE in the Australian context.

Table 6. Policies, guidelines and regulations driving a CE in the Australian AEC industry

Policy	Relevance to Circular Economy (CE)	Organisation
2018 Australia's National Waste Policy: Less Waste, More Resources[89]	This policy embodies a CE, shifting away from 'take, make, use and dispose' to a more circular approach where we maintain the value of re-sources for as long as possible	Department of Agriculture, Water and the Environment (DAWE)
2019 National Waste Policy Action Plan[92]	The action plan aims to address impediments to a CE for waste in Australia – to support businesses and households to realise the full value of recyclable materials and to work towards more sustainable resources use	DAWE
NSW Circular Economy Policy Statement: Too Good to Waste[26]	The policy statement provides a common language and direction for a CE, through a definition and seven CE principles. It also defines the NSW government's role in implementing CE principles across the state; provides clear principles that assist the NSW government to embed CE principles in government decision making, policies, strategies and pro-grams; outlines immediate next steps; and sets focus areas to guide planning and implementation	NSW government
A Circular Economy for Victoria[100]	The policy outlines the Victorian government's vision for how materials are used and managed throughout the state economy and provides long-term direction and certainty for Victorian businesses. The policy establishes goals for the Victorian waste and resources recovery system so that it effectively supports a circular economy (CE). It also clarifies the role of waste in energy technologies in this system	Victorian government
2021 National Circular Economy Roadmap for Plastics, Glass, Paper and Tyres[101]	This document reviews four materials that are common waste streams in our economy: plastics, tyres (automotive and mining), glass and paper. The roadmap has a focus on innovation and brings together industry stakeholders to explore CE opportunities for Australia	Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Closing the Loop: Waste Reforms for a Circular Economy[102]	This discussion paper seeks feedback on detailed legislative proposals to improve waste management and support a CE for Western Australia (WA)	WA Department of Water and Environmental Regulation
Designers for a Circular Economy[81]	This new policy seeks to identify key issues and priorities for action by designers and other sectors and stakeholders	Design Institute of Australia (DIA)

Policy	Relevance to Circular Economy (CE)	Organisation
Sustainable Procurement Guide[103]	The practical guide outlines the Australian federal government's commitment to transforming Australia's waste into a resource, with most goods and services continually used, reused, recycled and reprocessed as part of a circular economy (CE)	DAWE
SA Sustainable Procurement[104]	This guideline provides specific guidance on how to effectively integrate sustainability features and objectives into the procurement process for goods and services	SA government
Construction & Demolition Waste Credit	This guideline outlines the evaluation criteria used to assess projects' resource efficiency and C&D waste management	Green Building Council of Australia (GBCA)

Research and development (R&D)

Worldwide overview

With the growing CE movement fuelled by many national and international organisations worldwide, the number of studies focusing on the CE has sharply increased during recent years. Below is a document analysis to better understand the characteristics of a CE–AEC industry in the relevant literature. The analysis used a keyword string on the Scopus platform which resulted in 699 journal articles between 1984 and 2022. The keyword string was as follows:

(TITLE-ABS-KEY (circular AND economy) AND TITLE-ABS-KEY (construction AND industry) OR TITLE-ABS_KEY (architecture, AND engineering AND construction) OR TITLE-ABS-KEY (built AND environment).

As shown in Figure 5, a surge in the number of research outputs on a CE–AEC industry occurred from 2010–2020, reaching 191 documents in 2020. The increasing pattern of research on the CE provides evidence of the growing worldwide significance of this concept in the AEC industry.

