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DEVELOPMENT OF GUIDANCE FOR THE ADOPTION OF CIRCULAR ECONOMY IN CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT

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Abstract

The rise in the amount of construction and demolition waste and its negative impacts on the environment had made it become a hot issue globally. Therefore, efficient construction and demolition waste management are extremely important in the construction industry. The circular economy is introduced to shift the current linear economy practice of “take-make-consume-dispose” to “take-make-consume-reuse and recycle” toward a more sustainable and efficient construction and demolition waste management by decrease the illegal dumping and construction and demolition waste issues. However, the concept of circular economy has still not been widely developed in current practices of waste management where many of the players in the construction industry still in the process of understanding how to adopt circular economy practices. Thus, this research aims to develop the strategy for the adoption of Circular Economy (CE) for Construction and Demolition Waste Management (CDWM). The quantitative method is applied in this research to collect data and the data is collected through a questionnaire survey. A strategy is proposed on the adoption of the circular economy principle in the construction and demolition waste sector as a reference to improve the performance of the current construction and demolition waste management system.

Keyword: building life cycle, circular economy, construction, and demolition waste management

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INTRODUCTION

Environmental, economic, and social are the three aspects of sustainability that strongly influenced by the construction industry and the construction industry had greatly contributed to both Gross Domestic Product (GDP) and job opportunities. The construction industry is believed to be the major cause of environmental pollution as it had generated the most waste (Menegaki and Damigos, 2018). There are several ways to define C&D waste in different countries and regions. The most common definition of C&D waste is the waste generated throughout the process of construction, renovation, and repairing of any types of buildings such as individual premises or commercial buildings while the wastes arise from the razed structures been classified under demolition waste. Various pollutions would cause by C&D waste such as water, soil, air, and noise pollution. The continuous increase in C&D waste along with its environmental impacts made it become the biggest challenge of the construction industry (Ramón et al., 2019).

However, there is still lacking of awareness to adopt a proper CDWM in developing countries such as Malaysia (Esa et al., 2016b) with the evidence of an increase in illegal dumping cases (Nagapan et al., 2012). From the aspects of the built environment, the phases of the linear economy start from the raw material extraction and manufactured into new products which usually have no potential for reuse. The elements are then erected on-site and usually be disposed of before their real end of life when they are antiquated (Mangialardo and Micelli, 2018; Cheshire 2017; Ellen MacArthur Foundation, 2015).

To address the construction and demolition (C&D) waste problem, the construction industry had adopted the 3Rs principle (reduce, reuse, and recycle) as one of the measures to manage C&D waste sustainably but most of the cases that implement reuse and recycling practices for the waste management is inefficient which lead to increase in landfill and illegally dumping cases (Esa et al., 2017, Suárez et al., 2016). Circular economy (CE) is the concept that goes beyond 3Rs and is defined as “an industrial economy that is restorative or regenerative by intention and design” (Ellen MacArthur Foundation 2013). The focus of circular economy is on reducing (Osmani et al., 2006) and recycling C&D waste (Yuan and Shen, 2011) and explore the new design approach which like the design for deconstruction and increase the efficiency of materials (Kanters,2018; Kibert, 2003).

This provides an ideally shift from the current linear economy practice of “take-make-consume-dispose” to “take-make-consume-reuse and recycle” which is more sustainable. According to circular economy models, the components and materials are keeping in a closed loop which is proposed to reuse the end of life building materials and a new approach of material banks for a new building by using the deconstructed components (Hopkinson et al., 2019). Therefore, there is a need to shift to circular economy approach from the linear

economy approach in the construction industry to enhance the C&D waste management throughout the construction cycle (Dajian, 2004, IMSA, 2013) as efficient C&D waste management is a critical element to save the environment, natural resources, economy, society, etc. (Kabirifar et al., 2020). The shift to the circular economy approach needs a huge change in the society and structure of industry which this task is very challenging and usually related to business operation and waste management. (Lieder and Rashid, 2016). The circular economy approach is still not widely implemented in the construction industry even this approach already increasingly gaining interest. (Leising et al., 2018; Pomponi and Moncaster, 2017). This is because the construction project usually is complex and time consuming along with a large supply chain (Pomponi and Moncaster, 2017).

