Waste Effectiveness of the Construction Industry: Understanding the Impediments and Requisites for Improvements.

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Abstract

Construction industry contributes a large portion of waste to landfill, which in turns results in environmental pollution and CO_2 emission. Despite the adoption of several waste management strategies, waste reduction to landfill continues seeming an insurmountable challenge. This paper explores factors impeding the effectiveness of existing waste management strategies, as well as strategies for reducing waste intensiveness of the construction industry. Drawing on series of semi structured focus group discussions with experts from the UK leading construction companies, this paper combines phenomenological approach with a critical review and analysis of extant literatures.

Five broad categories of factors and practices are responsible for ineffectiveness of construction and demolition waste management strategies, which subsequently results in waste intensiveness of the industry. These include end of pipe treatment of waste, externality and incompatibility of waste management tools with design tools, atomism of waste management strategies, perceived or unexpected high cost of waste management, and culture of waste behaviour within the industry. To reduce waste intensiveness of the construction industry, the study suggests that six factors are requisites. These are tackling of waste at design stage, whole life waste consideration, compliance of waste management solutions with BIM, cheaper cost of waste management practice, increased stringency of waste management legislation and fiscal policies, and research and enlightenment. The proposed strategies are not only important for achieving low waste construction projects, they are important for reducing waste intensiveness of the construction. Implementation of the suggested measures would drive waste management practices within the construction industry.

Keywords: Effective Waste management; Landfill; BIM; Construction waste; Reuse and recycling.

1. Introduction

Owing to its waste intensiveness and consumption of large resources, construction industry has particularly remained a major target for environmental sustainability (Anderson et al, 2002). Evidence shows that the industry consumes up to 50% of mineral resources from nature (Anink *et al*., 1996) and generates up to 35% of waste to landfill (Solís-Guzmán *et al.,* 2009). It also contributes over 33% of global CO_2 (Baek *et al.,* 2013). In addition, waste reduction and reduced resource excavation have significant economic benefits (Coventry and Guthrie, 1998). Evidence shows that reducing construction waste by 5% could save up to £130million in the UK construction industry (BRE, 2003). Although these clearly show that reducing waste generated by construction activities tends to provide both economic and environmental benefits, waste generated by Construction and demolition (C&D) activities remains alarming. These concerns have influenced formulation of various strategic policies towards diverting construction waste from landfill sites.

Several waste management techniques and strategies have been adopted over the years, with ability to efficiently manage waste becoming criteria for measuring successful construction operations. Governments across nations have formulated various strategies towards minimizing waste to landfill, thus becoming a major driver of construction waste management in many regions (Yuan, 2013). For instance, in a bid to ensure that economic growth associated with increasing construction activities does not result in increasing waste and environmental pollution, waste management across the entire project lifecycle remains a top priority of the European Union’s Environment Action Plan (EU, 2010). These set of policies often become reviewed over the years to express change in government approach towards tackling impending environmental problems associated with waste generation.

While government’s efforts towards waste management is usually influenced by environmental concerns (Defra, 2011), financial gains associated with the strategies usually influence the industry professionals (Al-Hajj and Hamani, 2008; Oyedele *et al*., 2013). As such, economic benefit of implementing different waste management strategies is well investigated (Begum *et al.,* 2006; Durana *et al.,* 2006). However, the efficacy of Construction and Demolition (C&D) waste management strategies and associated Life Cycle Analysis (LCA) towards actual waste minimization are usually based on general assumptions, thus remains inadequately explored. Yuan and Shen (2011) reviewed trends in C&D waste management research and concluded that although various strategies have been employed towards managing waste in construction projects, there is no benchmark for determining effectiveness of the different approaches.

In addition, evidence shows that despite increasing waste management research and policies, proportion of construction waste landfilled increases. For instance, proportion of C&D waste in UK landfill sites increases from 33% in 2010 (Paine and Dhir, 2010) to 44% in 2013, according to the Department for Environment, Foods and Rural Affairs. This increasing proportion of C&D waste is not necessarily because of increasing construction activities. Rather, while other sectors have effectively put a check on their waste going to landfill through a set of proven strategies, waste landfilled by construction industry remains alarming. As such, there is a decrease in rate of landfill waste from household, industrial, commercial, mining and other activities (DEFRA, 2013). This suggests that existing strategies for managing construction waste remain largely ineffective and poorly conceptualised.

Meanwhile, Van Manen (1990) suggests that when an important phenomenon has been poorly conceptualised, a phenomenological approach is required to correct the misapprehensions. Phenomenologists believe that by putting asides the general belief about a concept and interacting with key players, it is possible that a new meaning and understanding could be derived (Crotty, 1998). Although, continuous efforts are being made towards diverting waste from landfill, opportunities offer by phenomenological understanding of waste management strategies is yet to be explored. In order to understand the impediments to effective waste management, this study approach the problem from phenomenological perspective. The overall aim of this study is to scrutinise construction waste management techniques in a bid to identify impediments and strategies for improving their effectiveness.

To achieve this goal, the study would fulfil the following objectives:

1. To identify and evaluate existing construction waste management strategies towards understanding impediments to their effectiveness.
2. To suggest strategies/framework for improving waste effectiveness of the construction industry.

Unlike other studies seeking to develop waste management strategies, the focus of this study is to illuminate factors hindering effectiveness of the existing strategies as well as measures that could be put in place to improve rate of diverting whole-life C&D waste from landfill. This paper offers insights into factors and strategies to be considered to achieve effective waste management strategy. It would assist both construction professionals and policy makers in understanding impediments that hinder effectiveness of existing waste management techniques as well as strategies required for their improvement.

2. Construction Waste Management Strategies

Apart from waste landfill, which has been widely discouraged as a waste management strategy, several strategies are being employed towards diverting waste from landfill. Summarised in Figure – II, the existing waste management strategies are briefly swotted below.

2.1. Sorting and Recycling

Waste recycling has been widely adopted in many industries, among which the construction industry is not left out. This strategy has been recognised as the next line of action in a bid to prevent waste landfilling, the oldest and most environmental harmful form of waste treatment (Manfredi *et al*., 2009). