Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 11(X), 2023:
http://dx.doi.org/10.7770/10.7770/safer.v11i1.2978

Impact of circular economy in construction sector: review of current trends and future research direction.

Impacto de la economía circular en el sector de la construcción: revisión de las tendencias actuales y dirección futura de la investigación.

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ABSTRACT

Nowadays, a global problem of resource scarcity and a need to reduce waste generation make a discussion about eco-friendly production models more severe than ever before. One of the world's largest waste generators is the construction sector, the Circular Economy can help diminish its environmental impact. In the world, large amount of solid waste is generated, and the extraction of natural resources takes place due to the construction sector. This procedure happens because the construction sector primarily acquires a linear economic model of "take, make and waste," using materials for the construction of buildings and disposing of them, as they are fabricated for one-time use and do not preserve the potential for reuse. A paradigm shift has been occurring in the industry at large over the last few decades with the acquisition of a Circular Economy model that objects to keeping the materials in a closed loop to maintain their maximum value. Therefore with a more significant potential of diminishing the waste generation and resources extraction for the Construction Sector. This research paper draws the attention towards environmental impact; innovative designs; utilization and manufacturing of sustainable, recyclable, and reusable products, components, and materials.
KEYWORDS- Circular Economy; Construction Sector; Waste; Reuse; Environmental Impact; Innovative Design

RESUMEN

Hoy en día, un problema global de escasez de recursos y la necesidad de reducir la generación de residuos hacen que la discusión sobre modelos de producción amigables con el medio ambiente sea más severa que nunca. Uno de los mayores generadores de residuos del mundo es el sector de la construcción, la Economía Circular puede ayudar a disminuir su impacto ambiental. En el mundo se genera gran cantidad de residuos sólidos y la extracción de recursos naturales se da debido al sector de la construcción. Este procedimiento ocurre porque el sector de la construcción adquiere principalmente un modelo económico lineal de "tomar, hacer y desechar", utilizando materiales para la construcción de edificios y disponiéndolos, ya que están fabricados para un solo uso y no conservan el potencial para reutilizar. Se ha producido un cambio de paradigma en la industria en general durante las últimas décadas con la adquisición de un modelo de economía circular que se opone a mantener los materiales en un circuito cerrado para mantener su valor máximo. Por lo tanto con un potencial más significativo de disminución de la generación de residuos y extracción de recursos para el Sector de la Construcción. Este trabajo de investigación llama la atención sobre el impacto ambiental; diseños innovadores; utilización y fabricación de productos, componentes y materiales sostenibles, reciclables y reutilizables.

PALABRAS CLAVE- Economía Circular; Sector de construcción; Desperdicio; Reutilizar; Impacto medioambiental; Diseño innovador

INTRODUCTION

The global ecosystem is the major source of human monetary activities, and opportunities for economic development can be limited by using a scarcity of raw materials to delivering factories and exchange stocks. In contrast, there are still untapped stocks for a few sources which are certain metals and minerals like bauxite, copper, iron ore, lithium and rare earths, by the US Geological Survey (2021). It is undeniable that the development enterprise has a massive impact on the planet. With the development zone experiencing a resurgence in growth, it will harm the environment. The building and construction sector is a critical area with significant economic and environmental implications(Zuo & Zhao, 2014). This sector contributes to the economy (roughly 9% of the EU's GDP) by offering direct and indirect job opportunities (18 million direct jobs in the EU), and meets people's needs for buildings and facilities(Zhao et al., 2019). a major consumer of resources, accounting for approximately 50% of total raw material consumption and 36% of global final energy consumption(Pérez-Lombard et al., 2008) and uses more than 400 million tonnes of fabric per year, which harms the environment, according to the United Kingdom Green Building Council (2015). As per the researchers, the research suggest that 39% of all energy and process-related emissions are done by this sector (Allouhi et al., 2015). As a result, any sector which combat global climate change and promote cleaner production should include this industry as a key player(Geng et al., 2017; Wu et al., 2014).

Similarly, the Environmental Protection Agency claims that some of the equipment and resources commonly used by agreement people and development corporations in the United States, such as on-site chemical compounds or even the diesel, are hazardous to the environment. The manufacturing industry in the United States accounts for 160 million tonnes, or 25%, of non-business waste technology each year, according to the Environmental Protection Agency(EPA,2017).

