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Sustainable Approach to Managing Construction and Demolition Waste: An Opportunity or a New Challenge?

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ABSTRACT: The handling of wastes remain a perpetual problem, all construction and demolition works and activities are confronted to this issue. Many investors, clients, construction and demolition professionals consider C&D waste management one of the most essential green construction practices in support to energy efficiency. In fact, there is a growing interest in sustainable waste management as potential stakeholders are pursuing innovative and integrated waste management and environmental strategies. Sadly, most traditional approach to reducing C&D waste is considered to be unsustainable as it lacks flexibility and long-term reliability. Thus, the move to a more sustainable society requires sophisticated approach to manage C&D waste, which incorporate feedback loops and focus more on processes, embodies adaptability and diverts waste from landfill disposal. This paper review current C&D waste management practices and propose a conceptual framework for optimising C&D waste management. The study adopts a Life-cycle (LCA) model based on C&D waste sustainability measure (LCASM) to justify the need for a green approach to C&D waste management. The central focus of the LCA model is to minimise C&D waste disposal and to enhance the application of 3Rs (reduce, reuse, recycle) concept. The study sought to determine whether this sustainable approach to C&D waste management is an opportunity or a new challenge. Recommendations are provided on how to enrich C&D waste management optimisation processes.

KEYWORDS: Construction and demolition (C&D) waste, green initiative, sustainability, 3R's principle, Life-cycle Analysis (LCA), Factor Analysis (FA), Analytic Hierarchy Process, waste management.

I. INTRODUCTION

The construction industry have been challenged by the unacceptable levels of waste generation over the years [1] Today, the construction industry has become increasingly aware of the importance of both economic and environmental impacts associated with waste generated during both the construction of new buildings and the demolition of old structures [2]. This is as a result of the significant amount of construction and demolition (C&D) waste generated which as huge impact in contributing to environmental damage both nationally and internationally [3, 4]. It is important to understand the C&D waste system which covers a broad range of building materials is often categorised as: waste arising from total or partial demolition of buildings and/or civil infrastructure, waste arising from the construction of buildings and/or building civil infrastructure, social, rocks and vegetation arising from site clearing, earth moving, civil works and/or excavations for foundations and materials arising from road construction and maintenance works [5]. With the increase in C&D waste generation through construction activities, the construction industry has been challenged with issues relating to economic and environmental impacts resulting from lack of waste minimisation techniques.

The economic and environmental benefits expected from C&D waste minimization are relatively essential [6, 7] as it provides key benefits to both the environment and the construction sector. Sadly, one of the key challenges to waste minimization is inability to apply a more sustainable approach and devise proper management strategy in order to reduce and/or prevent construction waste stream.Sustainable construction has received much attentionthroughout the world over the last few years. The concept of sustainable construction is relatively new to the construction industry and

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it often depicts the following attributes: a social progress, which recognizes the needs of everyone, effective protection of the environment, prudent use of natural resources, and maintenance of high and stable levels of economic and growth and employment [8]. According to BREEAM's definition [9] sustainable design and construction is concerned with implementing sustainable development at the scale of individual sites and buildings. It takes account of the resources used in construction, and of the environmental, social and economic impacts of the construction process itself and of how buildings are designed and used. The term sustainability may seem like a new name or an old concept with direct links to energy conservation, natural resource preservation, or waste reduction at its full potential. Today's concept of sustainability embraces all these ideas and maybe more, as the society at large pursue integrated approaches to green initiative [10]. The idea of sustainable development seems to be the best practice solution to managing C&D waste within the construction sector in order to enhance the durability and use of recycled materials as well as eliminating the development of building waste throughout the construction life cycle [1]. The significant improvement in construction site practices worldwide have led to C&D waste reduction through the reuse/recycle operations.