According to recent research, the researcher observed that there is only a minor shift from linear economy model to circular economy model (Mayer et al., 2019; Silva et al., 2017; and Haas et al., 2015). The shift to circular economy model need a better understanding on the entire building life cycle, the construction value chain and the involvement of stakeholder (Zimmann et al., 2016). Moreover, the concept of CE has still not been fully developed in current practices of waste management and the identification of new treatment methods of waste is lacking (Zhang et al., 2019; Bakajic and Parvi, 2018; and Fellner et al., 2017). The potentials for CE transition are relied on the efficiency of resources, waste reduction, investing in technology and tools, innovative practices, adoption of more flexible and modular concepts to create more value in the built environment. (EMF, 2017).

LITERATURE REVIEW

This section presents the discussion of the existing literature in the area of circular economy in various industries due to the limitation of circular economy studies conducted building construction context. The theoretical review and empirical review of the previous research in this field was reviewed to look into the issues related to the adoption of circular economy in construction industry, the circular economy practices in different building life cycle stages, identification of the relevant factors contributed to construction and demolition waste generation followed by of approaches and strategies needed for the adoption of circular economy in the construction and demolition waste management and ended with discussion. The result of this review will help in developing the components of the conceptual model of this study for the adoption of circular economy in the construction and demolition waste sector where the placement of each component is based on IPO model.

Building Life Cycle Stage (INPUT)

The wastes are generated throughout the building life cycle given that start from the materials of the demolition of previous construction on-site, polluted excavated materials, damage of materials, modification of changes, materials for temporary works, and so on (Schoenberger et al., 2018). Therefore, the connection between every building life cycle stage is essential for the communication across the entire network to facilitate circularity (BAMB, 2016).

Factors Contribute to Construction and Demolition Waste Generation (INPUT)

Identifying the root causes of construction and demolition waste generation is the key step that needs to be taken for successful waste management as the amount of waste generated depends on various factors (Ikau et al., 2016, Polat et al., 2017, Luangcharoenrat et al., 2019). The previous finding showed that the causes of C&D waste generation occurred throughout the whole project delivery. The factors found in the design and planning stage are more to decision making based while for other stages is more related to activity-based.

Building life cycle stage	Authors	Factors
Design and Planning stage	Ikau et al., 2016; Kaliannan et al., 2018; Whyte et al., 2018; Olabodec Emmanuel Ogunmakinde 2019; Luangcharoenrat et al., 2019	<ul style="list-style-type: none"> ● Changes in design ● Communication problem among design team ● Design error ● Unfamiliar with alternative products ● Unclear client specifications
Construction stage	Ikau et al., 2016; Kaliannan et al., 2018; Whyte et al., 2018; Olabodec Emmanuel Ogunmakinde 2019; Luangcharoenrat et al., 2019	<ul style="list-style-type: none"> ● Defective materials ● Poor supervision on site ● Poor storage systems ● Poor workmanship ● Construction method ● Lack of waste management plan ● Building shape ● Complex design
Operation stage	BAMB,2016; Benachio et al, 2020	<ul style="list-style-type: none"> ● Lack of information on building components ● Hard to access for repair and update. ● Information on building did not keep up to date
End of life stage	Zimmann et al.,2016; Groh & Dubik,2018; Adams et al.,2018; Ruiz et al., 2020	<ul style="list-style-type: none"> ● Demolition work ● Building component not suitable for reuse or recycle ● Building design not flexible and adaptable

Approaches for implementation of Circular Economy Strategies in Construction and Demolition Waste Management (PROCESS)

The circular economy principle is either implemented in the earlier stage (design stage) as a preventive measure or in later stages (construction, operation and management) as a management measure (Eberhardt et al, 2020).