Construction Blog Bimhow (2015) says that the development zone contributes to 23% of air pollution, 50% of the climatic change, 40% of ingesting water pollution, and 50% of landfill wastes. Thus, there is a need to address these environmental impact to make our environment sustainable and green.

The concept of the Circular Economy seeks to solve this environmental issue . It is inspired by natural mechanisms that work in a continuous production process, resorption, and recycling, self-managing and regulating themselves naturally, where waste is the input for the production of new products. Unlike linear

economics, where a raw material is produced, used, and then becomes non-recyclable waste (Figure 1). The circular Economy model objects to keeping the materials in a closed-loop to maintain their maximum value.
Therefore, it has a more significant potential to diminish waste generation and resource extraction for the Construction Sector. This is how more efficient, intelligent, and sustainable processes can break the link between economic growth and increased consumption of natural resources. The Circular Economy concept seeks to alter this paradigm.

The purpose is to study the extant literature and find the research gaps in the field of circular economy in construction sector. The aim is-

- To study and analyse the impact of design on the environment.
- To review the innovative design features can be applied for resolving this issue.
- To analyse the significance of innovative designs to reduced the negative impact on environment.

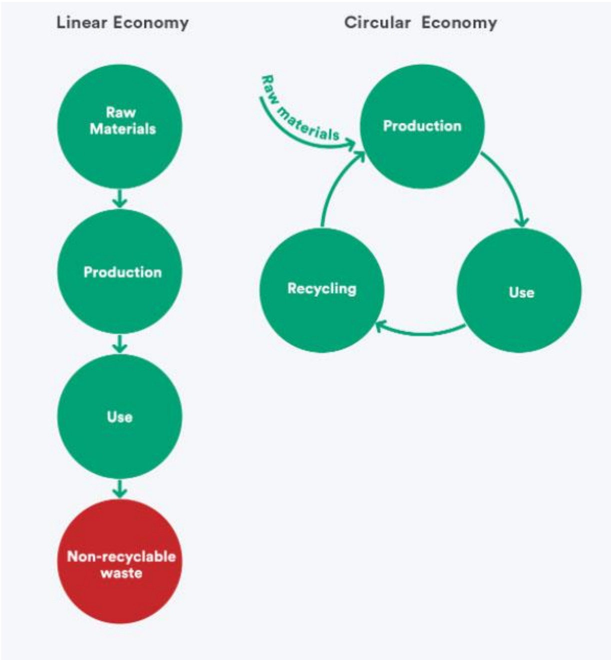

Figure 1. Shifting from linear to circular economy (source (-rts.com))

MATERIAL AND METHODS

An online search for papers for the literature review was conducted using Web of Science, Science Direct, and Google Scholar. "Circular Economy," "Circular Architecture," "Construction Sector," "Sustainable," "waste," "Reuse," "Recycle," "Raw Material," and "Environmental Impact" were among the keywords used to search papers. The theoretical and practical research papers, articles, conference papers, and theses that inspired this paper. Studies published in the last nine years (2013–present) were extracted without regard to geography. We identified an initial sample of 122 papers to be investigated from these searches, 53 from Science Direct and 69 from Elsevier. A further selection was made based on the following abstract content criteria:

• CE studies that evaluate and include discussions on the use of recovered materials in the manufacture of new construction materials. • Environmental and/or economic assessments of Construction and Demolition Waste reuse, recycling, and recovery, as well as other waste management practises. • Examines existing initiatives in the CDW sector in light of CE principles.• Studies that assess and discuss the environmental impact of the CDW sector.• Research that evaluates and includes discussions about innovative design strategies.

Based on the above criteria, the 21 most representative papers were chosen after reviewing the abstracts. Purposive sampling was used to select the sample for the case studies. The researcher studied various case studies, but the four case studies chosen on the basis of their both innovative design and environmental impact, which other case studies did not. They are : JLL: Landmark Office (Manchester), Margent Farm: Flat House (Cambridgeshire), Bartlett School of Architecture (London), and Sand End Community Centre (United Kingdom).

