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Exploring UAE's Transition Towards Circular Economy Through Construction and Demolition Waste Management in the Pre-construction Stage - A Case Study Approach

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Abstract

Purpose – This paper aims to explore UAE's transition towards Circular Economy (CE) through construction and demolition waste (CDW) management in the pre-construction stage. The extent of circularity is assessed by five key aspects of CE, such as policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans.

Design/methodology/approach - Multiple case studies were conducted in the context of the Dubai construction industry (UAE). Three significant and unique construction projects were selected as the cases. Semi-structured interviews were carried out to collect data, and the thematic analysis technique and NVIVO 12 software were used for data analysis.

Findings - Findings reveal several positive initiatives towards CE in the UAE context; yet it is identified that the transition is still at the initial stage. Selected case studies, the best-case scenarios of UAE (i.e., influential cases), demonstrated adequate measures in relation to four key CE aspects out of five. For instance, a) policies and strategic frameworks such as lean standards, green building standards and standards developed by the local authorities), b) design for waste prevention (e.g., adherence to the 3R principle, and construction planning with BIM), c) use of prefabricated elements and application of innovative construction technologies (e.g., 3DPC, DfMA), and d) CDW management planning such as 3R principle were evident. However, the selected cases hardly showcase designing for disassembly or deconstruction.

Originality - The findings of this study provide valuable insights for decision-making processes around CDW management towards a CE. This paper contributes to the literature by bridging the CE concept with CDW management in the pre-construction stage. The study provides insights for industry practitioners for planning CE in terms of policies and strategic frameworks, CDW management planning, construction planning and application of innovative construction technologies.

Research implications - The existing CDW practices are mostly conventional, as most constructions in UAE are procured through conventional building materials and methods. Therefore, there is a necessity of encouraging CE principles in CDW management. Even though the transition towards CE was evident in four key CE aspects out of five, the UAE construction industry has yet to adopt more effective CE-based CDW management practices to accelerate the circularity. Hence, it is necessary to enforce standard waste management guidelines, including the 3R principle, to standardise CDW management in UAE and encourage construction practitioners to adhere to CE principles.

Keywords: *Circular economy; Construction technology; Construction and demolition waste; Pre-construction; Waste management; 3R*

1.0 Introduction

Being a resource-intensive sector, the construction industry is perceived as the major contributor to waste generation. The massive scale of ongoing construction activities generates a significant amount of construction and demolition waste (CDW). An increased amount of CDW has become a severe environmental issue that necessitates immediate attention (Statistics Centre Abu Dhabi, 2019). The practicality of conventional waste management practices such as landfilling has been questioned due to the factors such as the impact on the environment, scarcity of lands, higher costs and time-consuming nature (Elgizawy *et al*., 2016). Hence, researchers have shifted their attention to implementing various measures that reduce waste generation in the first place (i.e., pre-construction stage) (e.g. Faniran and Caban, 1998; Tam and Hua, 2014; Superti *et al*., 2021). Yeheyis *et al*. (2013) stated that proper management of material delivery, storage and waste accounting are the best practices to minimise material wastage at site. Authors further suggested that the adherence with the 3R approach (i.e., reduce, reuse and recycle) in the design, construction, renovation and demolition stage to minimise the CDW. Christensen (2021) emphasised the importance of pre-demolition audits in construction projects to explore recycling opportunities. The author further recommended implementing the process innovation of establishing a material bank and recycling network for demolition waste. Moreover, recent studies have shown that innovative construction technologies such as 3D-printed concrete (3DPC) and prefabrication/Design for manufacture and assembly (DfMA) minimise on-site waste generation (Siddika *et al*., 2020; Poon *et al*., 2003).

Circular Economy (CE) has been recognised as a measure of effective CDW management process (e.g., Ruiz *et al*., 2020). It is considered a strategy that optimises the use of resources while minimising the generation of CDW. CE principles encourage effective CDW management throughout the project lifecycle–with the support of clients, building designers, contractors, and the government (Faniran and Caban, 1998; Ruiz *et al*., 2020; Yu *et al*., 2021). Nevertheless, considering the practical inefficiencies in recycling, Bao *et al*. (2019) emphasized the importance of innovative procurement for a CE. In traditional approach, CDW is treated as a zero-value material which is mostly ended up in the landfills. Hence, Wu *et al.* (2014) emphasised the importance of end-of-life treatments instead of landfilling for minimising Greenhouse Gas Emissions (GHE). Overall, the CE concept mainly focuses on reduce, reuse, and recycle activities, and to be further explored for the effectiveness for different industries (Padilla-Rivera *et al*., 2020). In the construction context, Norouzi *et al.* (2021) identified that CDW management and alternative construction materials are emerging topics under the umbrella of CE.

UAE is one of the world's highest per capita waste generation countries (Mawed *et al.*, 2020). Like the rest of the world, UAE is facing the issue of poor measures towards sustainability, particularly on construction sites (Al-Hajj and Hamani, 2011; Kim *et al*., 2020). In 2015, the United Nations established seventeen sustainable development goals (SDGs) to be achieved by 2030 by all the members (UN-SDG, 2015). Most of the UN SDGs are directly linked with construction and built environment sector. Umar *et al*., (2020) highlighted the fact that UAE is lagging in achieving most of the SDGs and the current plan lacks a clear roadmap for achieving the goals. Due to the rapid expansion of infrastructure in the region, the construction industry is currently at its peak. Thus, the construction industry in the UAE should be given priority in the planning process to achieve the SDGs by 2030 (Umar and Umeokafor, 2022). In 2017, the CDW generated in Dubai was over 18 million metrics, which has been estimated to grow by 11% annually (Dubai Municipality, 2017; Kim *et al*., 2020). Moreover, Umar *et al*., (2020) pointed out that only 25 % of the municipal solid waste generated in Dubai is recycled, and a significant portion of waste is being disposed in landfills continuing to greenhouse gas (GHG) emissions and other environmental issue. In 2019, over 3.5 million metric tons of CDW were generated in Abu Dhabi, the largest emirate in UAE, in which only 20% of the waste was recycled (SCAD, 2020). In fact, around 75 % of the solid waste generated in the UAE are from the construction industry. Initiatives in recycling and reusing materials will contribute to achieving environmental benefits while simultaneously reducing the overall construction costs (Umar *et al*., 2020; Umar and Umeokafor, 2022). In 2021, the UAE government initiated Circular Economy Policy promoting sustainable governance, in which the construction sector is given key concern. The UAE government is committed to achieving SDGs by shifting from degenerative linear economy to regenerative CE (UAE Government, 2021a). The construction sector in UAE is identified as a key sector in CE implementation as 10-15% of building materials are wasted during construction (Al-Hajj and Hamani, 2011: Ellen MacArthur Foundation, 2013), and most of waste is landfilled without extracting any value (Umar et al., 2020). The UAE Government identified developing programmes to support reuse and recycling of building materials and promoting better construction design mechanisms as key initiatives in reducing CDW (UAE Government, 2021a; UAE Government, 2021b).

However, the CE concept in the construction sector is barely discussed in the UAE context (e.g., Norouzi *et al*., 2021). CE being a new paradigm, the transition towards CE in terms of CDW management shall be discussed thoroughly addressing the full life cycle of CDW, focusing on pre-construction, construction, renovation, and demolition stages. Hence, to address this research gap the current study intends to explore the best practices implemented in the local context in achieving CE in terms of CDW management, that would be applied throughout the industry. However, to provide a holistic view and simultaneously narrow the scope, this study only focuses on the pre-construction stage, as the decisions made in the pre-construction stage critically affect CDW management throughout the life cycle (Yeheyis *et al*., 2013). The study is based on three best-case scenarios in UAE (i.e., influential cases), which demonstrated adequate measures in relation CE aspects. The findings of case studies are compared with prior research findings to deliver comparisons on CDW management and UAE's transition towards CE. Finally, conclusions and recommendations towards CE through CDW are provided.

2.0 Literature review

2.1 Circular economy through construction and demolition waste management

The concept of CE has been discussed in line with an economy with closed material loops. The CE addresses several consequences of the conventional linear economy of "take-make-dispose", such as resource depletion, high volume of waste generation and environmental pollution (Ellen MacArthur Foundation, 2013). In a broader aspect, CE encourages repeated use of a product as a secondary resource, keeping them in the production life cycle as long as possible (Shooshtarian *et al*., 2021; Ruiz *et al*., 2020). Núñez-Cacho *et al.* (2018) have shown that CE has become a crucial factor that defines the continuity of the construction sector. The concept of CE goes together with CDW management as this approach optimises the use of materials throughout their life cycle resulting in the minimisation of waste (Mahpour, 2018; Ruiz *et al*., 2020).

The CDW management regulations play a vital role in achieving CE, and well-implemented policies and strategic frameworks encourage CE principles in the construction industry. The renowned 3R concept is compatible with the CE principles where raw material utilisation is reduced, and used materials are reused and recycled by adding value to the waste. Applying 3R principles in CDW is a rudimentary practice for achieving CE in the construction sector (Bao *et al*., 2019). Many studies have shown that having a CDW disposal charge is one of the effective initiatives as it prioritizes reduce, reuse, and recycle practices over disposal (Ruiz *et al.*, 2020).

The five-life cycles of CDW in CDW are identified in implementing CE: pre-construction, construction and building renovation, collection and distribution, end-of-life and material recovery and production (Núñez-Cacho *et al*., 2018; Ruiz *et al*., 2020; Yeheyis *et al*., 2013). To narrow the research scope, this study focused on the pre-construction stage, as decisions made in the pre-construction stage critically affect CDW management throughout the life cycle. Figure I demonstrates the CE implementation opportunities of the CDW life cycle as identified by Ruiz *et al.* (2020).

Figure I: Stages in the analysis of CDW in the CE model

Mahpour (2018) emphasised several barriers that hinder the implementation of CE in the construction industry, such as ineffective collection, transport, sorting, and recovery process of CDW, use of construction materials with lack of quality, and lack of integration of the CDW management process. These hindering factors should be addressed through innovative strategies.

2.2 Circular economy principles in construction and demolition waste management in the pre-construction stage

Pre-construction stage is crucial in identifying and implementing waste minimisation strategies, which is essential in achieving a CE. Key areas to focus on in the pre-construction stage include policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans (Ruiz *et al*., 2020).

CDW disposal charge is one of the effective initiatives as it prioritizes reduce, reuse, and recycle practices over disposal (Ruiz *et al*., 2020). CDW policies and strategic framework shall encourage all stakeholders to invest in closed-loop construction (Ghaffar *et al.*, 2020). In addition, providing incentives for CDW treatment companies promotes recycling and recovery methods (Ruiz *et al*., 2020). End-of-life treatments for concrete and the use of recycled concrete aggregate shall be promoted (Wu *et al*. 2014).

Ruiz *et al.* (2020), in relation to waste prevention and minimisation, highlighted the importance of paying attention in the designing stage. The early stage of designing should be facilitated with waste minimisation concepts, making reuse a priority. Wu *et al.* (2014) discussed the importance of Building Information Modelling (BIM) and other simulation technologies in which BIM provides an immense contribution to waste prevention with an extensive amount of information (Núñez-Cacho *et al.*, 2018). BIM also facilitates future building disassembly and enables estimating the circularity of building materials (Ruiz *et al.*, 2020).

Moreover, deconstruction strategies are a critical concern in the design stage, as designing for disassembly and deconstruction significantly contributes to the CE concept (Núñez-Cacho *et al.*, 2018). The amount of potential reusable and recycling materials should be identified in the design stage (Ruiz *et al.*, 2020). Ghaffar *et al.* (2020) highlighted the smart dismantling of buildings, such as mobile robotic sorting and integration of IoT technologies that enhance the circularity in construction. Smart demolition and selective dismantling improve the re-usability of construction elements (Ghaffar *et al.*, 2020).

With the recent developments in construction technology, more hard approaches are accessible for CDW management. The emergence of 3DPC significantly contributes to CDW minimisation in the wet construction process. 3DPC is a form of additive manufacturing technology. It is a process of fabricating 3D objects (large and complex structures) through a rapid prototyping system (i.e., computer-aided model) (Hager *et al.*, 2016; Siddika *et al.*, 2020). 3DPC can utilise raw materials with low-embodied energy, such as recycled materials from CDW (Hager *et al.*, 2016). The prefabrication/DfMA is considered one of the effective hard approaches to minimise on-site waste (Jaillon *et al.*, 2009; Poon *et al.*, 2003). Prefabrication technology involves utilising precast elements such as facades, staircases, partition walls, semi-precast slabs and bathrooms, which are manufactured at a specialised facility off-site. Prefabrication technology enhances the quality while ensuring a safer working environment. Studies have shown that around 50% to 70% of waste reduction is achievable by adopting pre-fabrication technology. Moreover, a reduction of 70% of timberwork is feasible compared to traditional in-situ construction involving concreting and timer formwork (Jaillon *et al.*, 2009; Siddika *et al.*, 2020). These innovative construction technologies minimise various waste streams, such as concrete and wood, and ultimately contribute to achieving CE.

Finally, CDW management plans should be developed in the design phase comprising waste management measures for waste reduction— before, during and after the construction activities (Ruiz *et al.*, 2020). The adoption of policies and frameworks, such as the 3R concept and sustainability measures, should be decided in the pre-construction stage (Bao *et al.*, 2019). Based on the previous studies, CE principles in CDW management in the pre-construction stage are identified, as demonstrated in Figure II.

Figure II: CE principles in CDW management in the pre-construction stage

2.3 Circular Economy Implementation in UAE

The UAE Government has initiated several sustainable measures to manage CDW effectively. CDW recycling facilities have been implemented in every emirate, receiving daily a minimum of 4 tons of mixed CDW (Gernal *et al.*, 2020). In January 2021, the UAE government initiated the UAE Circular Economy Policy 2021-2031, where the construction sector was given key importance. The policy highlighted that the actual value of 10–15% of the building materials had not been utilised fully in the construction stage. Several initiatives including adoption of prefabricated building elements, off-site construction and 3DPC are suggested as key initiatives in achieving CE targets (UAE Government, 2021a&b).