Design stage

It could be effective to minimize the amount of CDW produced if the CDWM is adopted in the initial stage which is the design stage. The design decision made in this stage is closely linked to the following stage thus an effective design strategy could help in the reduction of waste, increase the rate of recycling and reuse of materials in the project. Many of the research had emphasized the need to implement a circular economy in the early stage of the project which is the design stage (Akanbi et al., 2018; Benachio et al., 2020). In the circular economy model, the buildings are designed for a lifecycle instead of just a simple end-use.

Construction stage

The construction method had a great impact on the amount of waste generated during construction. The techniques such as off-site manufacturing or construction using steel or timber frames could reduce the waste generation by 90% (Gálvez-Martos et al., 2018). The implementation of circular economy in the construction stage is mainly for the minimisation of waste generated on-site and the application of reusable and recyclable materials as the primary construction materials on-site (Groh & Dubik, 2018). With this, Adams et, al. (2017) recommended procuring reusable and recyclable materials and off-site construction.

Operation stage

The building should be designed in a manner that allows for minimal maintenance which eases any repair and upgrades the construction for new needs in order to extend the building lifespan (Groh & Dubik, 2018). Zimmann et al. (2016) also suggest that the buildings should be managed regularly through low energy and low-cost sensor technology which could help to maximise the lifespan of the building.

End of life

The end-of-life stage had been identified as the stage that generated the most CDW among the entire building lifecycle (Ruiz et al, 2020). The demolition practices are not encouraged under circular economy principles where the buildings are designed to adapt change and disassembly. The stakeholders could

decide to expand or contract the structure or redesign the building by reuse of the components (Zimmann et al., 2016; Groh & Dubik, 2018).

Circular Economy Strategies in Construction and Demolition Waste (OUTPUT)

Management sector

Reduce, reuse and recycle is known as 3Rs principles for the CDW management hierarchy where it offers an approach to manage CDW effectively (Kabirifar et al., 2020) while the promotion of CE in the construction and demolition industry had mostly focused on the reuse and recycling practices (Ginga et al., 2020).

Reduce

Waste reduction practice is the most preferable among the 3Rs principles as its priority in the waste hierarchy and its adverse impact on the environment is the lowest among all (Huang et al., 2018; Joensuu et al., 2020).

Reuse

The reuse practice is defined as all the construction materials, elements and building components collected could be used in a specific site (Gálvez-Martos et al., 2018).

Recycle

Waste recycling practice is carried out by breaking down the waste materials to form new materials or components or as part of another material (Huang et al., 2018; Ogunmakinde, 2019).

Design for change and disassembly

Disassembly refers to a systematic process to remove the desired components from a product at its end of life for further upgrade or fix (Groh & Dubik, 2018).

Material passport

According to BAMB (2016), materials passports are sets of data that provide the value of materials and components in both products and systems for present application and treatment at end-of-life based on the characteristics of materials and components shown in the data.

Selective deconstruction

Selective deconstruction is to boost the closing material loops and building components and materials for recovery by reverse the systematic building disassembling process.

Construction and demolition waste management plan

The development of a construction and demolition waste management plan is a must in a construction project coupled with the on-site waste management plan (SWMP). There are two stages for the development and implementation of SWMP where it is named as SWMP design and SWMP implementation.

Collection and segregation

The waste collection points are identified on-site and are separated into three types, i.e, normal waste collection, temporary waste collection and for hazardous wastes collection.

METHODOLOGY

The research employs the survey method, as this allows the collection of data from a sizeable population in a highly economical way, and it is easy to compare, explain and comprehend tangible evidence. The questionnaire forms will explore the strategies for implementing circular economy in the construction and demolition waste management sector, the existing and applicable circular economy practices for construction and demolition waste management, and how the practices could be adopted throughout the building lifecycle stages. This questionnaire survey will adopt the Likert-type scale, closed-ended questions and simple open-ended questions. The sample size will be 186 as according to Krejcie & Morgan's table (1970). The list of construction firms will be obtained from the Construction Industry Development Board (CIDB) Directory 2020 for the distribution and sending of the questionnaires. 186 firms sample size comprises of developer, consultant and contractor were selected based on their involvement in construction and demolition waste. The population size, which is 363 firms were obtained from the registration with Construction Industry Development Board (CIDB).