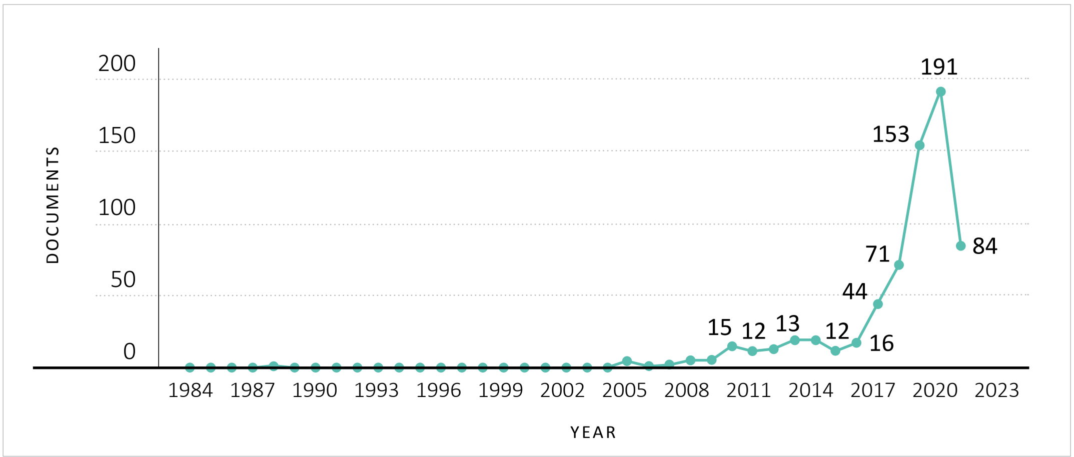

Figure 5. Publications on a CE and the AEC industry between 1984 and 2021

The document analysis findings showed that China, with 139 documents, had the highest number of publications on the CE–AEC industry (Figure 6), followed by Spain (63) and the UK (63).

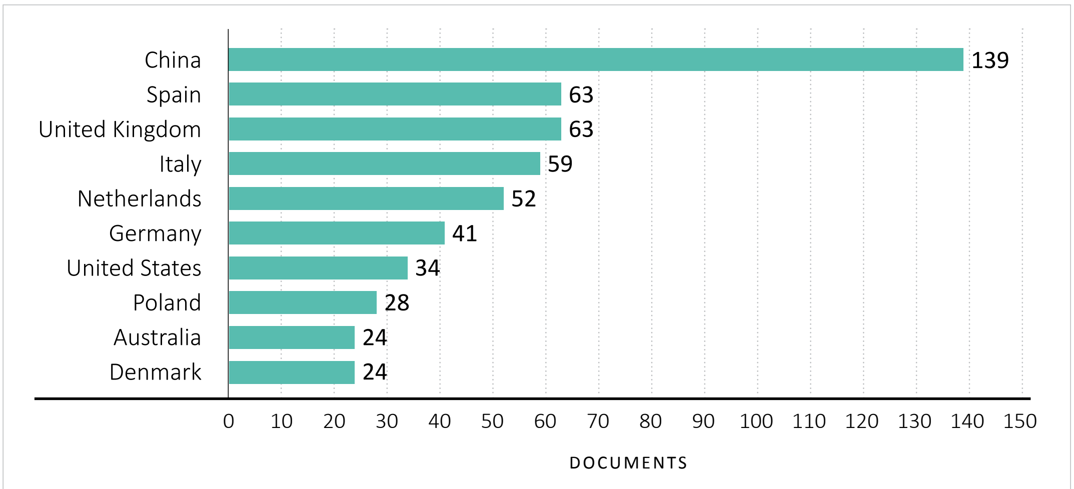

Figure 6. Countries with the highest number of CE–AEC industry publications

The study also conducted a network analysis of keywords (i.e. a scientometric analysis) using the VOSviewer 1.6.16[105] application to understand the research themes in a CE–AEC industry. Figure 7 shows the 19 major keywords and research interests referenced in the CE–AEC industry literature. The major keywords comprised 'the construction industry', 'lifecycle', 'sustainable development', 'environmental impact', 'recycling', 'lifecycle assessment' and 'waste management'. These analytical findings suggest that the CE is in its infancy worldwide, as the most widely used keywords demonstrate the rudimentary knowledge and practice of the CE in the AEC industry.