Table 1: C&D waste category and its sustainability potential: opportunities with reuse/recycle

C&D waste composition	Reuse/recycle Operations/Opportunities	Landfilling Potential	Composting/incineration	Market opportunity	Job creation
Paper/Cardboard	Composting, fire kindling, new product development (paper production)	No	Yes	Yes	Yes
Glass	Recyclable to new product (new glass development)	No	No	No	Yes
Metal	Reusable and recyclable to metal components	No	No	Yes	Yes
Hard-core	Reuse of rock, silt, rubbles for potential local market	Yes	No	Yes	Yes
Plastic	Plastic is recyclable to new product development	No	Yes	No	Yes
Building Materials	Reuse of salvage material for potential market	No	No	Yes	Yes
Plasterboard	Recycled gypsum board to new product, crushed wall as clay and silt mixture subject to compost	No	No	No	Yes
Wood	Recycled wood to create veneer board/paper pulp and reused wood product for potential market	Yes	Yes	Yes	Yes
Concrete	Recycled aggregate for civil works, road construction and modular panels	Yes	No	No	Yes
Soil, Sand & Gravel	Reuse soil/sand/gravel via excavation for potential market	Yes	No	Yes	Yes

This paper review the different applications used in current C&D waste management practices and further propose a conceptual framework for optimising C&D waste management. The study adopts a Life-cycle model based on C&D waste sustainability measure (LCASM) to justify the need for a green approach to C&D waste management. The proposed model focused on the minimisation of C&D waste disposal and the enhancement of the application of 3Rs (reduce, reuse, recycle) concept. The study sought to determine whether this sustainable approach to C&D waste

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management is an opportunity or a new challenge. Finally, the paper concludes with a recommendation to enrich C&D waste management optimisation and a summary of key research findings.

II. CHALLENGES AND OPPORTUNITIES FOR C&D WASTE MANAGEMENT

C&D waste generation

Construction and demolition (C&D) materials are generated when new structures are built and when existing structures are renovated or demolished.Structures include all residential and non-residential buildings, as well as public works projects, such as road, bridges and dams [10]. Materials resulting from construction and demolition of buildings and infrastructure constitute a significant amount (10-15%) of the total municipal solid waste stream [4].The UK generated 200 million tonnes of total waste in 2012. Half of this (50%) was generated by Construction, demolition, renovation and refurbishment works. Commercial and industrial activities generated almost a quarter (24%), with households responsible for a further 14%[11]. For the most part, construction wastes are largely slothful. The key challenge is that construction waste is bulky, solid to compress and often occupies space in overstrained and confined municipal landfill [8]. Reducing C&D waste is a priority for the European Union and the UK Government and there are many new regulations, measures and targets to reduce waste within the construction industry [11].Figure 1 below shows both construction and demolition waste composition at various stages in the UK in 2014. The key challenges with the generation of large amount of C&D waste on many construction sites is to apply operations such as reuse and recycle techniques which final leads provide sustainability in construction and demolition works and often led to the development of new products.

(1) (2)

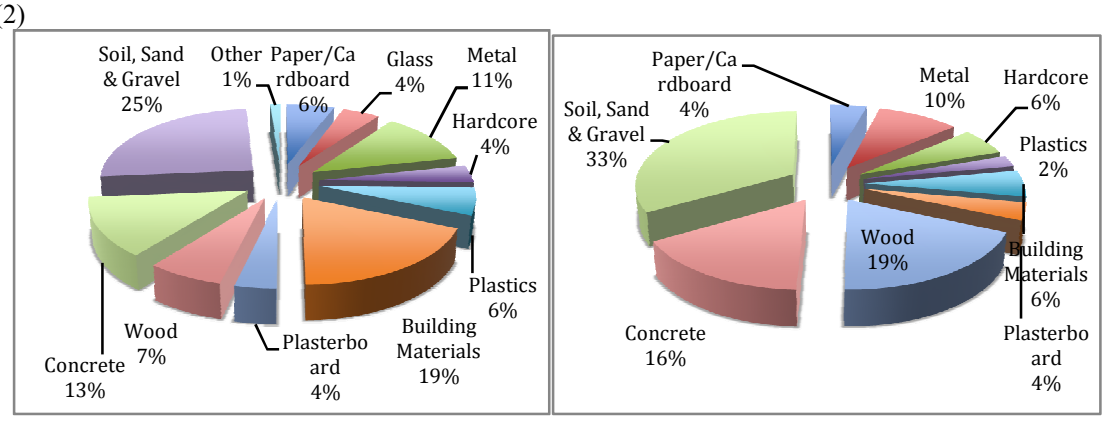

Figure 1: C&D Waste streams at various stages of construction and demolition: (1) Construction Waste Composition, (2) Demolition Waste Composition (Source ONS, output in the construction/demolition sector, 2014).