Enhancing material efficiency in the construction sector is a key UAE priority, as most of the resources need to be imported to the country. To meet the country's net-zero targets, a landfill tax scheme was introduced, encouraging the diversion of waste to resources. Dubai Municipality (DM) aims to achieve zero landfills in 20 years to protect the environment from harmful gases emitted and minimise the adverse environmental impact of the landfills (UAE Government, 2021a).

In the UAE context, the discussion of CE in the construction sector is scarce. As CE is still a relatively new concept, it is crucial to conduct a comprehensive study of the transition towards CE, encompassing the entire life cycle of CDW, giving special attention to the pre-construction, construction, renovation, and demolition stages. Nevertheless, to offer a comprehensive yet focused perspective, this study concentrates solely on the pre-construction stage. This stage is of utmost importance as the decisions made during pre-construction significantly impact the management of CDW throughout the entire life cycle. It is expected to explore the CE implementation during the construction stage as a future study.

The study examines three influential cases in the UAE. These cases have been carefully selected as they represent best-case scenarios that exemplify effective measures related to CE aspects. The cases representing CDW management strategies, prefabricated building elements, off-site construction, and 3DPC are given priority, as those measures are identified as successful approaches in the process of CE implementation in UAE, the UAE Circular Economy Policy 2021-2031. By analysing these cases, the study aims to highlight successful strategies, practices, and approaches employed in the UAE context that align with the principles of the CE. These cases serve as valuable examples and provide insights into how CE principles can be implemented in the construction sector, specifically in relation to the management of Construction and Demolition Waste (CDW).

3.0 Methodology

3.1 Multiple case study approach

This study aims at exploring UAE's transition towards CE through CDW management, focusing on the pre-construction stage. An in-depth and holistic investigation has been conducted to achieve the aim. Accordingly, a qualitative approach and multiple case study research methods have been adopted. A case is usually selected based on its potential to enhance the researcher's theoretical views on a phenomenon based on empirical findings; in this study, is the CE concept and CDW management practices are focused (Liamputtong, 2020).

However, the qualitative research approach has frequently been criticised for its credibility and reliability of findings. Hence, several actions have been implemented to maintain the required level of validity and reliability of the findings of this study. According to Creswell and Creswell (2017) and Yin (2018), Qualitative validity is ensured by three attributes that are internal validity, construct validity and external validity. Internal validity is obtaining logical and reasonable interpretations via an accurate and detailed data analysis. This study has ensured internal validity by carrying out the data collection and analysis process according to the standard procedure suggested by Creswell and Creswell (2017). The second attribute–construct validity is achieved by data triangulation through cross-case analysis. External validity–the third attribute refers to the generalisability of findings. Even though the qualitative findings do not allow statistical generalisation due to the context specifications, analytical generalisation is still available as the findings can contribute to the theories of CE, sustainability and CDW management (Yin, 2018). Moreover, empirical findings can be applied to similar contexts (i.e., different construction industries with similar characteristics) with necessary adjustments.

The credibility and reliability are ensured by adopting multiple case study approach rather than relying on a single case study. Accordingly, three construction projects in UAE (Dubai) that represent both conventional and innovative construction methods are selected for the case studies. Construction project is considered as the 'unit of analysis'. These case studies are exploratory, as the findings of cases are subject to interpretations Creswell and Creswell (2017).

3.2 Case studies

According to Seawright and Gerring (2008), cases can be selected depending on the requirement of the research and the way that population is represented. In this study, three case studies were selected to analyse and compare the findings of CE initiatives in CDW management in the pre-construction stage. UAE Circular Economy Policy 2021-2023 CDW management strategies, prefabricated building elements, off-site construction, and 3DPC as beneficial approaches of CE implementation in the UAE construction industry. These cases have been meticulously chosen because they serve as prime examples that demonstrate successful measures associated with CE aspects. The cases were selected to showcase the best-case scenarios in the UAE to identify all initiatives towards CE in the local context. Hence, the cases are influential rather typical, where typical cases would represent population in general and influential cases are the best or above average.. The following Table I summarises the details of three cases.

Table I: Details of case studies

3.3 Data collection

Semi-structured interviews were carried out following the standard procedure suggested by Creswell (2013) to collect data. Construction professionals such as project directors, project managers, site managers, consultant engineers, environmental engineers, quantity surveyors and health, safety, and environment (HSE) managers who had been working on the case study projects in relation to CDW management and knowledgeable in the concepts such as CE and CDW innovations were selected as the interviewees. All the interviewees have had not less than five years' experience in the construction industry. An interview guideline aimed to explore waste generation, project waste management strategies and the technologies used. Particularly, the attention was given on the best practices (i.e., innovative) CDW management practices which are well-planned and designed in the pre-construction stage of a construction project. The data collection mainly focused on the five key aspects of CE, such as policies and strategic frameworks, waste prevention design, disassembly or deconstruction, use of prefabricated elements, and CDW management plans (see Annexure 1 for the interview questions).The following Table II presents the demographic information of the interviewees.

Table II: Demographic information of interviewees

3.4 Data analysis

All the interviews, approximately half an hour, were conducted in English and audio-recorded with the permission of the interviewees. Transcripts were imported to the NVIVO 12 software. Thematic analysis technique–understanding the meaning of data and systematically analysing data–was adopted to analyse data (Joffe, 2012). The standard procedure based on the thematic analysis technique suggested by Creswell and Creswell (2017) was used in this study. First, data was organised and prepared for analysis. The next three steps, reading qualitative data, generating main and sub-themes, and coding data, have been done accordingly. Main themes are generated based on the questions in the interview guideline. For example, waste generation, CDW management strategies and CDW technologies have been selected as main themes. Likewise, sub-themes were created under the main themes, and the related content was coded under each theme/sub-theme.

Cross-case analysis: After analysing the data attained from each case, a cross-case analysis was conducted to compare the findings (Yin, 2018). Accordingly, similarities and differences among the three cases in relation to waste generation, storage, management, and technologies used were compared and discussed.

4.0 Findings

This section presents the findings of each case in terms of five CE principles in CDW management in the preconstruction stage. As summarised in Table III, all three projects have generated household waste, wood waste, solid waste like concrete debris and hard mortar and chemical waste in different stages of the project life cycle.

When the waste generation of case one is considered, CS1-8 mentioned that most waste generation is steel bars, concrete, and sand. According to the senior project manager—Interviewee CS1-1, the total non-value waste quantity is 93,330m^3. According to the project manager–CS2-2, "*general garbage on the original yard, soil, wooden waste (plywood and white wood), concrete debris, plastic package and household waste*" are the types of waste generated in case two. According to CS2-2, garbage skips have been used to store waste, and skid steer loader and/or telehandler are used to shift waste to the waste collection point in case two. The total waste generated in case three was 81,000 m^3, including the most common types.

Table III: Waste generation, storage, and management of three projects

4.1 Policies and Strategic frameworks

All three cases demonstrated adherence to the waste management regulations by the local authorities. Local authority mandates given for waste segregation, waste transportation, and disposal were followed in all three cases. Waste disposal charges and penalties imposed for improper waste handling were major motivations for adherence to waste management regulations.

The case one project is classified under the 'Green Building' category, where the contractor must reduce and recycle construction waste. Most of the construction waste is recycled by approved companies. In addition, construction materials are recycled to reduce waste generation.

CS1-4–the HSE manager explained the waste management practices of the project as follows:

> "*Our project has developed a waste management plan and has been approved by engineers for strict implementation. Waste is segregated at the designated area at the site and dispatched to DM-approved and designated disposal areas. Waste transported must be licensed from DM and must have a proper tracking document which authorities will closely monitor*" *CS1-4*

When the waste storage is concerned, a collection pool was allocated for concrete (solid) waste, and there have been baskets and steel cages assigned for paper and plastic waste in cases one and three. The senior project manager of case one–CS1-1 explained their waste storage mechanisms as follows:

> "*Site staff is obliged to sort waste at the workplace and waste collection point. We have spent a lot of time improving the awareness and training staff. Also, we have a permanent special team to monitor waste management on-site and record it weekly. Most importantly, we are following LEED standard in this regard*" CS1-1

4.2 Design for waste prevention

Design for waste prevention during the building design stage highly contributes to waste minimisation during the construction stage. Case one and case three used BIM technology in the construction design, which is known to enhance construction efficiencies and reduce material wastage during construction. Case two utilised 3DPC technology which used recycled construction materials as raw materials. CS2-3 (project manager) mentioned that building elements were printed using "*concrete waste and waste of other construction materials in China*". Thus, all three cases demonstrated satisfactory efforts in waste minimisation approaches during the design stage.

4.3 Use of prefabricated elements and application of innovative construction technologies

In case two, 3DPC technology was utilised, one of the innovative technologies in waste reduction at the site. In addition, CS2-3 further pointed out as "*more prefabricated items have been used in this project; therefore, less waste has been generated compared to the conventional construction method*". Most of the waste generated in case two was soil. Similarly, CS2-1 pointed out the reason for less waste generation in case two: "*the structural elements were fabricated in China and delivered to Dubai by shipment*".

Waste generation in case three is also low (approx. 85 m^3 per day) compared to projects with similar scales because toilets are constructed using the DfMA approach. The project manager–CS3-1 viewed the efficiency of waste management as "*standard fabrication procedures make the full use of materials. Therefore, the material waste is much less than on-site construction*". Similarly, the Design and Technical manager–CS3-3 emphasised that waste can be reduced by up to 90% of the total waste. The site manager of case three–CS3-3 explained waste reduction due to the off-site manufacturing of construction materials as follows:

> "*The pods are manufactured off-site, which means reducing the waste material includes packaging, adhesives and sealants, unused tiles and decorative trims, unused grouting materials and unused off-cuts such as plumbing and electrical materials*" CS3-3

CS3-3 further explained the adoption of this approach for the reuse of materials as "*the installation of the pods is standardized. Therefore, the assembling process, the materials and tools used in the installation can be used repeatedly*".

4.4 Designing for disassembly or deconstruction

Proper planning is required for disassembly or deconstruction to minimise waste generation in case of future renovations or demolition activities. However, the delegates of all three cases did not demonstrate awareness of disassembly or deconstruction planning with respect to their projects. Having prefabricated elements in case two and case three will provide an opportunity to plan disassembly or deconstruction with minimum waste.

4.5 CDW management planning

CDW management planning is evident in all three cases. Findings reveal that all three projects have been concerned with adopting the 3R concept by several means. For example, in case one, the use of plaster mortar waste for block wall installation and temporary road construction from waste is impressive. Case one assigned a specialised team consisting of safety officers, a foreman, and an expert consultant in CDW management planning. Having a consultant enable the project team to implement sustainable waste management solution. Thus, the waste generation of case one is less compared to other projects on a similar scale.

Similarly, the construction manager of case three–CS3-2, described the waste storage techniques as "*we have assigned different waste collection points at the site such as pool (for solid waste) and cages (for plastic and paper waste)*". As CS3-3–site manager of case three) mentioned, the environment team proposed a guideline for sorting and storing waste. This guideline aligns with the DM waste management guideline as well. According to CS3-3, "*wood, steel and contaminated solid waste are very common and easy to get sorted and recycled at the initial stage of the construction. The simpler the design, the lesser the construction waste and the harder to recycle. The latter stage of construction generates more solid waste, most of which is from abortive works".*

Overall, in all the cases, measures have been taken to sort and store waste, such as assigning a foreman and using technology in compliance with a guideline (e.g., in case three-DM waste management guidelines). Waste removal of each project was subcontracted to a professional waste management company.

Despite having developed a waste management plan, all three cases have faced challenges implementing the CDW management plan. In case one, CS1-8 explained how their waste management procedures changed throughout the project duration as follows:

> "*We did not properly manage the waste at the beginning of the project. Compulsory separation of the waste generated at the site has not been enforced, which has put a great burden on logistics management. But later, we stressed more waste separation, primarily separating them into their categories, namely recyclable wastes like steel bars and iron products, wastes with no scrap value*" *CS1-8*

The HSE manager of case two–CS2-3 emphasised that "*the current waste management procedure is not sufficient because it lacks integration, coordination and control*". On a positive note, the management of each three cases was aware of the significance of implementing waste management procedures. For example, CS1-4 explained that: *"controlling the construction waste will increase the contractor's profit by reducing the waste during the construction period. In addition, many of the waste materials are reusable, where contractor earns a certain amount of money by selling them. Ultimately, if the construction environment is not polluted due to construction activities, the developer is benefited by selling the property soon after the construction*" CS1-4

It should be noted that selected case studies are some of the best-case scenarios of UAE (i.e., influential cases) and demonstrated satisfactory measures in the transition towards CE.

5.0 Discussion

CE is an evolving concept in the current scientific landscape, yet barely discussed in CDW management. In relation, the five key areas of CE in the pre-construction stage are policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans, which have been observed in the case studies. Even though some elements of these key aspects were observed in the cases, a broader vision towards CE was rarely recognised.

In the pre-construction stage, all three projects have considered CDW management plans inclusive of methodologies for storing waste at the site and disposal through approved waste management service providers to avoid any penalties incurred by the government. Considerations have been given to waste minimisation, knowing the country's regulation of needing to pay for waste discharged into landfills.

In relation to the first key CE aspect—**policies and strategic frameworks**- cases one and three denote a positive movement towards implementing the 3R concept in a mega construction project. The findings highlight the importance of establishing higher management-level commitment in defining the waste management strategy of a project. Although the UAE Government established CE policies for the country in 2021, such initiatives are rarely implemented at the project level. The project shows the importance of setting internal waste management policies, site preparation with waste sorting and storage facilities, and assigning responsible staff to adhere to the 3R principle. In case one, these CDW management strategies ensured diverting of 85% of waste from landfills compared to a traditional construction project. Thus, case one sets an example of moving towards CE by identifying the hidden value of the waste and converting waste into a valuable resource. Furthermore, case one indicated some policies and strategic frameworks of CDW management yet did not necessarily make the concept of CE the ultimatum.