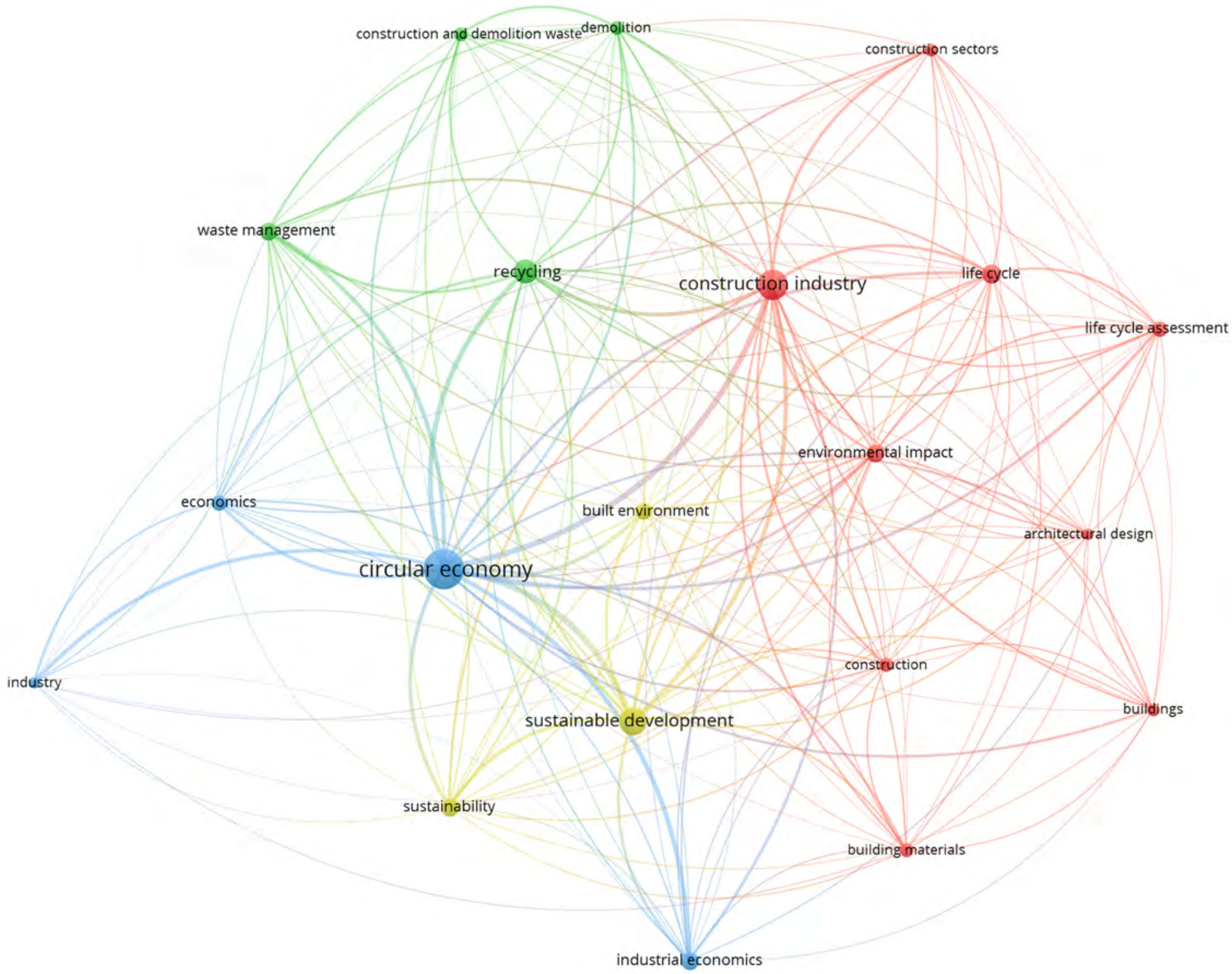

Figure 7. Keyword network analysis of CE studies

Australian overview

A keywords analysis was carried out to further understand the Australian CE–AEC industry research context. The results showed the same trend as seen in the worldwide context, that is, a surge in the number of publications in recent years. Overall, 24 publications were identified with a primary focus on the CE–AEC industry. This number, however, could be higher as the sources were only extracted from the Scopus platform and were based on the keywords string specified above. This keyword analysis, however, highlights the emerging need for further research into Australia's smooth transition to a CE.