Opportunities with C&D waste

Good practice in construction and demolition materials recovery facilities have driven the increase awareness of sustainability with the construction industry. Recovering of non-inert C&D materials requires strategic approach with measurable objectives. There a lot of cost saving by reducing the amount of C&D waste developed. Source reduction, however decreases disposal costs, lowers labour costs because less materials must be handled and cut and reduces spending for materials because less is wasted [12]. When site space allows, on-site source separation of C&D materials can yield reduced or eveneliminated tipping fees. In the case of steel and other metals, revenue can be received fromsalvage value.Time-based removal of C&D materials can be an effective method of segregating materials onsmaller projects [13]. C&D waste amount to about 17% of the total waste in the United Kingdom being reused and recycled as opportunities continue to grow over time [14].

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Sustainable Approach – A pursuit for 'green' initiative

There had been a competitive race for sustainable development across the world, primarily in the construction industry. Green initiative in construction was driving by the need for sustainable development. Since 2012, there have been significant efforts to fulfil the sustainable approach to C&D waste by investing on "*Halving C&D waste to Landfill"*as implemented by the UK Sustainable Construction Strategy [15]. This initiative sets a national target to "*Zero C&D waste"* to landfill by 2020 as UK Government continue to embark on a long term ambition to end the disposal of C&D waste in landfill as far as practicable. In order to meet the target set for 2020 national policy on waste management has been strengthened by preparing for a more sustainable approach to reuse, recycle and other material recovery practices [15]. Following the pursuit for green initiative, a number of fiscal and regulatory measures such as landfill taxes, aggregate levy, Site Waste Management Plan, BREEAM standard (offering credit for diversion of C&D from landfill 75% by weight and 65% by volume) are already driving resource efficiency [16].

Green Initiative vs. Traditional Waste Management

There are clear distinctions for values derived from green initiative (sustainable C&D waste management) and the system used in landfill disposal site (traditional waste management). Green initiative to managing C&D waste include all forms of reducing, reusing, recycling as well as waste-to-energy projects. This idea seemed to conserve energy, preserve natural resources and/or maximise waste reduction at its full potential. It is considered that most traditional approach to reducing C&D waste is considered to be unsustainable as it lacks flexibility and long-term reliability. By reducing the amount of waste being diverted to landfill the value of waste can be justified and re-evaluated in terms oflong-term vision. There are also great opportunities found with reducing C&D waste such as best practices, recognitions and award, high revenues generation and job creation. However, there is a need for green initiatives to be re-evaluated in terms of new technologies and the provision of essential knowledge of logistics, operations and the regulatory context.

Design out Waste

The ultimate goal of sustainable approach to C&D waste is to strategically reduce the amount produced. The site waste management practices across the world have been able to fulfil this vision. Arguably however, the best opportunities for enhancing materials resource efficiently in construction projects occur during the design stage [17]. Implementing these possible opportunities can further provide huge reductions in cost, waste and carbon emissions. Designers often use five key principles (design for reuse and recovery, design for off-site construction, design for materials optimisation, design for waste efficient procurement and finally design fro deconstruction and flexibility) these five principles are mostly guided by an extensive consultation, research and work carried regulatory bodies. It is quiet important to understand the design for reuse of material components and/or entire building has substantial potential to reduce the environmental weights from construction. With reuse, the effective life of materials is extended and thus annualised weights are spread over the years. Reuse, on the other hand in the waste hierarchy is generally preferable to recycling, where additional processes are involved [18]. The advantage of designing for off-site construction are well discussed in modern times as this process has potential in reducing C&D waste.