The conceptual model of this study was design based on Input-Process-Output (IPO) model and the components of this model was established based on theories and empirical evidences relating to circular economy in various industries. IPO model consist of 3 dimensions: input, process, and output. Input is defined as all factors that are independent, can be manipulated and directly impact the output through process (McCuspie, Hyman, Yakymyshy, Srinivasan, Dhau, & Drake, 2014; Cohen & Bailey, 1997). As for this study, input dimension is represented by factors that contribute to construction and emolition (C&D) waste Generation that was categorise according to the relevant building life cycle, in order to see what effects they have in which stage. Process is defined as a series of activities that influence by different input and affect the output (Herre, 2010; Cohen & Bailey, 1997). As for this study, process dimension is represented by

the element of approaches needed for every factors identified where the usage of every approach are influenced by different factors that contribute to C&D (input). While, output is defined as the result produced by the process (McCuspie, Hyman, Yakymshy, Srinivasan, Dhau, & Drake, 2014)

DATA ANALYSIS AND DISCUSSION

The survey recorded a response rate of only 20%, or equal to 72 respondents, with a range of positions and years of experience in their fields of research. Roscoe (1975) proposes that a rule of thumb in terms of determining an appropriate sample size is that it should be greater than 30 and lower than 500 for most research.

Factors contributing to construction and demolition waste generation.

From the findings, the construction stage contributes the most to waste generation. In the design and planning stage, change in design is the most significant causes of waste generation ($\bar{x}=4.1528$), followed by design error ($\bar{x}=4.0278$), unclear client specifications ($\bar{x}=3.8611$), lack of coordination and communication among the design team members ($\bar{x}=3.8611$) and designer not familiar with alternative products ($\bar{x}=3.7222$). For the construction stage, the most significant cause is the lack of a waste management plan on-site ($\bar{x}=4.3333$). Next is followed by the low quality of supervision ($\bar{x}=4.2778$), poor storage system ($\bar{x}=4.2394$), the poor workmanship ($\bar{x}=4.0278$), construction method ($\bar{x}=3.9583$), defective materials ($\bar{x}=3.8750$), complex design ($\bar{x}=3.5139$) and building shape ($\bar{x}=3.1806$). In the operation stage, the significant factors are information on building did not keep up to date ($\bar{x}=4.1389$), hard to access for repair and update ($\bar{x}=3.9028$) and lack of information on building components ($\bar{x}=3.762$). Besides, in the end of life stage are demolition work ($\bar{x}=4.3611$), building design not flexible and adaptable ($\bar{x}=4.1667$) and building material could not be reused or recycle ($\bar{x}=3.9861$). In short, the factors that contribute to waste generation are determined through analysed the data collected and test is conducted. The results showed that all the factors listed are significant.

The circular economy strategies in construction and demolition waste sector.

It involves the knowledge on CE principle, material passport, design for disassembly, selective deconstruction and opinion of respondents toward the CE strategies. It helps to determine whether the CE strategies are suitable and effective for CDWM which is important in developing the strategy. From the result, most of the respondents have not come across with CE strategies such as material passport, design for disassembly and selective deconstruction. Therefore, a presumption is made that majority of the respondents had never

applied practices other than 3Rs practices to manage the C&D wastes. Among the strategies, reduce strategy is the most significant in respondents' opinion. In summary, the CE strategies are identified and the findings are supported by the literature review.

The approaches for implementation of Circular Economy (CE) for Construction and Demolition Waste Management (CDWM).

The approaches suggested are taken from the CE strategies that had been identified earlier. A test is also be conducted to determine the significance of the approaches. From the result, all the approaches showed are significant. According to the findings, it found that 70 of the respondents are agreed that the CDWM should be carried out throughout the whole building life cycle stage. In the design and planning stage, there are 8 approaches listed, optimization of materials choice ranked at first place ($\bar{x}=4.3889$), followed by effective design strategy ($\bar{x}=4.3333$), develop a waste management plan ($\bar{x}=4.3333$), estimate the amount of materials available for reuse or recycle through the adoption of BIM ($\bar{x}=4.000$), adoption of BIM to visualize the effects of materials on salvage performance of the building ($\bar{x}=3.9167$), adoption of design for disassembly ($\bar{x}=3.9026$), adoption of open-source design ($\bar{x}=3.8333$) and adoption of material passport as a design decision support tool ($\bar{x}=3.7222$).