Most of these academic sources articulate the conditions for a CE in the Australian context and highlight the need to achieve resource efficiency and waste recovery for sustainable development. For instance, researchers at the University of New South Wales (UNSW)[106], through a systematic literature review, identified 14 concepts deemed to be the pillars of the CE in the Australian construction industry. That study developed a framework for the identification of suitable CE-based concepts for the construction industry. A fraction of these studies has focused on specific aspects of the CE, outlining the challenges and opportunities. These include EPR[97], building energy[107]; industrial symbiosis[108]; C&D waste cross-jurisdictional materials trading[109] and diversion rate[110]; application of cloud–BIM platform for C&D waste reuse[111]; and collaboration and knowledge sharing with other countries.[112]

Research institutes with a focus on a circular economy

Public awareness of the environmental damage caused by human activities, particularly in the AEC industry, has contributed to a change aimed at pushing political will towards more environmental sustainability and a CE in Australia. However, despite an increase in the development and implementation of CE building, design and construction strategies, the process has to date been incoherent and without a commonly acknowledged or established direction across the AEC industry. The Australian federal government as well as state and territory governments have therefore established programs that aim to support R&D institutes to map the industry's direction. Recent government supports have gained traction among researchers and experts, resulting in the convening of several national and local CE research hubs that are particularly active in CE planning in the AEC industry. Table 7 lists the active CE research hubs across Australia.

Table 7. Research and development (R&D) institutes with a focus on a CE in Australia

R&D entity	Vision	Organisation
Australian Circular Economy ACE) Hub	The ACE Hub will be Australia's 'go-to' resource for CE thinking and action. It will provide companies, individuals and communities with the tools and education to help implement circularity. The program was scheduled for official launch in the fourth quarter of 2020 with the support of the federal government.	Planet Ark **https://bit.ly/2PvVq0l**
Circular Economy Hub@RMIT	The RMIT Circular Economy Hub (CEH)'s cross-disciplinary nature supports empirical approaches to holistic and systemic engagement across research partnerships, expanding the university's impact and expertise on the circular economy (CE). It also supports the emergence of a new capability-building platform across micro-credentials, and executive training, vocational and higher educational outcomes.	Royal Melbourne Institute of Technology (RMIT) University **https://bit.ly/3e1dKI2**
Circular Economy (CE) Lab	The Queensland government pledged A$150,000 to start this initiative, which will launch innovative projects to change the way people think about materials, resources and waste in Queensland.	Circular Economy (CE) Lab **https://bit.ly/2QD9s0E**
NSW Circular	The NSW Circular is an NSW government-funded body that works with people, businesses, government agencies, not-for-profit organisations, researchers and finance organisations to remove barriers to the circular economy (CE).	NSW Circular **https://bit.ly/3sYtdgf**
Centre for Sustainable Materials Research and Technology (SMaRT)	SMaRT at the University of New South Wales (UNSW) works with industry, global research partners, not-for-profit organisations and local, state, territory, and federal governments on the development of innovative environmental solutions for the world's biggest waste challenges.	UNSW **https://bit.ly/3t1RX7c**
Transformation of Reclaimed Waste into Engineered Materials and Solutions (TREMS)	TREMS is a network formed among key stakeholders to progress research and innovation towards a circular economy (CE). The network provides the framework to bring together all stakeholders, broaden R&D and secure resources to address key challenges faced by all companies and individuals working in the management, recycling and utilisation of waste materials. The collective efforts of the industry, government and academia will offer a forum for attracting large-scale research funding to progress end-to-end solutions that can be prototyped and translated by the partners.	TREMS **https://bit.ly/3u5wiwv**

R&D entity	Vision	Organisation
SmartCrete Cooperative Research Centre (CRC)	The SmartCrete CRC is the pivot point for the facilitation of research for the concrete supply chain. It provides contacts, connections, and funding for successful research projects to address the various issues and challenges for concrete, especially in its application in infrastructure.	SmartCrete CRC **https://bit.ly/3yXXaRX**
Circular Economy Victoria	Circular Economy Victoria (CEV) is an incorporated not-for-profit organisation that works to catalyse transformative change through social innovation in Victoria. The vision is to help create a world where people can thrive in balance with the living planet. The CE is seen as a key economic mechanism to help realise this vision, with the individual viewed as the most important agent for systemic change.	Circular Economy Victoria **https://bit.ly/3bn3N69**
Victorian Circular Activator (VCA)	Created in a collaboration between Circular Economy Victoria (CEV), RMIT University, RMIT Activator, Swinburne Data for Social Good Cloud Innovation Centre, Planet Ark, City of Melbourne and others, the VCA is a physical space that supports the existing digital infrastructure underpinning circular innovation in Victoria.	VCA **https://bit.ly/2RMUF3y**
Circular Economy and Waste Management	As Australia's national science agency, the CSIRO is focused on solving the biggest challenges through innovative science and technology. This includes ensuring that Australia has a resilient and valuable environment, is moving towards clean energy and resources, and that the growth of future industries is supported around these goals.	CSIRO **https://bit.ly/33AUNWD**
Circular Education Initiative	The Circular Education Initiative uses open-source content to create and facilitate circular economic education workshops and master classes for the Victorian context.	Scheduled for launch in June 2021 **https://bit.ly/3xAYI39**