Implementing 3R's Principle

C&D waste management is required to be carried out after passing different stages. Figure 2 below indicated the various stages required for waste management based on hierarchical model as suggested by Peng et al. [18]. These authors recommends that waste management should be executed by reducing, reusing and recycling of C&D waste. However, certain events such as avoidance and minimisation, which further depicts the reduction, process alongside the recycling operations, which are considered to be desirable. Waste management concept is guided by level of hierarchy known as the 3R's principle explained by El-Haggar in 2007 [19]. This model produces an integrated approach in which options of waste management can be considered and thus serves as a systematic tool for those who generate and manage waste [20].El-Haggar argued that when waste is being managed effectively it could generate various benefits

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through the whole life cycle of the waste from its generation to its end disposal [20]. Significantly, it is believed that proper construction waste management will provide both economic and environmental benefits.

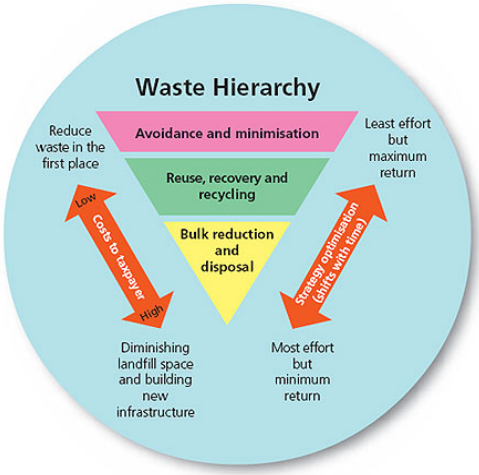

Figure 2: Waste management hierarchy model

Environmental Impact of 3Rs principle – Energy recovery

The application for 3Rs (reduce, reuse and recycle) principle is considered to have both economic and environmental benefits. However, the underlying question is *"how to do energy recovery by means of 3R principle?"*. A new model was developed in early 2011 for recovering energy based on 3Rs principle [21]. It is clear that the 3R principle of waste management hierarchy was introduced to fulfil its aim by providing the most preferred option to effectively and sustainably managed waste. All construction and demolition processes such as designing, constructing often leads to waste development and often managed by 3Rs principle, which is important to the 'green initiative' as provided for sustainable construction [2]. Energy is effectively recovered to this process with the intension to be beneficial to the entire environment on a long term.

Life Cycle Assessment – A sustainable approach to C&D waste

On a broader perspective, environment impact and concern are considered for all waste products either solid or non-solid waste and these forms a resource standpoint where waste hierarchy leads to the most resource-efficient and environmentally sound choice and positive outcomes. Lifecycle assessment support decision-making in the field of waste management and also helps to determine environmental viability. The LCA is a popular tool used to investigate the potential environment impact, throughout a product's life. The LCA methodology was first developed by ISO standard by considering four phases, namely, goal and scope definition, inventory analysis, (input/output), impact categories and interpretations. By analyzing the positive and negative environmental effects of all kids of projects or products, LCA pose as a reliable tool considered for several areas to analyze and to evaluate different alternatives. Huang et al. [23] adopt LCA to evaluate environmental impacts of using recycled materials in asphalt pavements. The authors evaluated relevant LCA model can be used a decision support tool for sustainable construction in the road industry. Other relevant LCA studies [24, 25, 26] on construction waste management as the study of Cherubini et al. [24] discouraged the diversion of construction waste to landfill in relation to environmental impacts. The integration of LCA in the construction sector as two perspectives (1) building material and (2) construction processes. These two elements further relate to C&D waste management phases: pre-construction phase, construction and renovation as well as demolition phase as indicated in figure 3 below.