Due to limited selection of research paper, three types of building use (Commercial, Residential and Institutional) were chosen to provide a diverse perspective on architecture.

RESULT AND DISCUSSION

A comprehensive review of the existing literature was carried out. The section that follows expands on the existing literature on innovative designs and environmental impact.

1) INNOVATIVE DESIGN: The process of identifying, pinpointing, and comprehending the needs of the user or audience is known as innovative design. A solution can be designed once the need has been identified. This is where the brainstorming begins, and it is here that you will need your creativity. Innovation drives economies, and economies drive the growth of entire nations and their peoples. Businesses can no longer afford to stand still in today's highly competitive global economy. Instead, they must always be looking ahead and developing long-term sustainable solutions. This approach ensures company growth while also contributing to the industry's overall development and even the lives of their customers. The current building sector's business model must be redesigned to incorporate new and improved methods, solutions, and innovative services, thereby advancing a positive transition from a linear to a circular economy. Recent construction and infrastructure development trends point to the use of a CE to reduce potential environmental burdens. Intelligent facades, passive solar systems, vertical planting, energy-efficient designs, and the use of recycled materials are just a few of the green design alternatives currently used in buildings (Norouzi et al., 2021). CE principles are fairly simple and begin with the product design phase, taking into account the use of biological and technical components that can be assembled, refurbished, and reused later. Other principles include the use of renewable energy sources and understanding the relationships between various elements in order to develop comprehensive systems. Circular economy strategies, when implemented proactively, can reduce material criticality risks. Many traditional approaches to sustainable design have either not explicitly focused on materials or have not been well aligned with the challenges associated with their extraction, use, and recovery. (Al-Hamrani et al., 2021).

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Table- 1 focuses on the buildings with innovative design strategies that use a circular economy approach. This section was examined using four case studies. The goal is to comprehend how various building types and their design features aid in approaching the circular economy.

Table 1. Case studies with design features. Source: advancing circular constructions from the Building and Infraestructure Sectors, n.d)

PROJECT NAME	JLL: LANDMARK OFFICE	MARGENT FARM: FLAT HOUSE	BERTLETT SCHOOL OF ARCHITECTURE	SAND END COMMUNITY CENTRE
VIEW	 *SOURCE : landmarkmanchester.co.uk*	 *SOURCE - www.architectsjournal.co.uk*	 *SOURCE - architectsjournal.co.uk*	 *SOURCE www.dezeen.com*
LOCATION	Manchester	Cambridgeshire	22 Gordon Street, London	Peterborough Rd, London SW6 3EZ, United Kingdom
PROJECT TYPE	Fit-out	New build	Complete retro-fit and extension	Adaptation and repurpose
ARCHITECT	JLL	Practice Architecture	Hawkins\Brown	Mae
BUILDING TYPE	Office	House	Academic centre	Community centre
DESIGN FEATURES	➢ Repurposed glass table as signage. ➢ Recycled plastic boards as desktops ➢ From cradle to grave Interface flooring was purchased. ➢ 90% of the products from the previous office reused.	➢ Prefabricated hempcrete panels ➢ Exterior cladding of hemp fibre	➢ New façade ➢ Hand-cut bricks. ➢ Original concrete frame saved not only money and time, but also 400 tonnes of carbon. ➢ Bespoke furniture with birch plywood ➢ Kee Klamp steel system.	➢ Nougat bricks ➢ Recyclable fixings ➢ Bolts were favoured over glue. ➢ The structure's frame is made of a combination of cross-laminated timber (CLT) and glue-laminated timber (glulam). ➢ Wood and a specialty brick made from construction

waste.