Application of BIM in cases one and three shall be considered as a facilitator of CDW minimisation. The amount of information obtainable through the BIM model will enhance the circularity not only in the pre-construction stage but also throughout the life cycle (Núñez-Cacho *et al.,* 2018; *Ruiz et al.,* 2020). Although BIM is a favourable tool in for CDW reduction, it is not a mandate in the GCC region. Hence, there are many challenges in adopting BIM such as lack of technical knowledge, lack of awareness and other organisational factors (Umar, 2022). In the same way, the other key CE aspects, such as **design for waste prevention, use of prefabricated elements and CDW management plans,** were evident. For instance, design for waste prevention and use of prefabricated elements were achieved using 3DPC structures in case two, and the adoption of the DfMA approach in cases two and three, respectively. Case two demonstrates an excellent example of applying innovative construction technology to achieving CE as the waste generated during the construction was only 300 m^3 for the entire project. This shows around a 60% reduction compared to conventional construction methods of a similar project. Moreover, most of the generated waste consisted of MEP waste, EIFS waste, gypsum, and packaging materials, where the amount of waste and dust generated during the wet construction process was significantly less. This outcome denotes a potential transition towards CE by adopting 3DPC structures in the construction sector.

Moreover, both case two and case three denote applications of the DfMA approach. All the structural elements were prefabricated at a specialised factory environment in China and delivered to Dubai, as case two is concerned. In case three, prefabricated toilets have been used. According to the findings, the DfMA approach significantly enhances the productivity, quality and efficiency of the construction project while minimising the CDW. Compared to traditional construction methods, the use of the DfMA approach in cases two and three contributed approximately 60% and 90% of waste reduction, respectively. Moreover, having standardised sizes allowed the reuse of the assembling tools of prefabricated elements.

On a positive note, even though the application of 3D printing in construction is still at a primary level, significant structural components have already been constructed using this technology. Nevertheless, there are challenges to be addressed with 3DPC technology, such as the development of 3D printers/robots for large-scale projects, improvement in the composition and quality of materials for concrete mixture and integration of reinforcement techniques for 3DPC technology (Siddika *et al*., 2020).

On a futuristic approach regarding 3DPC, Dubai is planning to construct 25% of its buildings through 3DPC by 2030, and the 3D printing market is estimated to reach USD 2 billion by 2025 (Government of Dubai Media Office, 2021). The movement towards 3DPC contributes to faster construction and reduction in material cost through waste minimisation. In addition, the concrete mixture of the 3DPC consisted of concrete waste and other waste generated from construction works. As shown in the previous studies, materials with low embodied energy, such as waste materials and by-products, can be utilised for the 3DPC mixture to add value (Hager *et al*., 2016; Siddika *et al*., 2020). In addition, using recycled materials in construction and 3DPC greatly contribute to achieving CE targets (Hager *et al*., 2016; Superti *et al*., 2021).

As stated by Gernal *et al*. (2020) and Mawed *et al*. (2020), there is a notable usage of recycled materials for construction projects in the UAE. The findings of case two also complement this view by notifying less waste generation. Thus, 3DPC ensures materials are kept in the product life cycle contributing to CE principles.

It is recommended to adopt DfMA in construction as it also works as a collaborative team working approach, which encourages the involvement of engineers and manufacturers in the early design stage; thus, it contributes to optimising the design while reducing waste generation. This approach is considered one of the radical construction innovations as it significantly changes traditional construction methods and delivers substantial outcomes. For instance, prior studies have shown that off-site manufacturing of structural elements substantially enhances the quality while reducing waste generation (Jaillon *et al*., 2009). This view is complemented by the findings of this study as well. The findings also confirm that the DfMA approach highly contributes to CE policies. Nevertheless, high initial cost, inflexibility, and ability to build complex components are some of the key challenges to be addressed in moving towards the DfMA approach (Jaillon *et al*., 2009; Tam and Hao, 2014).

The lack of evidence on design for disassembly or deconstruction in case study findings denotes the possibility of UAE's limited practice in this area. It should be noted that prefabricated elements are closely linked with disassembly or deconstruction planning in a CE (Ruiz *et al*., 2020). Thus, both cases two and three provide a good opportunity which shall have been addressed in the pre-construction stage. Even though the case study findings cannot be generalised, it cannot be disregarded that three influential projects have been selected as the cases of the study. Hence, it is recommended to have a vision of CE considering the aspect—design for disassembly or deconstruction.

Although the three cases are unique and in different scales, based on comparing the volume of waste generation per unit area of the project, case one demonstrated the minimum waste generation of 0.18 m^3/m^2. In contrast, cases two and three generated 1.2 m^3/m^2 and 0.49 $m^3/m^{2,}$ respectively. In addition, case one prevented 85% of waste from landfills. These findings denoted that the CDW management approach utilised in case one (i.e., implementation of the 3R concept, implementation of LEED standards and having a proper framework of CDW management) is more effective in achieving CE targets. Hence, soft approaches in CDW management shall not be underestimated.

6.0 Conclusions

Recent interests in CE encourage the diversion of CDW from landfills to overcome the adverse impact of the conventional linear economy of take-make-dispose. Following this perspective, this study aimed at exploring UAE's transition towards CE through CDW management practices. Circularity in CDW management requires a life cycle assessment covering pre-construction, construction, renovation, and demolition stages. However, to narrow the study scope, this study was conducted intending to explore the CE concept in the pre-construction stage. Decisions made during the pre-construction stage significantly impact CDW management throughout the lifecycle. CE transition has been explored through five key aspects in the pre-construction stage: policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans. Multiple case study approach has been adopted as the methodology in which three influential projects in Dubai in terms of adopting innovative CDW management strategies were selected as the cases. The first case is a mega construction project involving constructing a host village for a large international exhibition. The second case is a construction of an office complex using 3DPC. The third case is construction of a high-rise residential complex that used prefabricated elements.

As per the findings, CDW management strategies have been evident in all three projects. In line with the concept of polluter pay principal, all three cases have shown adequate responsibility in storing the waste generated at the site and disposal of waste to the designated areas through government-approved waste management service providers. Achieving CE through addressing key aspects such as policies and strategic frameworks, waste prevention design, prefabricated elements, and CDW management plans were evident. However, the design for the disassembly or deconstruction aspect found lacking in the context of the Dubai construction industry. As the evidence for policies and strategic frameworks and CDW management plans, different waste management guidelines (e.g., The UAE circular economy policy 2021-2023, frameworks developed by the local authorities, Lean standards, green building standards) have been developed and adopted in all three projects. The application of BIM was evident in cases one and three, and findings indicate that BIM facilitates CDW minimization by enhancing construction efficiencies and reducing material wastage during construction. In addition, BIM enables future disassembly of buildings and assists estimation of the circularity degree of building materials. In relation to the design for waste prevention and use of prefabricated elements, the implementation of innovations such as 3D-printed concrete (3DPC) and prefabrication/DfMA has been recognised, and these have contributed to waste reduction compared to conventional on-site construction approaches. In addition, waste recycling and reuse were evident in all three cases.

Among the three selected cases, case one demonstrated the lowest waste generation of 0.18 $(m^3)/(m^2)$ and achieved 85 % of waste diversion from landfills compared to a project on a similar scale. Therefore, initiatives such as implementing 3R measures, LEED standards and having a proper framework of CDW management were identified to be most effective in achieving CE targets. Furthermore, having innovative construction technologies such as 3DPC and DfMA facilitates waste reduction compared to a conventional on-site construction approach.

As the drawbacks of the existing practice, despite the availability of the UAE circular economy policy 2021-2023, lack of application of CE principles, limitations in law enforcement and high usage of traditional and non-innovative waste management practices have been found in addition to the absence of design for disassembly or deconstruction.

As limitations of this study, qualitative findings cannot be used to generalise the transition of UAE towards CE. Also, the selected cases were rather influential than typical; case studies represent the best-case scenario of UAE. While remarking on the need for future research to further explore this area, it is concluded that the status of UAE towards CE is still in the initial stage and yet to be upgraded. Even though the influential cases exhibited limitations of CDW practices, the role of BIM in CDW management shall be studied to quantify the benefits accurately.

As recommendations, it is suggested to implement CDW management with a broader vision of achieving CE and set targets in relation to the five key aspects—policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans. Along with the policies such as UAE circular economy policy 2021-2023, the authorities should encourage construction practitioners on sustainability commitments in CDW management (e.g., CDW management planning, implementation of BIM, adopting innovative construction technologies) and waste diversion targets (e.g., recycling, composting, and initiatives in waste to energy) to accelerate the transition towards CE. In addition, further studies are recommended on studying the life cycle analysis of CDW, including the end-of-life stage to provide a holistic overview of the CE transition.

Abbreviations list

3DPC - 3D-printed concrete
BIM - Building information modelling
CDW - Construction and demolition waste
CE - Circular economy
DfMA - Design for manufacture and assembly
DM - Dubai municipality
HSE - Health, safety and environment
LEED - Leadership in energy and environmental design

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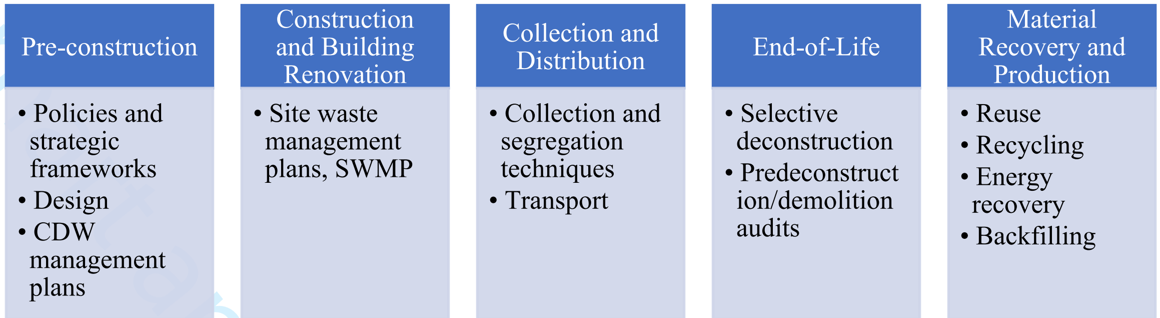

Figure I: Stages in the analysis of CDW in CE Model

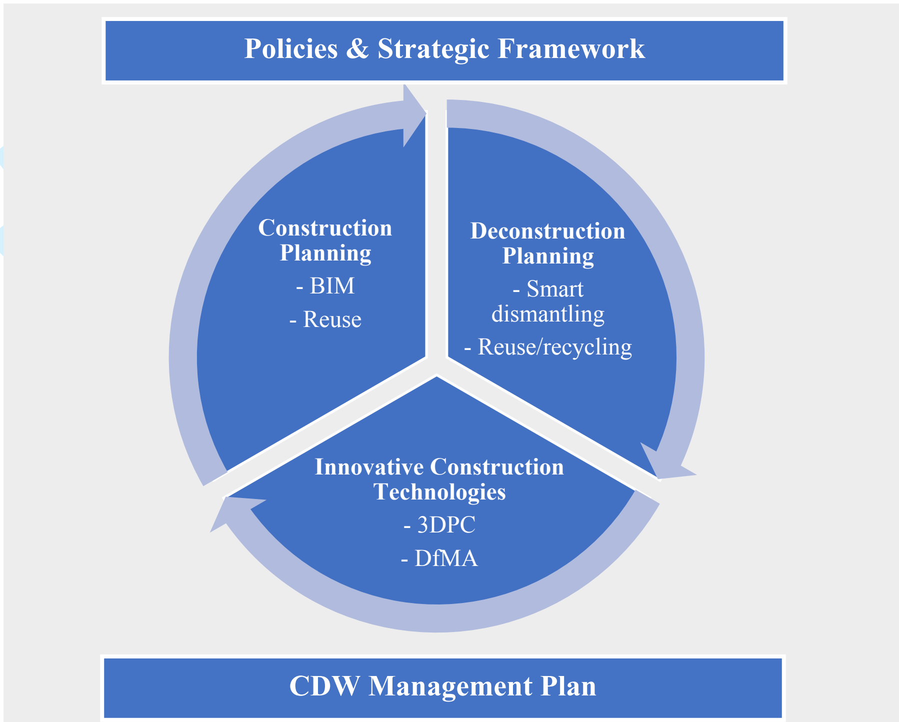

Figure II: CE principles in CDW management in the pre-construction stage

Table I: Details of case studies.

	Case 1	Case 2	Case 3
Project details	- A host village for a mega exhibition. - Consists of 15 residential towers, range between 10 and 16 floors. - Will accommodate approximately 3500 participants in 2100 apartments	- An office complex with meeting space for up to 16 people. - The full complex is developed with 3DPC structures	- A high-rise residential complex with 3 towers, 64, 59 and 52 floors - Utilised prefabricated elements
Project duration	32 months	6 months	36 months
Gross Floor Area (GFA) (m^2)	500,000 m^2	250 m^2	182,572 m^2
Total Project Value	USD 282 million	USD 2.5 million	USD 368 million
Application of Building Information Modelling (BIM)	Designed within BIM framework to achieve LEED Gold certification	N/A	Designed with BIM

Table II: Demographic information of interviewees.

Case	Interviewee	Position	Organisational level
Case 1	CS1-1	Senior project manager	Middle management
	CS1-2	QA/QC manager	Middle management
	CS1-3	Construction manager	Middle management
	CS1-4	HSE manager	Middle management
	CS1-5	Environmental engineer	Middle management
	CS1-6	Tendering manager	Middle management
	CS1-7	Purchaser	Technical level
	CS1-8	Trainee	Technical level
Case 2	CS2-1	Project director	Middle management
	CS2-2	Project manager	Middle management
	CS2-3	Project manager	Middle management
	CS2-4	HSE manager	Middle management
	CS2-5	Quantity Surveyor	Middle management
Case 3	CS3-1	Project manager	Middle management
	CS3-2	Construction manager	Middle management
	CS3-3	Site manager	Middle management
	CS3-4	Design and technical manager	Middle management
	CS3-5	Administrator	Low-level management
	CS3-6	HSE manager	Middle management
	CS3-7	Trainee	Technical level
	CS3-8	Trainee	Technical level

Table III: Waste generation, storage and management of three projects.