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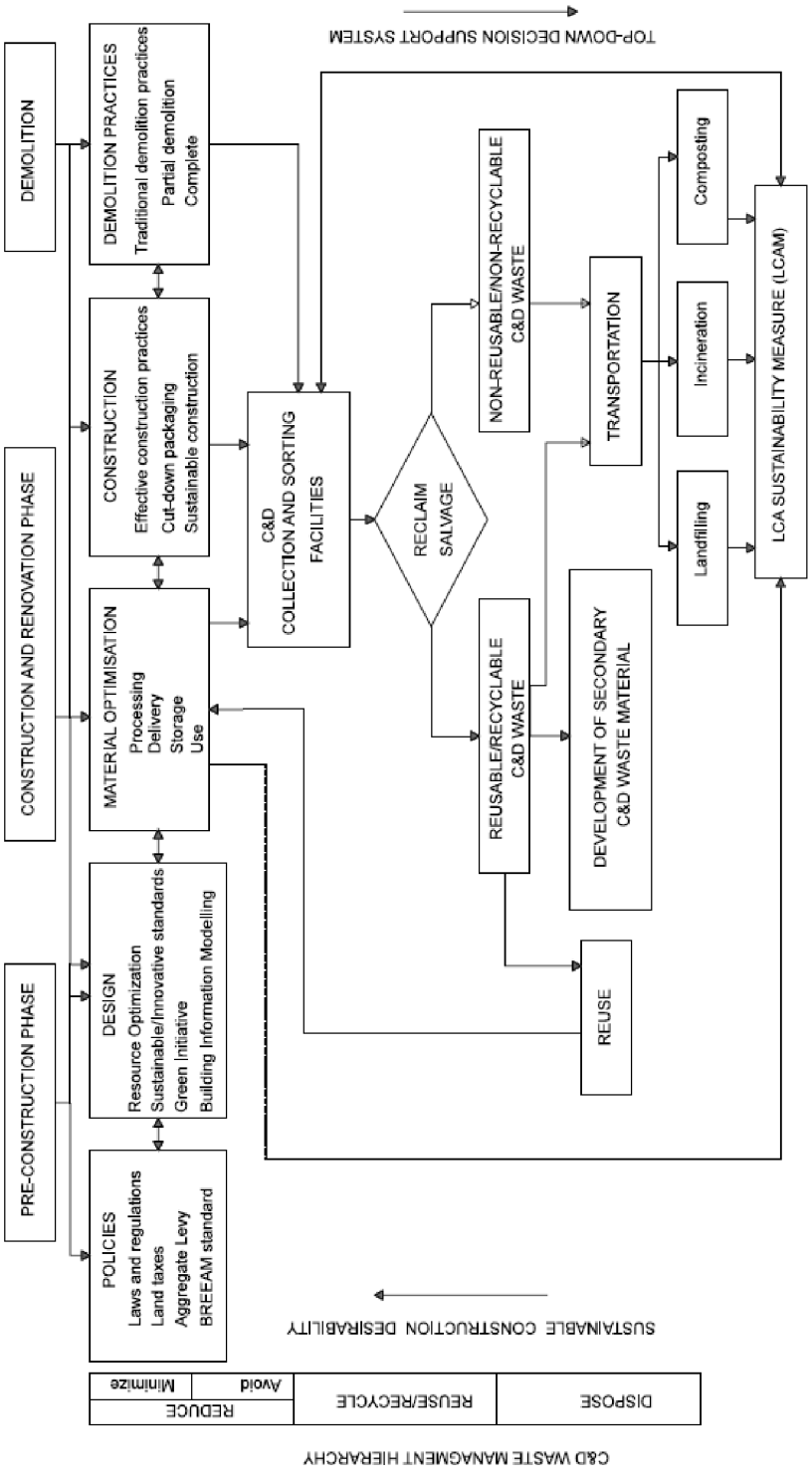

Figure 3: Conceptual framework for C&D waste management flow system using LCA mapping

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Information provided in figure 3 shows that each stage of the construction project life cycle consider C&D waste management hierarchy using the 3Rs (reduce, reuse and recycle) principle.The LCA inventory covers the input and output and that impact outcomes are derived from the inventory data processed. The life cycle map is developed to explain the waste material flow from the system start to finish. Sustainable approach to the waste flow system often supports reuse and recycle and reduction of disposal to landfill. Energy saving and natural resources are often conserved by reuse and recycling operations and the fact that there is a significant reduction of waste being diverted to landfill, the environmental concern can be easily addressed through this initiative.