During the search, it was found that the building design and construction strategies were interpreted and practised in different ways, with different goals, and with different names in the literature. In total, 16 overarching design and construction strategies were identified. Figure 2 presents the results of the comparative analysis of the 16 building design and construction strategies which was done by (Eberhardt et al., 2022) which leads to developed taxonomy (the procedure and science of categorization or classification). To make sense of the multitude of design and construction initiatives found from the selected literature, we focused on essential shared practices, quality and characteristics of each strategy in order to group the strategies into overarching design and construction strategies. For example, it was found that the strategy 'flexibility' and 'adaptability' reflect the same thing. Based on the overall objective of the study, the following information was registered for each strategy:

a. Number of occurrences
b. Relation to CE strategies (i.e. reduce, reuse, repair, refurbish, remanufacture, recycle and recover)
c. If stated, relation to project stage(s) from planning and design to decommissioning
d. If relevant, relation to building type e.g. school, office, hospital, residential, etc.
e. Level of application in buildings (i.e. if the strategy addresses the overall building level, component level and/or material level or in general terms)
f. Level of readiness

Based on the overall objective of the study a taxonomy summarising the 16 building design strategies identified was developed to provide an overview, systemise and enable comparison between state-of-the-art building design and construction strategies for a CE (see Table 1). The strategies were organised according to (a), (e) and (f), aiming to provide a simple overarching scheme of different strategies and how they are applied in terms of buildings and their level of readiness (Eberhardt et al., 2022).

2) IMPACT ON THE ENVIRONMENT - Most countries face numerous environmental challenges as a result of the construction of various types of infrastructure. These include things like soil modification and excessive resource use. One of the critical issues with the highest level of uncertainty is the identification and

assessment of environmental impacts. It is critical to identify and assess these effects. It is difficult to predict, manage, and address environmental impacts due to the various challenges involved with construction activities, such as differences in locality, site, parties involved, and tolerance levels. There are several approaches/initiatives that promote sustainable use and environmental protection (Aghimien et al, 2019).Today's urban planners and residents want environmentally sustainable and vibrant communities. Innovative and resourceful approaches to the built environment in general, and existing buildings in particular, are critical to achieving future sustainability (Foster, 2020). The need for shelter is undeniably important to human well-being. Buildings for shelter are then manufactured, used, and disposed of on a massive scale, resulting in significant consumption of natural resources extracted from the environment and waste returned to the environment. In the world, 25% of solid waste is generated, and more than 30% of the extraction of natural resources takes place due to the construction sector (Gabriel et al. 2020). The global sustainability agenda considers the construction industry to be one of the most important sectors. For example, global consumption of building materials has tripled from 6.7 billion tonnes in 2000 to 17.5 billion tonnes in 2017 (shown in figure 4). Furthermore, it is estimated that cement production is responsible for 5%–10% of global anthropogenic CO2 emissions(Beijia et al. 2020). According to Huntzinger and Eatmon (2009), the production of Portland cement has a wide range of environmental effects on a local, regional, and global scale. Noise pollution and natural disturbance caused by mining of raw materials such as limestone, iron ore, and clay are considered local impacts(Géssica et al. 2022).