Case / Dimension	Sub dimensions	Case 1	Case 2	Case 3
Waste generation	Total waste generation (m^3)	93,330 m^3	300 m^3	91,000 m^3
	Approximate Waste Generation (m^3) / Day	104 m^3	1.7 m^3	85 m^3
	Approximate Waste Generation (m^3) / (m^2)	0.18 (m^3) / (m^2)	1.20 (m^3) / (m^2)	0.49 (m^3) / (m^2)
	Categories	Category 1: household waste Category 2: steel, paper and plastic waste (valuable waste) Category 3: wood waste Category 4: solid waste like concrete, hard mortar, dust and gypsum product waste Category 5: poisonous and harmful waste like chemical waste Category 6: Paint drum		
Waste storage	Waste storage at the site (as garbage)	Wastebasket and steel cage for storing paper waste Concrete waste collection pool for concrete solid waste Chemical waste (Hazardous waste such as fuel, oil, lubricants, cleaning fluids,	Special garbage skips	Special garbage skips Baskets and steel cages for paper and plastic waste A pool for solid waste

Case / Dimension	Sub dimensions	Case 1	Case 2	Case 3
		and solvents)		
	Mechanisms for waste storage and sorting	Classified storage facilities and having assigned a person to manage Separation of chemical and toxic waste Compliance with DM waste management guidelines	Use of skid steer loader and telehandler to shift waste to the assigned location. Separation of chemical and toxic waste Compliance with DM waste management guidelines	Compliance with DM waste management guidelines Compliance with Green Building standards and government requirements
Waste management	The parties involved in the process of waste management	A person (foreman/staff) is assigned for the garbage removal (case 1, 2 & 3) The safety officer for supervision A weekly report should be submitted by the consultant party with the support of environmental engineers to the DM Environmental department (case 1) Overall, the DM monitors the CDW management strategies (case 1, 2 & 3)		

Case / Dimension	Sub dimensions	Case 1	Case 2	Case 3
	Waste collection and disposal	By the government-approved professional waste management service providers		
	Total expense for waste management (approx.)	USD 540,000	USD 4,080	USD 392,040
	Monthly expense for waste management (average)	USD 16,875	USD 680	USD 10,890
	Expenditure on waste management (as a percentage of the project cost)	0.19 %	0.16 %	0.11 %
Other	Awards received	LEED Gold certification Internal safety award merit-2019, British Safety council Internal safety award merit-2020, British Safety council	Guinness world record: The first 3D printed commercial building	An application has been submitted for an award in the environmental category

Interview guideline

Research Topic: Exploring UAE's Transition Towards Circular Economy Through Construction and Demolition Waste Management in the Pre-construction Stage - A Case Study Approach.

Case Study	*Case 1*	*Case 2*	*Case 3*

General

SN	*Question*	*Response*
1	Interviewer Name	
2	Interviewee Name	
3	Position Title	
4	Position Department	
5	Total years of experience	
6	Duration served at the project	
7	Interview Date	
8	Interview start time	
9	Interview end time	

Project Information

SN	*Question*	*Response*
10	Please provide a brief overview of this project.	
11	What is the duration of the project?	
12	What is the value of the project?	
13	What is the built-up area of the project?	
14	How much waste is generated in total for the project?	
15	How much waste is generated approximately per day?	
16	What are the categories of construction and demolition waste (CDW) generated at this site?	
17	Could you explain the waste storage mechanism at the site?	
18	Could you explain the process and the parties involved during the waste management process?	
19	Please provide details about the waste management budget of the project.	
20	Can you briefly explain your role and responsibilities related to construction and demolition waste management in the pre-construction stage?	
21	How familiar are you with the concept of a circular economy and its application in the construction industry?	
22	What are the current practices and challenges in	

	managing construction and demolition waste during the pre-construction stage?	
23	In your opinion, what are the main barriers or obstacles that hinder the transition towards a circular economy in construction and demolition waste management?	
24	Are there any existing policies, regulations, or guidelines in place to promote the adoption of circular economy principles in construction and demolition waste management during the pre-construction stage?	
25	How does your organization or project currently approach waste management in the pre-construction stage? Are there any specific strategies or initiatives in place to promote circularity?	
26	What are the potential benefits and opportunities associated with adopting circular economy principles in construction and demolition waste management during the pre-construction stage?	

Policies and Strategic frameworks

SN	*Question*	*Response*
27	Can you provide an overview of the existing policies and strategic frameworks related to construction and demolition waste management in the pre-construction stage within your project?	
28	How do these policies and strategic frameworks align with the principles of a circular economy?	
29	How are these policies and strategic frameworks implemented and enforced within your project?	
30	How do these policies and strategic frameworks integrate with other sustainability initiatives or green building certifications?	

Design for waste prevention

SN	*Question*	*Response*
31	Can you provide an overview of the design considerations and strategies currently employed in the pre-construction stage to prevent waste generation within your project?	
32	How does the concept of a circular economy influence the design decisions made in the pre-construction stage to minimize waste generation?	
33	What specific design principles or guidelines are in place	

SN	Question	Response
	to promote waste prevention and circularity in the pre-construction stage of your construction projects?	

Use of prefabricated elements and application of innovative construction technologies

SN	*Question*	*Response*
34	Can you provide an overview of the extent to which prefabricated elements and innovative construction technologies are currently utilized in the pre-construction stage within your project?	
35	How do prefabricated elements contribute to reducing construction and demolition waste generation during the pre-construction stage?	
36	What are the specific benefits and advantages associated with the use of prefabricated elements and innovative construction technologies in terms of waste reduction and resource efficiency?	
37	How do you evaluate the environmental impact and waste reduction potential of different prefabricated elements and construction technologies during the pre-construction stage?	

Designing for disassembly or deconstruction

SN	*Question*	*Response*
38	Can you provide an overview of the considerations and strategies currently employed in the pre-construction stage to facilitate disassembly or deconstruction for effective waste management within your project?	
39	How does the concept of designing for disassembly or deconstruction influence the decision-making process in the pre-construction stage to minimize waste generation?	
40	What specific design principles or guidelines are in place to promote disassembly or deconstruction and circularity in the pre-construction stage of your construction projects?	
41	Are there any tools, software, or methodologies used to assess the disassembly potential and waste reduction benefits of different design options in the pre-construction stage?	

CDW management planning

SN	*Question*	*Response*
42	Can you provide an overview of the CDW management planning process currently in place during the pre-construction stage in your or project?	
43	How does the concept of a circular economy influence the CDW management planning decisions made in the pre-construction stage?	
44	What are the main objectives and goals outlined in the CDW management plan during the pre-construction stage?	
45	What strategies or measures are in place to minimize CDW generation, maximize reuse and recycling, and minimize waste disposal during the pre-construction stage?	
46	Have you encountered any challenges or limitations in implementing the CDW management plan in the pre-construction stage? How have you addressed these challenges?	

Responses to Editor and Reviewers

Dear Editor,

We thank you for considering our work for publication in the journal "Smart and Sustainable Built Environment". We found the reviews forwarded very useful and have significantly contributed to enhancing the quality of our paper. We have revised our paper to address all points raised in the comments by the reviewers. Detailed responses are included in the below table and revised texts are indicated in blue font.

Thank you for your efforts in obtaining meaningful reviews.

Sincerely,
Dr. Kalani Chamika Dahanayake

SN	Comment	Response
Comments from the Editor in Chief		
1	The references are incorrectly formatted, and all references need to follow the journal requirements with no exception. Follow the author guidelines for further details. Most importantly, all references should have at least one of the followings: doi, ISBN (books only), URL (even for journal articles, where there is no doi). When you are referring to URL, you must indicate the last access date. Any reference which has none of these, must be removed from the text and bibliography. ALL references must be sorted in alphabetic order.	Thank you for the comment. We have corrected all the references as per the journal guideline.
2	The whole paper needs some thorough proofreading before final submission	Thank you for the comment. We have proofread the revised paper and made the necessary corrections.
3	When you upload your revisions, please make sure that you submit a clean version (without track-	Please find the attached revisions.

	changes), a track-changes version, and a table clearly indicating all changes been made. Without this, I will need to return your revisions back to you.	
Reviewer: 1 **Recommendation: Major Revision**		
1	The context and the problem of the research specific in relation to UAE is not demonstrated in the introduction. The general discussion around waste is fine but there are several studies which highlight the issues of sustainability and water in construction sector the gulf region, but they are totally ignored. For instance, most of the UN SDGs are directly linked with construction/ built environment sector, but I am surprised that these are totally ignored. Where UAE standing in terms of their progress on SDGs, this is an important discussion and there is a good overview of these goals in two recent papers “UAE’s commitment towards UN Sustainable Development Goals” and “Exploring the GCC progress towards United Nations sustainable development goals”. Likewise, there is a lot of waste coming from construction which simply goes to the landfill in this region. This has been covered in the paper	We thank Reviewer 1 for the valuable comments. We have considered all mentioned points and carefully addressed all aspects, as demonstrated below. The ***1.0 Introduction*** section is revised below highlighting the problem of the research specific in relation to UAE. We have also cited the three articles mentioned by the reviewer. **Changes made:** UAE is one of the world's highest per capita waste generation countries (Mawed *et al.*, 2020). Like the rest of the world, UAE is facing the issue of poor measures towards sustainability, particularly on construction sites (Al-Hajj and Hamani, 2011; Kim *et al.*, 2020). In 2015, the United Nations established seventeen sustainable development goals (SDGs) to be achieved by 2030 by all the members (UN-SDG, 2015). Most of the UN SDGs are directly linked with construction and built environment sector. Umar *et al.*, (2020) highlighted the fact that UAE is lagging in achieving most of the SDGs and the current plan lacks a clear roadmap for achieving the goals. Due to the rapid expansion of infrastructure in the region, the construction industry is currently at its peak. Thus, the construction industry in the UAE should be given priority in the planning process to achieve the SDGs by 2030 (Umar and Umeokafor, 2022). In 2017, the CDW generated in Dubai was over 18 million metrics, which has been estimated to grow by 11% annually (Dubai Municipality, 2017; Kim *et al.*, 2020). Moreover, Umar *et al.*, (2020) pointed out that only 25 % of the municipal solid waste generated in Dubai is recycled, and a significant portion of waste is being disposed in landfills continuing to greenhouse gas (GHG) emissions and other environmental issue. In 2019, over 3.5 million metric tons of CDW were generated in Abu Dhabi, the largest emirate in UAE, in which only 20% of the waste was recycled (SCAD, 2020). In fact, around 75 % of the solid waste generated in the UAE are from the construction industry. Initiatives in recycling and reusing materials will contribute to achieving environmental benefits while simultaneously reducing the overall construction costs (Umar *et al.*, 2020; Umar and Umeokafor, 2022). In 2021, the UAE government initiated Circular Economy Policy promoting sustainable governance, in which the construction sector is given

	"Frameworks for reducing greenhouse gas (GHG) emissions from municipal solid waste in Oman". Hope these papers will help you to develop a better context of your research.	key concern. The UAE government is committed to achieving SDGs by shifting from degenerative linear economy to regenerative CE (UAE Government, 2021a). The construction sector in UAE is identified as a key sector in CE implementation as 10-15% of building materials are wasted during construction (Al-Hajj and Hamani, 2011: Ellen MacArthur Foundation, 2013), and most of waste is landfilled without extracting any value (Umar et al., 2020). The UAE Government identified developing programmes to support reuse and recycling of building materials and promoting better construction design mechanisms as key initiatives in reducing CDW (UAE Government, 2021a; UAE Government, 2021b). However, the CE concept in the construction sector is barely discussed in the UAE context (e.g., Norouzi *et al*., 2021). CE being a new paradigm, the transition towards CE in terms of CDW management shall be discussed thoroughly addressing the full life cycle of CDW, focusing on pre-construction, construction, renovation, and demolition stages. Hence, to address this research gap the current study intends to explore the best practices implemented in the local context in achieving CE in terms of CDW management, that would be applied throughout the industry. However, to provide a holistic view and simultaneously narrow the scope, this study only focuses on the pre-construction stage, as the decisions made in the pre-construction stage critically affect CDW management throughout the life cycle (Yeheyis *et al*., 2013). The study is based on three best-case scenarios in UAE (i.e., influential cases), which demonstrated adequate measures in relation CE aspects. As the research methodology, the multiple case study approach is adopted with three construction projects in UAE that represent both conventional and innovative construction methods. The findings of case studies are compared with prior research findings to deliver comparisons on CDW management and UAE's transition towards CE. Finally, conclusions and recommendations towards CE through CDW are provided. **References Added:** Umar, T. (2020). Frameworks for reducing greenhouse gas (GHG) emissions from municipal solid waste in Oman. *Management of Environmental Quality*, Vol. 31 No. 04, pp. 945-960. https://doi.org/10.1108/MEQ-11-2019-0231. Umar, T. and Umeokafor, N. (2022). "Exploring the GCC progress towards United Nations sustainable development goals". *International Journal of Social Ecology and Sustainable Development*, Vol. 13 No. 1, pp. 1-32. https://doi.org/10.4018/IJSESD.2022010105. Umar, T., Egbu, C., Ofori, G., Honnurvali, M. S., Saidani, M., Shibani, A., Opoku, A., Gupta, N., and Goh, K. (2020), "UAE's commitment towards UN Sustainable Development Goals", in Tom,

		D (Ed.), *Proceedings of the Institution of Civil Engineers-Engineering Sustainability,* Vol. 173 No. 7, pp. 325-343. https://doi.org/10.1680/jmapl.18.0000. UN-SDG (United Nations Sustainable Development Goals), 2015. About the Sustainable Development Goals. United Nations, New York, United States. See: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed 23/04/2019).
2	There is good coverage of the literature in section two of the paper, but some content is quite general, have limited contribution of the problem which are aiming to address. It would be good to revisit this, as you do not want to disengage with your readers.	We have revised the literature section by removing the general content under the sub-titles of "*2.1 Construction and Demolition waste management*" and "*2.2 Construction and demolition waste management in UAE*". Moreover, a section is added under the title of "*2.2 Circular Economy Implementation in UAE*" highlighting the problem statement of the study. **Changes made:** *2.3 Circular Economy Implementation in UAE* The UAE Government has initiated several sustainable measures to manage CDW effectively. CDW recycling facilities have been implemented in every emirate, receiving daily a minimum of 4 tons of mixed CDW (Gernal *et al.*, 2020). In January 2021, the UAE government initiated the UAE Circular Economy Policy 2021-2031, where the construction sector was given key importance. The policy highlighted that the actual value of 10–15% of the building materials had not been utilised fully in the construction stage. Several initiatives including adoption of prefabricated building elements, off-site construction and 3DPC are suggested as key initiatives in achieving CE targets (UAE Government, 2021a&b). Enhancing material efficiency in the construction sector is a key UAE priority, as most of the resources need to be imported to the country. To meet the country's net-zero targets, a landfill tax scheme was introduced, encouraging the diversion of waste to resources. Dubai Municipality (DM) aims to achieve zero landfills in 20 years to protect the environment from harmful gases emitted and minimise the adverse environmental impact of the landfills (UAE Government, 2021a).