Pre-construction phase – Planning and Design

The early stage of construction often cover the planning and design phases which are considered very thorough through a construction project life cycle. Designers such as architects, civil engineers, and CAD technicians are expected to design building following guidance from the WRAP "design out waste" [17]. Thorough consideration is giving to standard sizes, densities, positioning and height to improve the process of waste minimization and predominantly to achieve significant cost savings in construction. Recyclable/secondary building materials are required to be incorporated in design at the pre-construction. Architects have a major role to play in providing the right specifications when designing out waste. This approach presents a proactive target options to reduce waste, recognizing that some key solutions on a project are most likely to achieve waste minimization, along with cost savings, carbon reduction and other related benefits. Solid waste management practices have identified the reduction, recycling, and reuse of wastes as essential for sustainable management of resources.Addressing problems of C&D waste and best practices for most designers are assumed to be the avoidance of waste during design phase as it helps many to identify early problems with design concepts [26]. At the preconstruction stage of many construction project, local and national regulations and laws applies as well as incentives to encourage professionals to embark on the use of 3Rs concept. The introduction of the Site Waste Management Plan have helped many professionals to significant cut down the amount of waste through construction and demolition works. Most importantly, the introduction of the BREEAM standard, which offers credit for diversion of C&D from landfill 75% by weight and 65% by volume, continue to improve resource efficiency [16]. To move towards a more sustainable approach to waste management for construction and demolition projects the pre-construction phase consider the use of Building Information Modelling (BIM).

Building Information Modelling (BIM) – Application on Waste Reduction

Building Information Modeling (BIM) is changing how buildings, infrastructure, and utilities are planned, designed, built, and managed. This unique tool is a process involving the generation and management of digital representations of physical and functional characteristics of places. Quantitative waste prediction is crucial for waste management. It can enable contractors to pinpoint critical waste generation processes and to plan waste control strategies. In addition, waste estimation could also facilitate some government waste management policies on local taxes, recycling rate, and aggregate levy [27]. BIM is considered a type of estimating tool that can accurately and conveniently estimate the amount of waste from construction, renovation, and demolition projects. The concept of green building and sustainable design is becoming a main factor for change in construction projects within the built environment owning to its effectiveness on reducing energy consumption and material usage. BIM plays an important role with regards to reducing waste during design and pre-construction phase. BIM filters into the major generation source of waste and eliminates the non-value adding activities that are nor consistent or necessary [28]. The premise behind BIM is coordination of among all stakeholders in different phases over the lifecycle of a facility that will help to insert, extract, update or modify information. BIM provides a design team with a tool to evaluate the impact of the design decisions on the overall construction process with the assistance of virtual prototyping on the other hand; it is widely acknowledge that associating BIM with development and use of 3D parametric, 4D time dimension and 5D which is the quantities and costs of material. BIM solutions for C&D waste reduction include conflict, interference and collision detection, construction sequencing and construction planning, reducing rework, synchronizing design and site layout and detecting errors and omission in design [28].

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III. LCA SUSTAINABILITY MEASURE (LCAM)

Measuring sustainability within the C&D waste management system is not an easy task. To quantify the amount of waste system under study requires certain parameters used by decision makers. Both qualitative and quantitative measure is considered for the LCA measurement. To measure the amount of C&D waste within the system flow, information is collected and measure against based criteria and parameters. LCASM parameters are shown in figure 3 and are further divided into two elements (1) the criteria set include economic, environmental and social impact for C&D waste processing, storage, transportation and disposal (2) weightings of the LCAM based on decision makers input. Figure 4 shows the hierarchical process of estimating C&D waste management system flow via LCA.