Databases on the circular economy

Creating accessible databases plays an important role in furthering the understanding of the CE in the built environment. This section analyses the established databases relevant to the main streams of the CE–AEC industry in Australia. Table 8 summarises these databases.

Table 8. Databases with a link to a CE in Australia

Database	Focus	Organisation
EPiC Database: Environmental Performance Construction	The EPiC Database will be an invaluable resource for anyone involved in the planning, design, construction, operation or management of Australia's buildings and cities. It provides decision makers with critical information needed to understand, predict and improve the environmental performance of building and engineering projects	University of Melbourne
National Waste Report 2020	The National Waste Report (NWR) provides data and information on Australia's waste generation, recovery and fate for all waste streams and various categories of materials. It analyses this information by state and territory and on a per capita basis	Department of Agriculture, Water and the Environment (DAWE)
GBCA Case Studies[113]	This database provides details of green star-rated projects with ideal energy efficiency and C&D waste management	Green Building Council of Australia (GBCA)

Research and development (R&D) and industry funds

As indicated earlier, governments in Australia and public sector organisations aim to expand the CE in industry and have committed to multiple R&D and industry funds. Table 9 summarises the current funds and their aims and objectives.

Table 9. Research funds to support CE application in Australia

Fund Title	Focus	Organisation
Government's Recycling Modernisation Fund	The Australian federal government has committed to providing A$21 million to the ACT government's materials recovery facility (MRF). The objective of this fund is to better separate and process recycling streams. This fund will enhance market development and stimulation for waste materials, including C&D waste sources	Australian federal government/ACT government
Resource Recovery Industry Development Program	The Queensland government has provided a A$100 million funding program for waste and recycling to meet enforceable demands created due to a growth in landfill levy rates and diversion of waste materials	Queensland government
Circular Economy Market Development Grant	This grant aims to encourage councils, not-for-profit organisations, research institutes and businesses that produce, manufacture, sell or promote SA-recycled materials and recycled products	Green Industries SA
Recycling Victoria: A New Economy	The fund aims to drive investment in world-class infrastructure and technology, to make Victoria's future recycling system more sustainable, to create cutting-edge local industries and to support thousands of new local jobs	Victorian government
Sustainable Infrastructure Fund	The fund helps to roll out recycled materials for local construction projects. Infrastructure projects across 79 local councils in Victoria are expected to cost A$8 billion over the next three years. The Victorian government intends to leverage this funding to encourage the use of recycled products	Victorian government
Housing Research Funding	The Australian Housing and Urban Research Institute (AHURI) is a national independent research network with an expert not-for-profit research management company, AHURI Limited, at its centre. Through its national network of university research partners, AHURI undertakes research leading to the advancement of knowledge on key housing policy and practice issues	Australian Housing and Urban Research Institute (AHURI)

Table 10 below presents the latest Cooperative Research Centre projects (CRC-Ps)[114] which primarily focus on a CE in the built environment. These projects are supported by the Australian federal government and mostly investigate the recycling of C&D waste products.