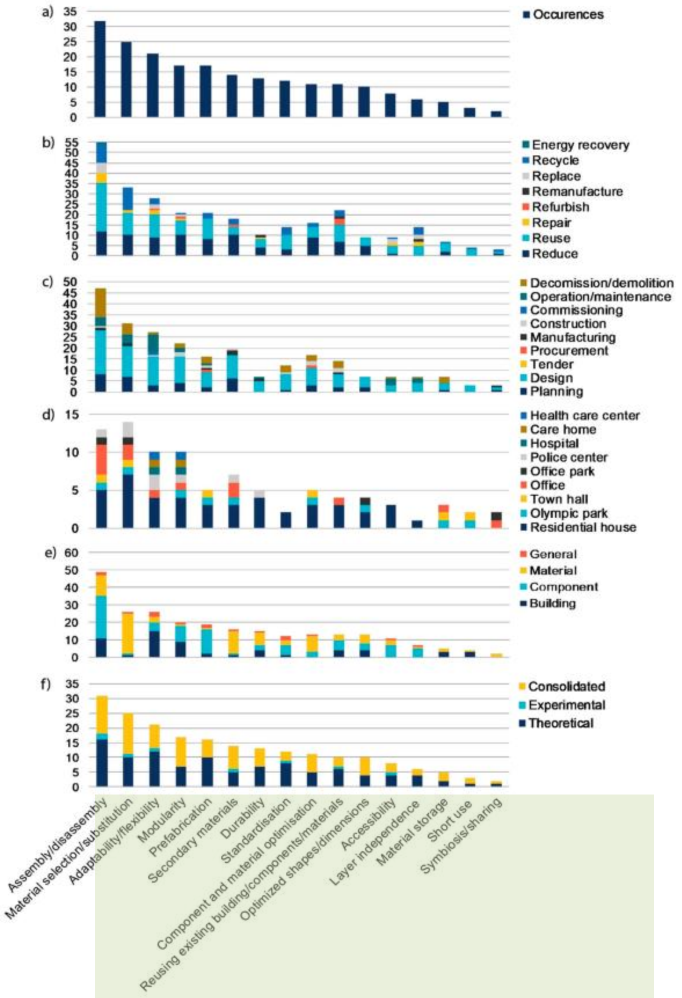

Figure 2. The design strategies' (a) number of occurrences, relation to (b) CE, (c) project stages, (d) building types, (e) application level and (f) readiness level. –Source: (Eberhardt et al., 2022)

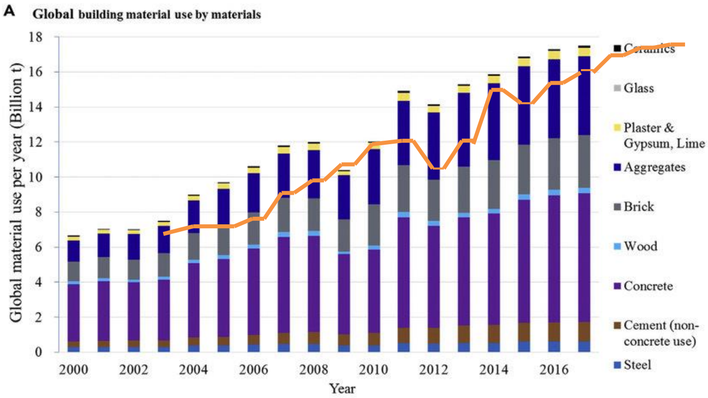

Figure 3 -annual global building material use during 2000-2017 by material and region

Source: Heeren and Fishman (2019), Huang et al. (2018) Marinova et al. (2020); data source of annual constructed building area: Deetman et al. (2020)

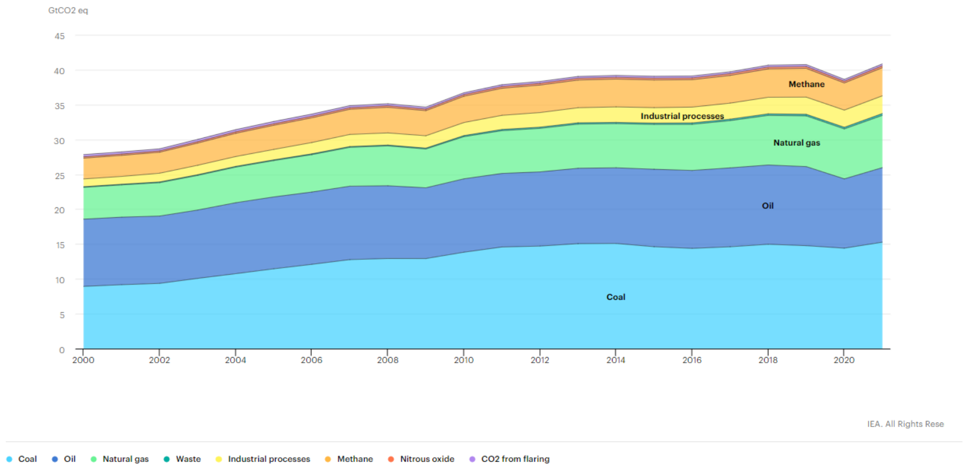

Figure 4. Energy related greenhouse gas emissions, 2000-2021

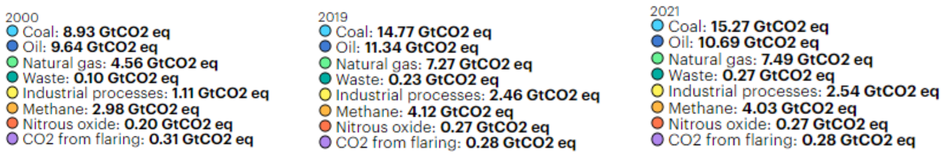

Figure 5. Comparison greenhouse gas emissions between 2000, 2019 & 2000

Source: (IEA 2022)