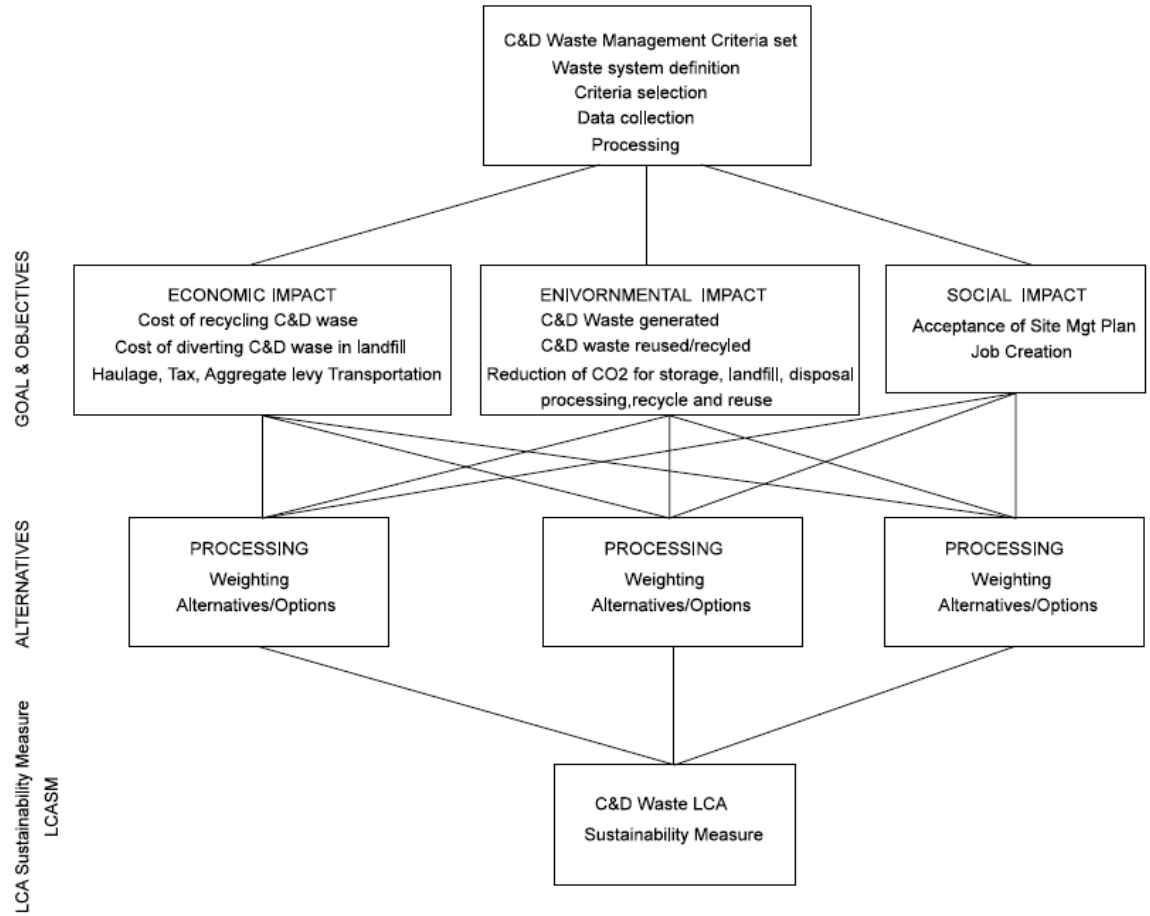

Figure 4: Hierarchical process for estimating C&D waste management system flow

The first step involved in the LCASM is the selection of suitable parameters linked with the three criteria set (economic, environmental and social impacts). The evaluation of C&D waste management with its sustainable potential, basic performance measure is considered in terms of the environment measure in terms of reduction of carbon emissions through transportation, storage, processing, landfilling, composting, recycling and reuse operations. Both economic and social impact relate to cost-saving capability of recycling, landfilling, recycling gate fees, haulage, aggregate levy and local taxes, social acceptance, job creation are considered. The social impact measure under the LCA inventory category helps to determine the extent of social acceptance of Site Waste Management Plan, recycling

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operations, and job creation through various reuse/recycling operations. The goal and objective set for measuring the economic, environmental and social impact of C&D waste forms the three pillars of sustainability. To successfully justify the measure for LCASM, the weighting system is normalized and aggregated. Choosing alternatives or options to C&D waste management requires decision maker's preferences. The parameters considered for LCASM is introduced to understand how (economic, environmental and social) impact affects the successful optimisation of C&D waste management. The weighting systems consider different alternatives for managing C&D waste system. However impact categories for LCA such as economic, environmental and social impacts are directly linked to sustainable measure of successful C&D waste management techniques. Detailed discussion of expert information incorporating both quantitative and qualitative criteria with numerous levels of criteria can be found with popular weighting models such as Analytic Hierarchy Process (AHP), Factor Analysis (FA), and Equal Weighting (EW) respectively.