		In the UAE context, the discussion of CE in the construction sector is scarce. As CE is still a relatively new concept, it is crucial to conduct a comprehensive study of the transition towards CE, encompassing the entire life cycle of CDW, giving special attention to the pre-construction, construction, renovation, and demolition stages. Nevertheless, to offer a comprehensive yet focused perspective, this study concentrates solely on the pre-construction stage. This stage is of utmost importance as the decisions made during pre-construction significantly impact the management of CDW throughout the entire life cycle. It is expected to explore the CE implementation during the construction stage as a future study. The study examines three influential cases in the UAE. These cases have been carefully selected as they represent best-case scenarios that exemplify effective measures related to CE aspects. The cases representing CDW management strategies, prefabricated building elements, off-site construction, and 3DPC are given priority, as those measures are identified as successful approaches in the process of CE implementation in UAE, the UAE Circular Economy Policy 2021-2031. By analysing these cases, the study aims to highlight successful strategies, practices, and approaches employed in the UAE context that align with the principles of the CE. These cases serve as valuable examples and provide insights into how CE principles can be implemented in the construction sector, specifically in relation to the management of Construction and Demolition Waste (CDW).
3	I am not sure why you have focused just on the pre-construction state. You are trying to base this with the previous studies, but the context of those studies might be different. You need to look into this in the context of UAE. The problem is in pre-construction or in the construction stage. Based on my own experience, the problem is the construction stage, where contractors want to rush to finish and catch the next project.	We agree with the Reviewer that researching on the construction stage is important. However, CE concept is barely discussed in the UAE context, hence this study focuses on the pre-construction stage to offer a comprehensive yet focused perspective. We will be studying the construction stage as a future study. We have revised the literature section "*2.3 Circular Economy Implementation in UAE*" reasoning why this particular study is just focused on the pre-construction stage. **Changes made:** In the UAE context, the discussion of CE in the construction sector is scarce. As CE is still a relatively new concept, it is crucial to conduct a comprehensive study of the transition towards CE, encompassing the entire life cycle of CDW, giving special attention to the pre-construction, construction, renovation, and demolition stages. Nevertheless, to offer a comprehensive yet focused

		perspective, this study concentrates solely on the pre-construction stage. This stage is of utmost importance as the decisions made during pre-construction significantly impact the management of CDW throughout the entire life cycle. It is expected to explore the CE implementation during the construction stage as a future study. The study examines three influential cases in the UAE. These cases have been carefully selected as they represent best-case scenarios that exemplify effective measures related to CE aspects. The cases representing CDW management strategies, prefabricated building elements, off-site construction, and 3DPC are given priority, as those measures are identified as successful approaches in the process of CE implementation in UAE, the UAE Circular Economy Policy 2021-2031. By analysing these cases, the study aims to highlight successful strategies, practices, and approaches employed in the UAE context that align with the principles of the CE. These cases serve as valuable examples and provide insights into how CE principles can be implemented in the construction sector, specifically in relation to the management of Construction and Demolition Waste (CDW).
4	There appears to be no rationale on selecting the case studies. There has to be a logical/ scientific approach to select these studies. For instance, based on the project cost, duration etc. You can select different case studies which has different dimensions; however, two out of the three case studies are more or less same, based on the project duration.	Thank you for the comment. **Changes made:** The first para of sub-heading “3.2 Case studies was revised to explain the basis of case study selection as follows. According to Seawright and Gerring (2008), cases can be selected depending on the requirement of the research and the way that population is represented. In this study, three case studies were selected to analyse and compare the findings of CE initiatives in CDW management in the pre-construction stage. The UAE Circular Economy Policy 2021-2023, CDW management strategies, prefabricated building elements, off-site construction, and 3DPC as beneficial approaches of CE implementation in the UAE construction industry have been primarily explored. These cases have been meticulously chosen because they serve as prime examples that demonstrate successful measures associated with CE aspects. The cases were selected to showcase the best-case scenarios in the UAE to identify all initiatives towards CE in the local context. Hence, the cases are influential rather typical, where typical cases would represent population in general and influential cases are the best or above average.
5	What is the main contribution of these case study, expect you selected the interviewees from these projects. There appears to be no	Thank you for the comment and suggestion.

	scientific rationale on the selection of interviewees, which is significantly important in such types of studies. These parameters are normally based on the experience, qualifications and the knowledge of the interviewees on the specific matter under investigation. This paper provides a good overview of the semi-structured interview process with philosophical background "Perceptions on safety climate: a case study in the Omani construction industry".	Sub-heading "*3.3 Data collection*", first para, was revised to indicate how the interviewees were selected based on their experience in CDW management and knowledge in the concepts such as Circular Economy and CDW innovations. The data collection mainly focused on the five key aspects of CE, such as policies and strategic frameworks, waste prevention design, disassembly or deconstruction, use of prefabricated elements, and CDW management plans, as follows. **Changes made:** Semi-structured interviews were carried out following the standard procedure suggested by Creswell (2013) to collect data. Construction professionals such as project directors, project managers, site managers, consultant engineers, environmental engineers, quantity surveyors and health, safety, and environment (HSE) managers who had been working on the case study projects in relation to CDW management and knowledgeable in the concepts such as CE and CDW innovations were selected as the interviewees. All the interviewees have had not less than five years' experience in the construction industry. An interview guideline aimed to explore waste generation, project waste management strategies and the technologies used. Particularly, the attention was given on the best practices (i.e., innovative) CDW management practices which are well-planned and designed in the pre-construction stage of a construction project. The data collection mainly focused on the five key aspects of CE, such as policies and strategic frameworks, waste prevention design, disassembly or deconstruction, use of prefabricated elements, and CDW management plans (see annexure 1 for the interview questions).
6	Where are interview questions – need to be attached in the appendix	Please see Annexure 1 for the interview questions
7	I can see the argument that all the selected case studies demonstrate the adherence to the waste management regulations by the local authorities, but what is the ground reality, where is the problem them. think about the other projects, smally, medium and large project, where influential people are part of those projects or the projects which are in remote areas – what is the	The current study intends to explore the best practices implemented in the local context in achieving CE in terms of CDW management, that would be applied throughout the industry. These cases have been carefully selected as they represent best-case scenarios that exemplify effective measures related to CE aspects. The cases representing CDW management strategies, prefabricated building elements, off-site construction, and 3DPC are given priority, as those measures are identified as successful approaches in the process of CE implementation in UAE, as per the UAE Circular Economy Policy 2021-2031. By analyzing these cases, the study aims to highlight successful strategies, practices, and approaches employed in the UAE context that align with the principles of the CE, that can be applied industrywide.

	situation there. I think we do not need overstate the results – keep the ground reality in mind.	Yes, we understand that the ground reality would be different from the case study findings. However, as we stated in the response to the comment 4, most influential projects in UAE in terms of CDW management practices towards CE were selected as the cases in this study. Hence, the findings of the study should be applied to similar and relevant contexts. This has been mentioned in 6.0 Conclusion, 5th para (limitations of the study) as follows. "As limitations of this study, qualitative findings cannot be used to generalise the transition of UAE towards CE. Also, the selected cases were rather influential than typical; case studies represent the best-case scenario of UAE. While remarking on the need for future research to further explore this area, it is concluded that the status of UAE towards CE is still in the initial stage and yet to be upgraded. Even though the influential cases exhibited limitations of CDW practices, the role of BIM in CDW management shall be studied to quantify the benefits accurately".
8	I can also agree with the respondents, most of the projects in UAE has those waste management plans but the problem is these are not implemented is a true letter and spirit.	Thank you for the comment.
9	Both discussion and conclusion are unnecessary lengthy, having a lot of general discussion. I do not clearly see the contribution of this research. what this research contributes to the existing knowledge. Do the readers will gain anything new from this study. This is why, you need to be very specific, concise in these sections, avoiding general discussion and or overstating the results.	We have removed "Section 5.1 – Construction and Demolition Waste Management in the Pre-Construction Stage", in order to shorten the section. The remaining sections under Discussion and Conclusions The CE concept in the construction sector is barely discussed in the UAE context. This study intended to explore the UAE's transition towards CE in terms of CDW management based on three best-case scenarios by exploring the best practices implemented in the local context and identifying opportunities for improvement. As the key contribution of this study the CE transition has been explored through five key aspects: the pre-construction stage: policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans. Findings revealed several positive initiatives towards CE in the UAE context; yet it is identified that the transition is still at the initial stage. Selected case studies, the best-case scenarios of UAE (i.e., influential cases), demonstrated adequate measures in relation to four key CE aspects out of five. The Discussion and Conclusion sections elaborate the achievement of the each of the five factors in UAE context along with the improvement opportunities.

10	BIM can be a good tool for waste management/ reduction, but it is not mandatory in the GCC region. There are several challenges in the implementation of BIM in the GCC construction projects. See this paper which covers these challenges is a very detailed manner considering the different problem in the construction in the GCC region "Challenges of BIM implementation in GCC construction industry".	We have revised the 4th para of the Discussion section as below, highlighting the fact there are challenges in the BIM implementation. **Changes made:** Application of BIM in cases one and three shall be considered as a facilitator of CDW minimisation. The amount of information obtainable through the BIM model will enhance the circularity not only in the pre-construction stage but also throughout the life cycle (Núñez-Cacho *et al.,* 2018; *Ruiz et al.,* 2020). Although BIM is a favourable tool in for CDW reduction, it is not a mandate in the GCC region. Hence, there are many challenges in adopting BIM such as lack of technical knowledge, lack of awareness and other organisational factors (Umar, 2022). **References Added:** Umar, T. (2022), "Challenges of BIM implementation in GCC construction industry", *Engineering, Construction and Architectural Management*, Vol. 29 No. 3, pp. 1139-1168. https://doi.org/10.1108/ECAM-11-2019-0608

Exploring UAE's Transition Towards Circular Economy Through Construction and Demolition Waste Management in the Pre-construction Stage - A Case Study Approach

Abstract

Purpose – This paper aims to explore UAE's transition towards Circular Economy (CE) through construction and demolition waste (CDW) management in the pre-construction stage. The extent of circularity is assessed by five key aspects of CE, such as policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans.

Design/methodology/approach - Multiple case studies were conducted in the context of the Dubai construction industry (UAE). Three significant and unique construction projects were selected as the cases. Semi-structured interviews were carried out to collect data, and the thematic analysis technique and NVIVO 12 software were used for data analysis.

Findings - Findings reveal several positive initiatives towards CE in the UAE context; yet it is identified that the transition is still at the initial stage. Selected case studies, the best-case scenarios of UAE (i.e., influential cases), demonstrated adequate measures in relation to four key CE aspects out of five. For instance, a) policies and strategic frameworks such as lean standards, green building standards and standards developed by the local authorities), b) design for waste prevention (e.g., adherence to the 3R principle, and construction planning with BIM), c) use of prefabricated elements and application of innovative construction technologies (e.g., 3DPC, DfMA), and d) CDW management planning such as 3R principle were evident. However, the selected cases hardly showcase designing for disassembly or deconstruction.

Originality - The findings of this study provide valuable insights for decision-making processes around CDW management towards a CE. This paper contributes to the literature by bridging the CE concept with CDW management in the pre-construction stage. The study provides insights for industry practitioners ~~to enhance~~for planning ~~for~~ CE in terms of policies and strategic frameworks, CDW management planning, construction planning and application of innovative construction technologies.

Research implications - The existing CDW practices are mostly conventional, as most constructions in UAE are procured through conventional building materials and methods. Therefore, there is a necessity of encouraging CE principles in CDW management. Even though the transition towards CE was evident in four key CE aspects out of five, the UAE construction industry has yet to adopt more effective CE-based CDW management practices to accelerate the circularity. Hence, it is necessary to enforce standard waste management guidelines, including the 3R principle, to standardise CDW management in UAE and encourage construction practitioners to adhere to CE principles.

Keywords: *Circular economy; Construction technology; Construction and demolition waste; Pre-construction; Waste management; 3R*

1.0 Introduction

Being a resource-intensive sector, the construction industry is perceived as the major contributor to waste generation. The massive scale of ongoing construction activities generates a significant amount of construction and demolition waste (CDW). An increased amount of CDW has become a severe environmental issue that necessitates immediate attention (Statistics Centre Abu Dhabi~~Statistics Centre~~, 2019). The practicality of conventional waste management practices such as landfilling has been questioned due to the factors such as the impact on the environment, scarcity of lands, higher costs and time-consuming nature (Elgizawy *et al.*, 2016). Hence, researchers have shifted their attention to implementing various measures that reduce waste generation in the first place (i.e., pre-construction stage) (e.g. Faniran and Caban, 1998; Tam and Hua, 2014; Superti *et al.*, 2021). Yeheyis *et al.* (2013) stated that ~~During the construction stage,~~ proper management of material delivery, storage and waste accounting ~~is~~ are the best practices to minimise material wastage at ~~the~~ site. ~~(Yeheyis *et al.*, 2013). Yeheyis *et al.* (2013)~~ Authors further ~~proposed~~ suggested the adherence with the 3R approach (i.e., reduce, reuse and recycle) in the design, construction, renovation and demolition stage to minimise the CDW. ~~Saez *et al.* (2019) highlighted the applicability of glass waste in construction.~~ Christensen (2021) emphasised the importance of pre-demolition audits in construction projects to explore recycling opportunities. The author further recommended implementing the process innovation of establishing a material bank and recycling network for demolition waste. Moreover, recent studies have shown that innovative construction technologies such as 3D-printed concrete (3DPC) and prefabrication/Design for manufacture and assembly (DfMA) minimise on-site waste generation (Siddika *et al.*, 2020; Poon *et al.*, 2003).