There are 8 approaches in the construction stage, apply an on-site waste management plan is the most significant approach among them ($\bar{x}=4.4028$). Second go to off-site manufacturing and prefabrication ($\bar{x}=4.2778$) followed by application of reusable and recyclable materials as primary construction materials on-site ($\bar{x}=4.2500$), set up waste collection point according to waste type ($\bar{x}=4.1111$), evaluate the potential for salvage used products at the end of construction phase ($\bar{x}=4.0417$), use of resins and renewable materials for substrates ($\bar{x}=3.9167$), information on the location and connection method of the components be documented ($\bar{x}=3.8889$) and lastly application of 3D printing. For the operation stage there are two significant approaches which document the information of building keep up to date ($\bar{x}=4.2778$) and design the building with easy access to any repairs and upgrades of a construction ($\bar{x}=4.1250$). In the end of life stage, there are a total of 5 approaches and are considered significant. They are reuse of building components, selective deconstruction, closed-loop and open-loop recycling, redesign the building by reuse of the components and expand or contract the structure.

CONCLUSION

This study has explored the integration of circular economy concept in the construction industry, which were termed as sustainable construction as responds

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towards sustainable development. In the context of building construction, sustainable construction aims to improve the existing ways of constructing buildings. Sustainable construction literature documented that, there are many models being developed purposely to enhance sustainable building construction, but there is only a minor study focusing on shifting from linear economy to circular economy in the construction industry. The shift to circular economy model can be done through the integration of the factors, approach and strategies included in Figure 1, which help in CE transition into building life cycle. Therefore, the objective of this study was achieved through the development of strategy for the adoption of CE in CDWM for encouraging the transition from linear economy to circular economy.

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Table 1: Strategy on the adoption of CE in CDWM

BUILDING LIFE CYCLE STAGE	FACTORS (INPUT)	APPROACH (PROCESS)	STRATEGIES (OUTPUT)
Design and Planning	<ul style="list-style-type: none"> • Change in design. • Design error • Unclear client specifications • Poor communication problem • Designer not familiar with alternative products 	<ul style="list-style-type: none"> • Effective design strategy. • Optimize material choice • Open-source design • Visualize salvage performance of building through BIM • Develop waste management plan • Adoption of design for disassembly • Adopt material passport as design support tool. 	<ul style="list-style-type: none"> • Reduce • Design for Disassembly • CDWM plan • Material Passport
Construction Stage	<ul style="list-style-type: none"> • Lack of waste management plan • Low quality of supervision • Poor storage system • Poor workmanship • Construction method • Defective materials • Complex design • Building shape 	<ul style="list-style-type: none"> • Apply waste management plan. • Off-site manufacturing & prefabrication • Reusable & recyclable materials as primary construction materials on-site • Set up waste collection point according to waste type information on the location and connection method of the components. • Apply 3D printing. 	<ul style="list-style-type: none"> • Reduce • Reuse • Recycle • Design for Disassembly • CDWM Plan • Collection & Segregation
Operation Stage	<ul style="list-style-type: none"> • Hard to access for repair & update. • Lack of information on building components • Information on building did not keep up to date. 	<ul style="list-style-type: none"> • Document the information of building keeps up to date. • Design the building with easy access to any repairs and upgrades of a construction. 	<ul style="list-style-type: none"> • Reduce
End of Life Stage	<ul style="list-style-type: none"> • Demolition work • Building material could not be reused or recycle. • Building design not flexible & update 	<ul style="list-style-type: none"> • Reuse of building components • Selective deconstruction • Closed-loop & open-loop recycling. • Redesign the building with reused components. 	<ul style="list-style-type: none"> • Design for Disassembly • Selective deconstruction • Reuse • Recycle

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