Implication to Current Practice

The current state of managing C&D waste still pose some challenges as more techniques are introduced in recent times. The current C&D waste practices. There are many other impacts categories (i.e. noise and vibration disturbance, global warming, greenhouse gas, CO_2 emissions etc.) for C&D waste management. Arguably, there are limitations to waste management techniques performed locally and internationally.For example, rate of developing recyclable and reusable waste materials often varies from regions, districts, and construction sites.With the growing concern about global warming and basic environmental concerns, estimating actual greenhouse emission has become relatively impossible for future predictions. The use of LCA model has its downside in terms of uncertainties in waste material flow system [29]. C&D waste systems are effectively managed and investigated within a set time frame and schedule by the help of LCA with great attention of justifying the environmental impact. Thus, the technology used in such process often varies in a number of districts as waste management facilities to becoming more location-specific. This results to the challenges facing sustainable approach to managing waste as the broader the extent of measurement the more the uncertainty in using varieties of techniques for waste management in current practice [24]. The three pillars (i.e. environment, economic and social) of sustainability have become a popular criteria t be consider in terms of LCA measure. However, C&D waste management have pose some kind of opportunities to explore these three measure as the opportunities found in recycling and reusing C&D waste are far more seen visible in terms of job creation, cost savings and conserving natural resources [25].

IV. RECOMMENDATIONS

The C&D waste management practices have successful account for carbon emissions, social impact such as acceptance and employment opportunities as well as the cost-savings initiatives. Thus, these impact categories still face challenges today as sustainable construction seemed to attract the entire society. To enrich the C&D waste management optimisation processes there is a need to rethink the techniques considered for recycling and reusing C&D waste management and access the opportunities within these processes. To maximise the full reduction of C&D waste, the BIM tool have proven its worth in waste reduction as the tool can accurately and conveniently estimate the amount of waste from construction, renovation, and demolition projects. Using BIM tool, the construction industry have been able to demonstrate on-time project delivery and zero waste initiative in the last few years. Thus, the 3R's principle remains an ultimate fundamental concept that assist in achieving sustainable construction desirability.The study, however, recommends that to incorporate sustainable approach to C&D waste, it is essential to consider the right model to access sensitive impact categories not only economic, environment and social but also institutional and political challenges to C&D waste management. LCA model continue to become a sustainable tool that provides a more comprehensive analysis and assessment of environmental impact of a products or processes. Significantly, LCA often helps in reducing the impacts of processing C&D waste system at designated facilities. For the weighting systems where goal/objectives are measure against individual criterion and alternatives to C&D waste, the Analytic Hierarchy Process (AHP) model continue to outperform other similar models as its focus more on providing expert information incorporating both quantitative and qualitative criteria with numerous levels of criteria, Thus, the opportunities found within this model are far more than the challenges seen within.

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V. CONCLUSION

There is plenty of interesting way to demonstrate the benefits derived from managing C&D waste within the construction industry. One of these ways is by meeting the sustainable construction needs and providing value for many construction projects. The use of innovative tools such as LCA, AHP, FA etc. gave a better approach to weighing various options for effective management of C&D waste. However, sustainable approach to C&D waste management cannot be performance without its challenges. The opportunities within this process outnumber that found in challenges within. Job creation through various stages of C&D waste processing, disposal and transporting have given the social value of effective management of C&D waste. This paper reviewed available and current waste management practices and provide implication to practices. The paper further proposed conceptual framework for C&D waste management flow system using LCA mapping. This framework considers the fundamental principle of 3Rs (reduce, reuse and recycle) and exploded this principle into an integrated LCA platform for C&D waste management with the consideration for four key project phases (i.e. pre-construction, design and construction, renovation and demolition). The proposed framework suggest that there are significant reduction of waste material at the design stage with reference to local laws and regulation, taxes, aggregate levy, BREEAM standard and the use of BIM tool. Sustainable approach to C&D waste incorporates these important factors and further provides a roadmap to how impact categories can be justified. Finally, the development of the LCA sustainable measure (LCASM) in the conceptual framework is intended to help decision makers to make inform decisions in relation to selection of various alternatives to managing C&D waste.

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