The rise in energy-related CO_2 emissions pushed overall greenhouse gas emissions from energy to their highest ever level in 2021 (Figure 4). Total greenhouse gas emissions reached 40.8 Gt of CO_2 equivalent (CO_2eq) in 2021 when using a 100-year global warming potential time horizon, above the previous all-time high in 2019. CO_2 emissions from energy combustion and industrial process accounted for close to 89% of energy sector greenhouse gas emissions in 2021. CO_2 emissions from gas flaring accounted for another 0.7%. Beyond CO_2, fugitive and combustion-related methane emissions represented 10% of the total, and combustion-related emissions of nitrous oxide 0.7%.Methane emissions from the energy sector rose by just under 5% in 2021 but remain below their 2019 level (Figure 5) (IEA 2022).

These statistics emphasise the importance of managing the environmental impacts of buildings, particularly greenhouse gas emissions, in order to achieve a sustainable economy and limit global warming.

In general, countries with the highest circular economy scores — Germany, the United Kingdom, and France topped the list — have robust recycling systems and high levels of innovation in circular economy sectors (Politico, 2018), as illustrated in table 2.

Table 2. Countries ranking for the circular economy (Source: Politico, 2018)

	Municipal waste (per year per person)	Food waste (per year per person)	Municipal recycling rate	Share of goods traded that are recyclable raw materials	Material reuse rate	Patents related to circular economy (since 2000)	Investment in circular economy sectors
Netherlands	520 kg	541 kg	53%	0.17%	27%	169	€5.2M
Italy	497 kg	179 kg	45%	0.19%	19%	294	€17.8M
France	511 kg	136 kg	42%	0.24%	18%	542	€21.3M
Belgium	420 kg	345 kg	54%	0.22%	17%	105	€2.8M
United Kingdom	483 kg	236 kg	44%	0.35%	15%	292	€31M
Poland	307 kg	247 kg	44%	0.18%	13%	298	€4.7M
Estonia	376 kg	265 kg	28%	0.26%	11%	3	-
Germany	627 kg	149 kg	66%	0.25%	11%	1260	€28.7M
Luxembourg	614 kg	175 kg	48%	0.97%	11%	24	-
Denmark	777 kg	146 kg	48%	0.31%	10%	53	€2.3M
Malta	621 kg	76 kg	7%	0.12%	10%	1	-
Austria	564 kg	209 kg	58%	0.32%	9%	122	€3.5M
Slovenia	466 kg	72 kg	58%	0.41%	8%	8	€0.5M
Spain	443 kg	135 kg	30%	0.20%	8%	210	€11M
Czech Republic	339 kg	81 kg	34%	0.25%	7%	72	-
Finland	504 kg	189 kg	42%	0.06%	7%	111	€2M
Sweden	443 kg	212 kg	49%	0.19%	7%	49	€4.1M
Croatia	403 kg	91 kg	21%	0.23%	5%	4	€0.6M
Hungary	379 kg	175 kg	35%	0.23%	5%	36	€0.9M
Slovakia	348 kg	111 kg	23%	0.15%	5%	10	€0.6M
Lithuania	444 kg	119 kg	48%	0.15%	4%	19	€0.4M
Bulgaria	404 kg	105 kg	32%	0.11%	3%	10	€0.5M
Cyprus	640 kg	327 kg	17%	0.13%	3%	4	€0.1M
Latvia	410 kg	110 kg	25%	0.18%	3%	11	€0.2M
Ireland	563 kg	216 kg	41%	0.18%	2%	38	-
Portugal	461 kg	132 kg	31%	0.26%	2%	22	€1.4M
Romania	261 kg	76 kg	13%	0.13%	2%	34	€1.1M
Greece	498 kg	80 kg	17%	0.14%	1%	5	€0.6M

NOTE*: Data for private investment in the circular economy sectors was not available for five countries; their overall score was calculated out of six criteria instead of seven.*

POLITICO

Table 3 focuses on the circular economy principle used while designing a building and their environmental impact on society. The goal is to comprehend how circular principles helps to reduce carbon emission and save carbon footprint during the construction.