Circular Economy (CE) has been recognised as a measure of effective ~~—~~ CDW management process (~~e.g.,~~ Ruiz *et al.*, 2020). ~~Adopting the CE concept is considered an~~It is considered as a strategy that ~~effective strategy to~~ optimises the use of resources while minimising the generation of CDW. CE principles encourage effective CDW management throughout the project lifecycle–with the support of clients, building designers, contractors, and the government (Faniran and Caban, 1998; Ruiz *et al.*, 2020; Yu *et al.*, 2021). Nevertheless, considering the practical inefficiencies in recycling, Bao *et al.* (2019) emphasized the importance of innovative procurement for a CE. ~~CDW considered a zero-value material, mostly ended up in landfills.~~ In traditional approach, CDW is treated as a zero-value material which is mostly ended up in landfills. Hence, Wu *et al.* (2014) emphasised the importance of end-of-life treatments instead of landfilling for minimising Greenhouse Gas Emissions (GHE). Overall, t~~T~~he CE concept mainly focuses on reduce, reuse, and recycle activities, and to be further explored for the effectiveness for different industries (Padilla-Rivera *et al.*, 2020). In the construction context, Norouzi *et al.* (2021) identified that CDW management and alternative construction materials are emerging topics under the umbrella of CE ~~in the construction sector~~.

UAE is one of the world's highest per capita waste generation countries (Mawed *et al.*, 2020). Like the rest of the world, UAE is facing the issue of poor measures towards sustainability, particularly on construction sites (Al-Hajj and Hamani, 2011; Kim *et al.*, 2020). In 2015, the United Nations established ~~17~~Seventeen sustainable development Goals (SDGs) to be achieved ~~to be achieved~~ by 2030 by all the members (UN-SDG, 2015). Most of the UN SDGs are directly linked with construction and built environment sector. Umar *et al.*, (2020) highlighted the fact that UAE is lagging in achieving most of the SDGs and ~~more importantly~~ the current plan lacks a clear roadmap for achieving the goals. Due to the rapid expansion of infrastructure in the region, the construction industry is currently at its peak. Thus, the construction industry in the UAE should be given priority in the planning process to achieve the SDGs by 2030 (Umar and Umeokafor, 2022). In 2017, the CDW generated in Dubai was over 18 million metrics, ~~WHICH WAS~~which has been ~~-~~estimated to grow by 11% annually (Dubai Municipality, 2017; Kim *et* *al*., 2020). Moreover, Umar *et al*., (2020) pointed out that only 25 % of the municipal solid waste generated in Dubai is recycled, and a significant portion of waste is being disposed in landfills continuing to greenhouse gas (GHG) emissions and other environmental issue. In 2019, over 3.5 million metric tons of CDW were generated in Abu Dhabi, the largest emirate in UAE, in which only 20% of the waste was recycled (SCAD, 2020). In fact, around 75 % of the solid waste generated in the UAE are from the construction industry. Initiatives in recycling and reusing materials will contribute to achieving environmental benefits while simultaneously reducing the overall construction costs (Umar *et al*., 2020; Umar and Umeokafor, 2022). As a global tourism hub, the UAE is facing rapid growth; therefore, it is imperative to address issues such as poor CDW management as a long-term strategy (Bodolica *et al*., 2020; Hittini and Shibeika, 2019). In 2021, the UAE government initiated Circular Economy Policy promoting sustainable governance, in which the construction sector is given key concern. The UAE government is committed to achieving SDGs by shifting from degenerative linear economy to regenerative CE (UAE Government, 2021a). The construction sector in UAE is identified as a key sector in CE implementation as 10-15% of building materials are wasted during construction (Al-Hajj and Hamani, 2011: Ellen MacArthur Foundation, 2013), and majority ofmost of the waste areis landfilled without extracting any value (Umar *et al*., 2020). The UAE Government identified developing programmes to support reuse and recycling of building materials and promoting better construction design mechanisms as key initiatives in reducing CDW (UAE Government, 2021a; UAE Government, 2021b).

However, the CE concept in the construction sector is barely discussed in the UAE context (e.g., Norouzi *et al*., 2021). CE being a new paradigm, the transition towards CE in terms of CDW management shall be discussed thoroughly required to be studied throughout addressing the full life cycle of CDW, focusing on pre-construction, construction, renovation, and demolition stages. Hence, to address this research gap the current study intends to explore the best practices implemented in the local context in achieving CE in terms of CDW management, that would be applied throughout the industry. However, to provide a holistic view and simultaneously narrow the scope, this study only focuses on the pre-construction stage, as the decisions made in the pre-construction stage critically affect CDW management throughout the life cycle (Yeheyis *et al*., 2013). The study is based on three best-case scenarios in UAE (i.e., influential cases), which demonstrated adequate measures in relation CE aspects. As the research methodology, the multiple case study approach is adopted with three construction projects in UAE that represent both conventional and innovative construction methods. The findings of case studies are compared with prior research findings to deliver comparisons on CDW management and UAE's transition towards CE. Finally, conclusions and recommendations towards CE through CDW are provided.

2.0 Literature review

2.1 Construction and demolition waste management

The composition of the CDW generated in each site solely depends on the construction materials and the technology employed in a construction project (Li Hao *et al*., 2008; Wu *et al*., 2014). CDW is divided into two major categories: inert waste and non-inert waste. Inert waste has stable chemical properties and does not undergo any significant physical, chemical, or biological transformations. Typically, a substantial quantity of CDW comprises inert materials such as concrete, bricks and soil, which arises from construction, excavation, renovation, demolition, and roadwork. However, CDW also contains non-inert waste such as bamboo, paper, timber, vegetation, packaging waste and other organic materials, which is biodegradable or otherwise physically or chemically react (Jaillon *et al*., 2009; Wu *et al*., 2014).

CDW management strategies not only encompass effective waste disposal but also result in effective control of the CDW generation (Kim *et al*., 2020; Esa *et al*., 2017). Lu and Yuan (2011) highlighted the importance of exploring hard and soft approaches when addressing CDW. Hard approaches include environmental engineering initiatives in waste management and recycling (Lu *et al*., 2018). Manufacturing recycled aggregates, and land reclamation have frequently been employed as hard approaches. On the other hand, soft approaches in CDW management consist of economic or managerial measures mainly focusing on waste minimisation and effective administration (Li Hao *et al*., 2008; Lu and Yuan, 2011). The 3R principle to be applied in CDW management is based on the desirability in a given scenario (Lu *et al*., 2018). Reduce is the most desirable strategy as it is a preventive practice aiming at lessening the waste generated from the source (Tam, 2008). Recycling aids towards reprocessing CDW as much as possible to make it a useful resource while using a minimum number of raw materials (Yeheyis *et al*., 2013).

2.2 Construction and demolition waste management in UAE

UAE is one of the world's highest per capita waste generation countries (Mawed *et al*., 2020). CDW accounts for 70 % of the waste generated in the country. In 2019, over 3.5 million metric tons of CDW were generated in Abu Dhabi, the largest emirate in UAE, in which only 20% of the waste was recycled (SCAD, 2020). Dubai is the second largest emirate of the UAE. The Dubai construction industry has undergone drastic development in recent decades. In 2017, the CDW generated in Dubai was over 18 million metrics, estimated to grow by 11% annually (Dubai Municipality, 2017; Kim *et al*., 2020). The Government has initiated several sustainable measures to manage CDW effectively. CDW recycling facilities have been implemented in every emirate, receiving daily a minimum of 4 tons of mixed CDW (Gernal *et al*., 2020).

In January 2021, the UAE government initiated the UAE Circular Economy Policy 2021-2031, where the construction sector was given key importance. The policy highlighted that the actual value of 10–15% of the building materials had not been utilised fully in the construction stage. Thus, CE principles are encouraged in the building design and construction stage to minimize CDW. Adoption of prefabricated building elements, off-site construction and 3DPC are suggested as key initiatives in achieving CE targets (UAE Government, 2021b). Several other initiatives in waste sorting and recycling have been introduced to minimise the amount of CDW in municipal landfills or dumpsites (UAE Government, 2021a). Enhancing material efficiency in the construction sector is a key UAE priority, as most of the resources need to be imported to the country. To meet the country's net-zero targets, a landfill tax scheme was introduced, encouraging the diversion of waste to resources. Dubai Municipality (DM) aims to achieve zero landfills in 20 years to protect the environment from harmful gases emitted and minimise the adverse environmental impact of the landfills (UAE Government, 2021a).

2.3 1 Circular economy through construction and demolition waste management

The concept of CE has been discussed in line with an economy with closed material loops. The CE addresses several consequences of the conventional linear economy of "take-make-dispose", such as resource depletion, high volume of waste generation and environmental pollution (Ellen MacArthur Foundation, 2013). In a broader aspect, CE encourages repeated use of a product as a secondary resource, keeping them in the production life cycle as long as possible (Shooshtarian *et al*., 2021; Ruiz *et al*., 2020). Núñez-Cacho *et al.* (2018) have shown that CE has become a crucial factor that defines the continuity of the construction sector. The concept of CE goes together with CDW management as this approach optimises the use of materials throughout their life cycle resulting in the minimisation of waste (Mahpour, 2018; Ruiz *et al*., 2020).

The CDW management regulations play a vital role in achieving CE, and well-implemented policies and strategic frameworks encourage CE principles in the construction industry. The renowned 3R concept is compatible with the CE principles where raw material utilisation is reduced, and used materials are reused and recycled by adding value to the waste. Applying 3R principles in CDW is a rudimentary practice for achieving CE in the construction sector (Bao *et al*., 2019). Many studies have shown that having a CDW disposal charge is one of the effective initiatives as it prioritizes reduce, reuse, and recycle practices over disposal (Ruiz *et al*., 2020). ~~CDW policies and strategic framework encourage the stakeholders to invest in closed-loop construction (Ghaffar *et al*., 2020). In addition, providing incentives for the CDW treatment companies promotes recycling and recovery methods (Ruiz *et al*., 2020). Likewise, end-of-life treatments for concrete and recycled concrete aggregate should be promoted (Wu *et al*. 2014). Adherence to CE principles in the CDW management process promises environmental and economic benefits.~~

~~Similarly, Ghaffar *et al.* (2020) emphasised the importance of implementing a CDW management strategy throughout the life cycle of CDW to achieve a CE. The~~ F~~f~~ive-life cycles of CDW in CDW are identified in implementing CE: pre-construction, construction and building renovation, collection and distribution, end-of-life and material recovery and production (Núñez-Cacho *et al*., 2018; Ruiz *et al*., 2020; Yeheyis *et al*., 2013). To narrow the research scope, this study focused on the pre-construction stage, as decisions made in the pre-construction stage critically affect CDW management throughout the life cycle. Figure I demonstrates the CE implementation opportunities of the CDW life cycle as identified by Ruiz *et al.* (2020).

Figure I: Stages in the analysis of CDW in the CE model

~~Nevertheless,~~ Mahpour (2018) emphasised several barriers that hinder the implementation of CE in the construction industry, such as ineffective collection, transport, sorting, and recovery process of CDW, use of construction materials with lack of quality, and lack of integration of the CDW management process. These hindering factors should be addressed through innovative strategies.

2.~~4~~2 Circular economy principles in construction and demolition waste management in the pre-construction stage

Pre-construction stage is crucial in identifying and implementing waste minimisation strategies, which is essential in achieving a CE. Key areas to focus on in the pre-construction stage include policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans (Ruiz *et al*., 2020).

CDW disposal charge is one of the effective initiatives as it prioritizes reduce, reuse, and recycle practices over disposal (Ruiz *et al*., 2020). CDW policies and strategic framework shall encourage all stakeholders to invest in closed-loop construction (Ghaffar *et al.*, 2020). In addition, providing incentives for CDW treatment companies promotes recycling and recovery methods (Ruiz *et al*., 2020). End-of-life treatments for concrete and the use of recycled concrete aggregate shall be promoted (Wu *et al*. 2014).

Ruiz *et al.* (2020), in relation to waste prevention and minimisation, highlighted the importance of paying attention in the designing stage. The early stage of designing should be facilitated with waste minimisation concepts, making reuse a priority. Wu *et al.* (2014) discussed the importance of Building Information Modelling (BIM) and other simulation technologies in which BIM provides an immense contribution to waste prevention with an extensive amount of information (Núñez-Cacho *et al*., 2018). BIM also facilitates future building disassembly and enables estimating the circularity of building materials (Ruiz *et al*., 2020).

Moreover, deconstruction strategies are a critical concern in the design stage, as designing for disassembly and deconstruction significantly contributes to the CE concept (Núñez-Cacho *et al.*, 2018). The amount of potential reusable and recycling materials should be identified in the design stage (Ruiz *et al*., 2020). Ghaffar *et al.* (2020) highlighted the smart dismantling of buildings, such as mobile robotic sorting and integration of IoT technologies that enhance the circularity in construction. Smart demolition and selective dismantling improve the re-usability of construction elements (Ghaffar *et al.*, 2020).

With the recent developments in construction technology, more hard approaches are accessible for CDW management. The emergence of 3DPC significantly contributes to CDW minimisation in the wet construction process. 3DPC is a form of additive manufacturing technology. It is a process of fabricating 3D objects (large and complex structures) through a rapid prototyping system (i.e., computer-aided model) (Hager *et al*., 2016; Siddika *et al*., 2020). 3DPC can utilise raw materials with low-embodied energy, such as recycled materials from CDW (Hager *et al*., 2016). The prefabrication/DfMA is considered one of the effective hard approaches to minimise on-site waste (Jaillon *et al*., 2009; Poon *et al*., 2003). Prefabrication technology involves utilising precast elements such as facades, staircases, partition walls, semi-precast slabs and bathrooms, which ~~will be~~are manufactured at a specialised facility off-site. Prefabrication technology enhances the quality while ensuring a safer working environment. Studies have shown that around 50% to 70% of waste reduction is achievable by adopting pre-fabrication technology. Moreover, a reduction of 70% of timberwork is feasible compared to traditional in-situ construction involving concreting and timer formwork (Jaillon *et al*., 2009;

Siddika *et al*., 2020). These innovative construction technologies ~~minimize~~ minimise various waste streams, such as concrete and wood, and ultimately contribute to achieving CE.