Table 10. Cooperative Research Centre projects (CRC-Ps) with a CE focus in the built environment (2021)

Title	Partners	Description
Recycling construction demolition waste to manufacture sustainable bricks	• Sycamore Civil Group Pty Ltd • KHG Contracting Pty Ltd • Brajkovich Demolition & Salvage Pty Ltd • Sany Australia Pty Ltd • University of Melbourne • Deakin University • Aboriginal Construction Specialists Pty Ltd	The building and construction sector in Australia produces 20.4 million tonnes of C&D waste per year. This accounts for 43% of Australia's waste production, with more than 35% of CDW becoming landfill. The steady growth of CDW (at 2% p.a.) is increasingly impacting on the environment and waste management nationally. This urgent problem can be addressed by developing advanced recycling and manufacturing processes that utilise CDW in high-value sustainable brick products, which will be used in large volumes by the building and construction sector. This CRC-P will boost the recycling capacity of CDW, thereby reducing landfill waste, enhancing sustainability and resource efficiency, and growing the circular construction economy.
Development of high content recycled glass building materials technology	• Livefield Pty Ltd • Royal Melbourne Institute of Technology (RMIT) University • Trustee for Harris HMC Interiors • Recycled Glass Technology Pty Ltd	Australia manufactures over one million tonnes of glass each year but only 33% is recycled. This CRC-P will develop new applications with existing recycled glass-stabilising technology to manufacture building materials. The technology utilises 65% waste glass content bringing improvements to building safety and performance while achieving environmental outcomes. The funding will expedite the development of the technology supporting the Australian government's National Waste Policy Action Plan that aims to turn Australia's waste into valuable commodities and products with recycled content. This research and innovation will play an important role in developing sustainable technologies while boosting domestic jobs and industries.

Title	Partners	Description
Recycling plastic and paperboard waste into value-added asphalt additives	• State Asphalts NSW Pty Ltd • University of New South Wales Closed Loop Environmental Solutions Pty Ltd • Primaplas Pty Ltd Asphaltech Pty Ltd	Australia disposes of over four million tonnes of plastic and paper waste annually, at a cost of A$600 million. Australia's current recycling infrastructure lacks capability and capacity, relying on landfill and waste export. This CRC-P will commercialise technologies to convert plastic and paper waste into value-added additives for asphalt. State Asphalts NSW and Asphaltech will use the products, while distribution partners Closed Loop and Primaplas will source waste materials and distribute recycled products. The work will create technical leadership, improve competitiveness through reduced infrastructure costs, and create environmental benefits through reducing landfill and exports of waste.

Research directions

Key components

For the AEC industry, establishing supply chain collaboration across the entire lifetime of projects and enabling smooth information flows predicate successful circular business models.[75] To be specific, evidence from the AEC industry shows that technical design concerns, smooth information flows and established collaboration are the pillars of success for construction circular business models.[29] Formulating a research agenda for a CE in such a diverse industry is a large but necessary step towards the successful implementation of CE principles across the industry value chain. Several researchers have provided priority research areas according to their analysis and within their contextual conditions. This report, however, builds on the European Commission (EC)'s document[28] and suggests the following key areas for future research directions for a CE in the AEC industry:

1. **Durability:** building and elemental service life planning, encouraging a medium- to long-term focus on the design life of major building elements, as well as their associated maintenance and replacement cycles.
2. **Adaptability:** extending the service life of the entire building, either by facilitating the continuation of its intended use or through possible future changes in use – with a focus on replacement and refurbishment.
3. **Reduction of waste and facilitation of high-quality waste management:** facilitating the future circular use of building elements, components and parts, with a focus on producing less waste and on the potential for the reuse, or high-quality recycling, of major building elements following deconstruction. This includes efforts along the value chain to promote:
    a. the reuse or recycling of resources (i.e. materials) in such a way that most of the value of materials is retained and recovered at the end of a building's life span; and
    b. the component design and use of different construction methods to influence the recovery of materials for reuse or recycling to avoid down-cycling.
4. **Business models:** highly efficient circular business models, enabled by collaboration between stakeholders, are needed, in which building trusted partnerships and long-term relationships with suppliers and customers can facilitate the co-creation of value for construction organisations.
5. **Collaboration:** to offer added value from new business models, circular supply chains rely on the integration of the supply chain, fostering collaboration among all stakeholders and making the required information readily available to all parties.
6. **Cultural shift:** the AEC industry needs a cultural shift to overcome the stigma attached to reused products and to build the confidence of end-users, designers, architects and clients in these products.
7. **Value delivery:** the widespread adoption of the CE in the AEC industry is reliant on reducing costs and offering good value in reusing resources. Future studies should assess and provide evidence of the value of adopting circular business models, compared to traditional methods.

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The information contained in this report was correct
at the time of publication (July 2021).

Deakin University CRICOS Provider Code: 00113B