Table 3. Case studies

PROJECT NAME	JLL: LANDMARK OFFICE	MARGENT FARM: FLAT HOUSE	BERTLETT SCHOOL OF ARCHITECTURE	SAND END COMMUNITY CENTRE
CIRCULAR PRINCIPLES	➢ Reuse ➢ refurbishment ➢ repurpose ➢ flexibility ➢ optimization	➢ Standardisation ➢ modularisation	➢ Reuse ➢ refurbishment ➢ repurpose ➢ flexibility ➢ optimization	➢ carbon negative material ➢ Recycle
CO_2 EMMISSION	0.56 tCO_2 e/corporate office employee	2.32 t/year	4320 tCO_2 e (total whole life carbon)	24.7 $kgCO_2/m^2$ (as built)
CARBON FOOTPRINT SAVING	62.25 tonnes CO_2e	24 tonnes CO_2e	440 tonnes carbon saved by retaining original concrete frame	➢ -28 tonnes saved from landfill ➢ -35% of the building being sourced from recycled products

(SOURCE - (*ADVANCING CIRCULAR CONSTRUCTION Case Studies from the Building and Infrastructure Sectors*, n.d.))

Featured case studies show the benefits of applying various circular principles in a range of project types. These case study approaches considered best practices include:

- Carbon-negative materials from renewable resources isolate more carbon than they emit and are designed for disassembly.
- Design for deconstruction allows components to be isolated and reused.
- The flexible space is designed to meet the changing needs of users of the building.
- Flexible spaces which are designed to accommodate changing user requirements for the building
- Remanufacturing previously used products into an as-new items which come with a warranty

- Repurposing existing building structures rather than demolishing and replacing with a new building (Community economy, 2020)

CONCLUSION

The research topic determines the application of the development circular economy concept in some countries around the world and how the implementation of a circular economy has influenced the construction sector. However, the benefits of a circular approach extend far breyond ecology. It can even result in significant social and economic benefits. The most common linear economic model is based on the belief that resources are infinite and that there is no room for waste disposal. A model like this is unsustainable, and changes must be made. Transitioning to a circular economy requires broad changes in the industry, social components, energy, transportation, and other areas. Every economic sector has its own set of principles and constraints, and each country has its own set of circumstances, resulting in a variety of approaches and time frames for transitioning to a circular economy. This includes everything from the look section through building, usage, and eventually deconstructionism and recycling for the development sector. The findings of this review paper show that there is a link between economic development and indicators of the circular economy. It is not possible, at least not while there is a time lag and extensive analysis, to replicate a system from around the world and expect excellent results. However, there are numerous examples of adopting the development circular economy concept from around the world with stunning results from which to learn. Implementing the circular economy concept must not be limited to waiting for government interventions and subsidies. Adopting the circular economy concept in construction will allow corporations to anticipate potential constraints such as resource scarcity, taxation, externalities, and more. A circular economy is a financial system aimed at reducing waste and maximizing resource utilization. A circular economy seeks to reimagine growth by emphasizing societal benefits. The circular model can generate financial gain while also creating new jobs, which most countries require. The circular economy model will do a good job of connecting economic and environmental benefits, which will aid in the development of entrepreneurship. It is possible to achieve new economic milestones by utilizing waste as a resource and applying the principles of a circular economy. It will take time to complete the transition because it will require much stronger social involvement, collaboration on both the native and national levels, the adoption of new business models, the support of trade clusters to exchange by-products, and a replacement urban management system. It will be discovered that, in addition to funding for the spread of information, education, and technology, it is also necessary to develop and vigorously promote circular economy-based entrepreneurship.

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ACKNOWLEDGEMENT

I would also like to express my gratitude to K.R. Mangalam University for providing me this research opportunity.

ABBREVIATION

CE – Circular Ecomony

CO_2e – Carbon dioxide equivalent

$GtCO_2$ – eq – billions tonnes of carbon dioxide equivalent

EU – European Union

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Received: 20th October 2022; Accepted: 20th October 2022; First distribution: 29th October 2022.

Note: special edition procedure.