Finally, CDW management plans should be developed in the design phase comprising waste management measures for waste reduction— before, during and after the construction activities (Ruiz *et al*., 2020). The adoption of policies and frameworks, such as the 3R concept and sustainability measures, should be decided in the pre-construction stage (Bao *et al*., 2019). Based on the previous studies, CE principles in CDW management in the pre-construction stage are identified, as demonstrated in Figure II.

Figure II: CE principles in CDW management in the pre-construction stage

2.3 Circular Economy Implementation in UAE

The UAE Government has initiated several sustainable measures to manage CDW effectively. CDW recycling facilities have been implemented in e~~very~~ach emirate, receiving daily a minimum of 4 tons of mixed CDW (Gernal *et al*., 2020). In January 2021, the UAE government initiated the UAE Circular Economy Policy 2021-2031, where the construction sector was given key importance. The policy highlighted that the actual value of 10–15% of the building materials had not been utilised fully in the construction stage. ~~Thus, CE principles are encouraged in the building design and construction stage to minimize CDW.~~ Several initiatives including a~~A~~doption of prefabricated building elements, off-site construction and 3DPC are suggested as key initiatives in achieving CE targets (UAE Government, 2021a&b). ~~Several other initiatives in waste sorting and recycling have been introduced to minimise the amount of CDW in municipal landfills or dumpsites (UAE Government, 2021a).~~

Enhancing material efficiency in the construction sector is a key UAE priority, as most of the resources need to be imported to the country. To meet the country's net-zero targets, a landfill tax scheme was introduced, encouraging the diversion of waste to resources. Dubai Municipality (DM) aims to achieve zero landfills in 20 years to protect the environment from harmful gases emitted and minimise the adverse environmental impact of the landfills (UAE Government, 2021a).

In the UAE context, the discussion of CE in the construction sector is scarce. As CE is still a relatively new concept, it is crucial to conduct a comprehensive study of the transition towards CE, encompassing the entire life cycle of CDW, giving special attention to the pre-construction, construction, renovation, and demolition stages. Nevertheless, to offer a comprehensive yet focused perspective, this study concentrates solely on the pre-construction stage. This stage is of utmost importance as the decisions made during pre-construction significantly impact the management of CDW throughout the entire life cycle. It is expected to explore the CE implementation during the construction stage as a future study.

The study examines three influential cases in the UAE. These cases have been carefully selected as they represent best-case scenarios that exemplify effective measures related to CE aspects. The cases representing CDW management strategies, prefabricated building elements, off-site construction, and 3DPC are given priority~~,~~ as those measures are identified as successful approaches in the process of CE implementation in UAE~~, as per~~ based on the UAE Circular Economy Policy 2021-2031. By analy~~z~~sing these cases, the study aims to highlight successful strategies, practices, and approaches employed in the UAE context that align with the principles of the CE. These cases serve as valuable examples and provide insights into how CE principles can be implemented in the construction sector, specifically in relation to the management of Construction and Demolition Waste (CDW).

3.0 Methodology

3.1 Multiple case study approach

This study aims at exploring UAE's transition towards CE through CDW management, focusing on the pre-construction stage. Previous studies showed that proper planning of waste management in the pre-construction stage heavily impacts the resource circularity of projects. An in-depth and holistic investigation has been conducted to achieve the aim. Accordingly, a qualitative approach and multiple case study research methods have been adopted. A case is usually selected based on its potential to enhance the researcher's theoretical views on a phenomenon based on empirical findings; in this study, it is the CE concept and CDW management practices are focused (Liamputtong, 2020).

However, the qualitative research approach has frequently been criticised for its credibility and reliability of findings. Hence, several actions have been implemented to maintain the required level of validity and reliability of the findings of this study. According to Creswell and Creswell (2017) Creswell (2013) and Yin (2018), Qualitative validity is ensured by three attributes that are internal validity, construct validity and external validity. Internal validity is obtaining logical and reasonable interpretations via an accurate and detailed data analysis. This study has ensured internal validity by carrying out the data collection and analysis process according to the standard procedure suggested by Creswell and Creswell (2017)Creswell (2013). The second attribute–construct validity is achieved by data triangulation through cross-case analysis. External validity–the third attribute refers to the generalisability of findings. Even though the qualitative findings do not allow statistical generalisation due to the context specifications, analytical generalisation is still available as the findings can contribute to the theories of CE, sustainability and CDW management (Yin, 2018). Moreover, empirical findings can be applied to similar contexts (i.e., different construction industries with similar characteristics) with necessary adjustments.

The credibility and reliability are ensured by adopting multiple case study approach rather than relying on a single case study. Accordingly, three construction projects in UAE (Dubai) that represent both conventional and innovative construction methods are selected for the case studies. Construction project is considered as the 'unit of analysis'. These case studies are exploratory, as the findings of cases are subject to interpretations (Creswell and Creswell, 2017)Creswell, 2013).

3.2 Case studies

Three case studies were selected to analyse and compare the findings of CE initiatives in CDW management in the pre-construction stage. The cases were selected to showcase the best-case scenarios in the UAE to identify all initiatives towards CE. According to Seawright and Gerring

(2008), cases can be selected depending on the requirement of the research and the way that population is represented. In this study, three case studies were selected to analyse and compare the findings of CE initiatives in CDW management in the pre-construction stage. The UAE Circular Economy Policy 2021-2023, identified CDW management strategies, prefabricated building elements, off-site construction, and 3DPC as beneficial approaches of CE implementation in the UAE construction industry have been primarily explored. These particular cases have been meticulously chosen because they serve as prime examples that demonstrate successful measures associated with CE aspects. The cases were selected to showcase the best-case scenarios in the UAE to identify all initiatives towards CE in the local context. Hence, the cases are influential rather typical, where typical cases would represent population in general and influential cases are the best or above average. These case studies were identified as the best opportunities to investigate various leading approaches to CDW and CE initiatives emerging in Dubai. The following Table I summarises the details of three cases.

Table I: Details of case studies

3.3 Data collection

The interview method accompanied by sSemi-structured interviews was adoptedwere carried out following the standard procedure suggested by Creswell (2013) to collect data. Construction professionals Professionals such as project directors, project managers, site managers, consultant engineers, environmental engineers, quantity surveyors and health, safety, and environment (HSE) managers who had been working on the case study projects in relation to CDW management and knowledgeable in the concepts such as CE and CDW innovations were selected as the interviewees. All the interviewees have had not less than five years' experience in the construction industry. An interview guideline aimed to explore waste generation, project waste management strategies and the technologies used. Particularly, the attention was given on the best practices (i.e., innovative) CDW management practices which are well-planned and designed in the pre-construction stage of a construction project. The data collection mainly focused on the five key aspects of CE, such as policies and strategic frameworks, waste prevention design, disassembly or deconstruction, use of prefabricated elements, and CDW management plans (see annexure for the interview questions).

Semi-structured interviews carried out following the standard procedure suggested by Cresswell (2013). The interview guideline was prepared on theoretical grounds which is UAE's transition towards CE through construction and demolition waste management in the pre-construction stage. Particularly, the attention was given on the best practices (i.e., innovative) CDW management practices which are well-planned and designed in the pre-construction stage of a construction project.

The following Table II presents the demographic information of the interviewees.

Table II: Demographic information of interviewees

3.3 4 Data analysis

All the interviews, approximately half an hour, were conducted in English and audio-recorded with the permission of the interviewees. Transcripts were imported to the NVIVO 12 software.

Thematic analysis technique–understanding the meaning of data and systematically analysing data–was adopted to analyse data (Joffe, 2012). The standard procedure based on the thematic analysis technique suggested by Creswell and Creswell (2017)~~Creswell (2013)~~ was used in this study. First, data was organised and prepared for analysis. The next three steps, reading qualitative data, generating main and sub-themes, and coding data, have been done accordingly. Main themes are generated based on the questions in the interview guideline. For example, waste generation, CDW management strategies and CDW technologies have been selected as main themes. Likewise, sub-themes were created under the main themes, and the related content was coded under each theme/sub-theme.

Cross-case analysis: After analysing the data attained from each case, a cross-case analysis was conducted to compare the findings (Yin, 2018). Accordingly, similarities and differences among the three cases in relation to waste generation, storage, management, and technologies used were compared and discussed.

4.0 Findings

This section presents the findings of each case in terms of five CE principles in CDW management in the preconstruction stage. As summarised in Table III, all three projects have generated household waste, wood waste, solid waste like concrete debris and hard mortar and chemical waste in different stages of the project life cycle.

When the waste generation of case one is considered, CS1-8 mentioned that most waste generation is steel bars, concrete, and sand. According to the senior project manager—Interviewee CS1-1, the total non-value waste quantity is 93,330m^3. According to the project manager–CS2-2, "*general garbage on the original yard, soil, wooden waste (plywood and white wood), concrete debris, plastic package and household waste*" are the types of waste generated in case two. According to CS2-2, garbage skips have been used to store waste, and skid steer loader and/or telehandler are used to shift waste to the waste collection point in case two. The total waste generated in case three was 81,000 m^3, including the most common types.

Table III: Waste generation, storage, and management of three projects

4.1 Policies and Strategic frameworks

All three cases demonstrated adherence to the waste management regulations by the local authorities. Local authority mandates given for waste segregation, waste transportation, and disposal were followed in all three cases. Waste disposal charges and penalties imposed for improper waste handling were major motivations for adherence to waste management regulations.

The case one project is classified under the 'Green Building' category, where the contractor must reduce and recycle construction waste. Most of the construction waste is recycled by approved companies. In addition, construction materials are recycled to reduce waste generation.

CS1-4–the HSE manager explained the waste management practices of the project as follows:

> "*Our project has developed a waste management plan and has been approved by engineers for strict implementation. Waste is segregated at the designated area at the*

site and dispatched to DM-approved and designated disposal areas. Waste transported must be licensed from DM and must have a proper tracking document which authorities will closely monitor" *CS1-4*

When the waste storage is concerned, a collection pool was allocated for concrete (solid) waste, and there have been baskets and steel cages assigned for paper and plastic waste in cases one and three. The senior project manager of case one–CS1-1 explained their waste storage mechanisms as follows:

"*Site staff is obliged to sort waste at the workplace and waste collection point. We have spent a lot of time improving the awareness and training staff. Also, we have a permanent special team to monitor waste management on-site and record it weekly. Most importantly, we are following LEED standard in this regard*" CS1-1

4.2 Design for waste prevention

Design for waste prevention during the building design stage highly contributes to waste minimisation during the construction stage. Case one and case three used BIM technology in the construction design, which is known to enhance construction efficiencies and reduce material wastage during construction. Case two utilised 3DPC technology which used recycled construction materials as raw materials. CS2-3 (project manager) mentioned that building elements were printed using "*concrete waste and waste of other construction materials in China*". Thus, all three cases demonstrated satisfactory efforts in waste minimisation approaches during the design stage.

4.3 Use of prefabricated elements and application of innovative construction technologies

In case two, 3DPC technology was utilised, one of the innovative technologies in waste reduction at the site. In addition, CS2-3 further pointed out as "*more prefabricated items have been used in this project; therefore, less waste has been generated compared to the conventional construction method*". Most of the waste generated in case two was soil. Similarly, CS2-1 pointed out the reason for less waste generation in case two: "*the structural elements were fabricated in China and delivered to Dubai by shipment*".

Waste generation in case three is also low (approx. 85 m^3 per day) compared to projects with similar scales because toilets are constructed using the DfMA approach. The project manager–CS3-1 viewed the efficiency of waste management as "*standard fabrication procedures make the full use of materials. Therefore, the material waste is much less than on-site construction*". Similarly, the Design and Technical manager–CS3-3 emphasised that waste can be reduced by up to 90% of the total waste. The site manager of case three–CS3-3 explained waste reduction due to the off-site manufacturing of construction materials as follows:

"*The pods are manufactured off-site, which means reducing the waste material includes packaging, adhesives and sealants, unused tiles and decorative trims, unused grouting materials and unused off-cuts such as plumbing and electrical materials*" CS3-3

CS3-3 further explained the adoption of this approach for the reuse of materials as "*the installation of the pods is standardized. Therefore, the assembling process, the materials and tools used in the installation can be used repeatedly*".

4.4 Designing for disassembly or deconstruction

Proper planning is required for disassembly or deconstruction to minimise waste generation in case of future renovations or demolition activities. However, the delegates of all three cases did not demonstrate awareness of disassembly or deconstruction planning with respect to their projects. Having prefabricated elements in case two and case three will provide an opportunity to plan disassembly or deconstruction with minimum waste.

4.5 CDW management planning

CDW management planning is evident in all three cases. Findings reveal that all three projects have been concerned with adopting the 3R concept by several means. For example, in case one, the use of plaster mortar waste for block wall installation and temporary road construction from waste is impressive. Case one assigned a specialised team consisting of safety officers, a foreman, and an expert consultant in CDW management planning. Having a consultant enable the project team to implement sustainable waste management solution. Thus, the waste generation of case one is less compared to other projects on a similar scale.

Similarly, the construction manager of case three–CS3-2, described the waste storage techniques as "*we have assigned different waste collection points at the site such as pool (for solid waste) and cages (for plastic and paper waste)*". As CS3-3–site manager of case three) mentioned, the environment team proposed a guideline for sorting and storing waste. This guideline aligns with the DM waste management guideline as well. According to CS3-3, "*wood, steel and contaminated solid waste are very common and easy to get sorted and recycled at the initial stage of the construction. The simpler the design, the lesser the construction waste and the harder to recycle. The latter stage of construction generates more solid waste, most of which is from abortive works*".

Overall, in all the cases, measures have been taken to sort and store waste, such as assigning a foreman and using technology in compliance with a guideline (e.g., in case three-DM waste management guidelines). Waste removal of each project was subcontracted to a professional waste management company.

Despite having developed a waste management plan, all three cases have faced challenges implementing the CDW management plan. In case one, CS1-8 explained how their waste management procedures changed throughout the project duration as follows:

> "*We did not properly manage the waste at the beginning of the project. Compulsory separation of the waste generated at the site has not been enforced, which has put a great burden on logistics management. But later, we stressed more waste separation, primarily separating them into their categories, namely recyclable wastes like steel bars and iron products, wastes with no scrap value*" *CS1-8*

The HSE manager of case two–CS2-3 emphasised that "*the current waste management procedure is not sufficient because it lacks integration, coordination and control*". On a positive note, the management of each three cases was aware of the significance of implementing waste management procedures. For example, CS1-4 explained that: *"controlling* *the construction waste will increase the contractor's profit by reducing the waste during the construction period. In addition, many of the waste materials are reusable, where contractor earns a certain amount of money by selling them. Ultimately, if the construction environment is not polluted due to construction activities, the developer is benefited by selling the property soon after the construction*" CS1-4

It should be noted that selected case studies are some of the best-case scenarios of UAE (i.e., influential cases) and demonstrated satisfactory measures in the transition towards CE.

5.0 Discussion

5.1 Construction and Demolition Waste Management in the Pre-construction Stage

Case study findings reveal that the contractor, consultant, and government authorities, such as the environment department and DM, are involved in the waste management procedure in all three construction projects. As denoted in the findings section, the organisational and project management have implemented soft waste management practices by developing and adhering to waste management guidelines (e.g., waste management standards, Environmental guidelines issued by local authorities, Green Building standards and LEED Standards). These guidelines consist of 3R measures arranged in ascending order to minimise the environmental impact (Yeheyis *et al*., 2013; Lu *et al*., 2018).

Nevertheless, case one has been appreciated for its strategies on waste management as it won the internal safety award merit in 2019 and 2020, awarded by British Safety Council. Recognizing these awards and certifications, such as LEED, motivates construction firms to implement waste management procedures efficiently and effectively (Lu *et al*., 2019).

Both hard and soft approaches have been employed in the waste management process (Lu and Yuan, 2011, Lu *et al*., 2018). As a hard waste management approach, landfilling with solid waste is common in many countries (Bai and Sutanto, 2002), which is also practised in UAE. When the sorting and waste storage are concerned, all three projects suffer from logistics issues such as inadequacy of space allocation for waste storage, deficiencies in manhandling, and lack of efficiency and accountability of workers who sort waste. For example, interviewees from case three have highlighted that allowing waste disposal only at night is a disadvantage. The main reasons for such issues are low financial incentives and increased overhead costs (Tam, 2008).

Reduction and reuse minimise waste generation and reduces the cost of construction, waste disposal and recycling (Jaillon *et al*., 2009). As distinguished by Lu and Yuan (2011) in their review, solutions to reduce waste generation can be generally classified into five categories, that are a) through government legislation, b) by design, c) by developing an effective waste management system, d) use of low waste technologies and e) improving practitioners' attitudes. Utilising recycled materials in the construction process is a hard approach that contributes to achieving CE targets (Iodice *et al*., 2021). The use of plaster mortar waste for block wall installation (recycling) in case one and the use of 3DPC (from waste) in the structure in case two are examples that eliminate waste through the superior design of materials (also ordering), products or systems (Ellen MacArthur Foundation, 2013). Findings also indicate waste reuse and recycling practices. Conventional methods such as reusing waste for the same function

~~(e.g., F/W) and a different function (e.g., plaster mortar waste for block wall installation) have been observed in case one. In cases two and three, innovative methods such as using 3DPC and prefabrication are evident. Specific positive approaches are evident, such as waste reduction by innovative designs and implementing effective waste management systems. Moreover, adopting innovative techniques that reduce waste is observable in Dubai. 3DPC technology reduces waste generation and enhances efficiency and productivity (i.e., only seventeen days were taken to print structures and two days to install on-site). However, such practices should be encouraged further by rewards and incentives. Findings also reveal that the attitudes and behaviour of middle management (the professionals responsible for implementing waste management practice) are satisfactory.~~

~~*5.2 Transition towards circular economy: Pros, gaps, and recommendations*~~

CE is an evolving concept in the current scientific landscape, yet barely discussed in CDW management. In relation, the five key areas of CE in the pre-construction stage are policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans, which have been observed in the case studies. Even though some elements of these key aspects were observed in the cases, a broader vision towards CE was rarely recognised.

In the pre-construction stage, all three projects have considered CDW management plans inclusive of methodologies for storing waste at the site and disposal through approved waste management service providers to avoid any penalties incurred by the government. Considerations have been given to waste minimisation, knowing the country's regulation of needing to pay for waste discharged into landfills.

In relation to the first key CE aspect—**policies and strategic frameworks**- cases one and three denote a positive movement towards implementing the 3R concept in a mega construction project. The findings highlight the importance of establishing higher management-level commitment in defining the waste management strategy of a project. The project shows the importance of setting internal waste management policies, site preparation with waste sorting and storage facilities, and assigning responsible staff to adhere to the 3R principle. In case one, these CDW management strategies ensured diverting of 85% of waste from landfills compared to a traditional construction project. Thus, case one sets an example of moving towards CE by identifying the hidden value of the waste and converting waste into a valuable resource. Furthermore, case one indicated some policies and strategic frameworks of CDW management yet did not necessarily make the concept of CE the ultimatum.

Application of BIM in cases one and three shall be considered as a facilitator of CDW minimisation. The amount of information obtainable through the BIM model will enhance the circularity not only in the pre-construction stage but also throughout the life cycle (Núñez-Cacho *et al.,* 2018; *Ruiz et al.,* 2020). Although BIM is a favourable tool in for CDW reduction, it is not a mandate in the GCC region. Hence, there are many challenges in adopting BIM such as lack of technical knowledge, lack of awareness and other organisational factors (Umar, 2022). In the same way, the other key CE aspects, such as **design for waste prevention, use of prefabricated elements and CDW management plans,** were evident. For instance, design for waste prevention and use of prefabricated elements were achieved using 3DPC structures in case two, and the adoption of the DfMA approach in cases two and three, respectively. Case two demonstrates an excellent example of applying innovative construction technology to achieving CE as the waste generated during the construction was only 300 m^3 for the entire project. This shows around a 60% reduction compared to conventional construction methods of a similar project. Moreover, most of the generated waste consisted of MEP waste, EIFS waste, gypsum, and packaging materials, where the amount of waste and dust generated during the wet construction process was significantly less. This outcome denotes a potential transition towards CE by adopting 3DPC structures in the construction sector.

Moreover, both case two and case three denote applications of the DfMA approach. All the structural elements were prefabricated at a specialised factory environment in China and delivered to Dubai, as case two is concerned. In case three, prefabricated toilets have been used. According to the findings, the DfMA approach significantly enhances the productivity, quality and efficiency of the construction project while minimising the CDW. Compared to traditional construction methods, the use of the DfMA approach in cases two and three contributed approximately 60% and 90% of waste reduction, respectively. Moreover, having standardised sizes allowed the reuse of the assembling tools of prefabricated elements.

On a positive note, even though the application of 3D printing in construction is still at a primary level, significant structural components have already been constructed using this technology. Nevertheless, there are challenges to be addressed with 3DPC technology, such as the development of 3D printers/robots for large-scale projects, improvement in the composition and quality of materials for concrete mixture and integration of reinforcement techniques for 3DPC technology (Siddika *et al*., 2020).

On a futuristic approach regarding 3DPC, Dubai is planning to construct 25% of its buildings through 3DPC by 2030, and the 3D printing market is estimated to reach USD 2 billion by 2025 (Government of Dubai Media Office, 2021). The movement towards 3DPC contributes to faster construction and reduction in material cost through waste minimisation. In addition, the concrete mixture of the 3DPC consisted of concrete waste and other waste generated from construction works. As shown in the previous studies, materials with low embodied energy, such as waste materials and by-products, can be utilised for the 3DPC mixture to add value (Hager *et al*., 2016; Siddika *et al*., 2020). In addition, using recycled materials in construction and 3DPC greatly contribute to achieving CE targets (Hager *et al*., 2016; Superti *et al*., 2021). As stated by Gernal *et al*. (2020) and Mawed *et al*. (2020), there is a notable usage of recycled materials for construction projects in the UAE. The findings of case two also complement this view by notifying less waste generation. Thus, 3DPC ensures materials are kept in the product life cycle contributing to CE principles.

It is recommended to adopt DfMA in construction as it also works as a collaborative team working approach, which encourages the involvement of engineers and manufacturers in the early design stage; thus, it contributes to optimising the design while reducing waste generation. This approach is considered one of the radical construction innovations as it significantly changes traditional construction methods and delivers substantial outcomes. For instance, prior studies have shown that off-site manufacturing of structural elements substantially enhances the quality while reducing waste generation (Jaillon *et al*., 2009). This view is complemented by the findings of this study as well. The findings also confirm that the DfMA approach highly contributes to CE policies. Nevertheless, high initial cost, inflexibility, and ability to build complex components are some of the key challenges to be addressed in moving towards the DfMA approach (Jaillon *et al*., 2009; Tam and Hao, 2014).

The lack of evidence on design for disassembly or deconstruction in case study findings denotes the possibility of UAE's limited practice in this area. It should be noted that prefabricated elements are closely linked with disassembly or deconstruction planning in a CE (Ruiz *et al*., 2020). Thus, both cases two and three provide a good opportunity which shall have been addressed in the pre-construction stage. Even though the case study findings cannot be generalised, it cannot be disregarded that three influential projects have been selected as the cases of the study. Hence, it is recommended to have a vision of CE considering the aspect—design for disassembly or deconstruction.

Although the three cases are unique and in different scales, based on comparing the volume of waste generation per unit area of the project, case one demonstrated the minimum waste generation of 0.18 m^3/m^2. In contrast, cases two and three generated 1.2 m^3/m^2 and 0.49 m^3/m^2, respectively. In addition, case one prevented 85% of waste from landfills. These findings denoted that the CDW management approach utilised in case one (i.e., implementation of the 3R concept, implementation of LEED standards and having a proper framework of CDW management) is more effective in achieving CE targets. Hence, soft approaches in CDW management shall not be underestimated.

6.0 Conclusions

Recent interests in CE encourage the diversion of CDW from landfills to overcome the adverse impact of the conventional linear economy of take-make-dispose. Following this perspective, this study aimed at exploring UAE's transition towards CE through CDW management practices. Circularity in CDW management requires a life cycle assessment covering pre-construction, construction, renovation, and demolition stages. However, to narrow the study scope, this study was conducted intending to explore the CE concept in the pre-construction stage. ~~—~~Decisions made during the pre-construction stage significantly impact CDW management throughout the lifecycle. CE transition has been explored through five key aspects in the pre-construction stage: policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans. Multiple case study approach has been adopted as the methodology in which three ~~influential~~ best projects in Dubai in terms of adopting innovative CDW management strategies were selected as the cases (i.e., influential cases). The first case is a mega construction project involving constructing a host village for a large international exhibition. The second case is a construction of an office complex using 3DPC. The third case is construction of a high-rise residential complex that used prefabricated elements. ~~Findings are also discussed under the five key aspects of CE.~~

As per the findings, CDW management strategies have been evident~~received attention in the pre-construction stage~~ in all three projects. In line with the concept of polluter pay principal, all three cases have shown adequate responsibility in storing the waste generated at the site and disposal of waste to the designated areas through government-approved waste management service providers. Achieving CE through addressing key aspects such as policies and strategic frameworks, waste prevention design, prefabricated elements, and CDW management plans were evident. However, the design for the disassembly or deconstruction aspect ~~is lacking~~found lacking in the context of the Dubai construction industry. As the evidence for policies and strategic frameworks and CDW management plans, different waste management guidelines (e.g., The UAE circular economy policy 2021-2023, frameworks developed by the local authorities, Lean standards, green building standards) have been developed and adopted in all three projects. The application of BIM was evident in cases one and three, and findings indicate that BIM facilitates CDW minimization by enhancing construction efficiencies and reducing material wastage during construction. In addition, BIM enables future disassembly of buildings and assists estimation of the circularity degree of building materials. In relation to the design for waste prevention and use of prefabricated elements, the implementation of innovations such as 3D-printed concrete (3DPC) and prefabrication/-DfMA has been recognised, and these have contributed to waste reduction compared to conventional on-site construction approaches. In addition, waste recycling and reuse were evident in ~~studied~~ all three cases ~~(construction projects)~~.

~~As the gaps, the inadequacy of motives for CE initiatives in laws and regulations and poor waste management have been found in addition to the absence of design for disassembly or deconstruction. Hence, CDW management practices in Dubai should further be improved by enacting necessary laws and improving the attitudes of workers and practitioners.~~

Among the three selected cases, case one demonstrated the lowest waste generation of 0.18 $(m^3)/(m^2)$ and achieved 85 % of waste diversion from landfills compared to a project on a similar scale. Therefore, initiatives such as implementing 3R measures, LEED standards and having a proper framework of CDW management were identified to be most effective in achieving CE targets. Furthermore, having innovative construction technologies such as 3DPC and DfMA facilitates waste reduction compared to a conventional on-site construction approach.
As the drawbacks of the existing practice, despite the availability of the UAE circular economy policy 2021-2023, lack of application of CE principles, limitations in law enforcement and high usage of traditional and non-innovative waste management practices have been found in addition to the absence of design for disassembly or deconstruction.

As limitations of this study, qualitative findings cannot be used to generalise the transition of UAE towards CE. Also, the selected cases were rather influential than typical; case studies represent the best-case scenario of UAE. While remarking on the need for future research to further explore this area, it is concluded that the status of UAE towards CE is still in the initial stage and yet to be upgraded. Even though the influential cases exhibited limitations of CDW practices, the role of BIM in CDW management shall be studied to quantify the benefits accurately.

As recommendations, it is suggested to implement CDW management with a broader vision of achieving CE and set targets in relation to the five key aspects—policies and strategic frameworks, design for waste prevention, design for disassembly or deconstruction, use of prefabricated elements, and CDW management plans. ~~Accordingly,~~Along with the policies such as UAE circular economy policy 2021-2023, the authorities ~~should~~ encourage construction practitioners on sustainability commitments in CDW management (e.g., CDW management planning, implementation of BIM, adopting innovative construction technologies) and waste diversion targets (e.g., recycling, composting, and initiatives in waste to energy) to accelerate the transition towards CE. In addition, further studies are recommended on studying the life cycle analysis of CDW, including the end-of-life stage to provide a holistic overview of the CE transition.

Abbreviations list

3DPC - 3D-printed concrete
BIM - Building information modelling
CDW - Construction and demolition waste
CE - Circular economy
DfMA - Design for manufacture and assembly
DM - Dubai municipality
HSE - Health, safety and environment
LEED - Leadership in energy and environmental design

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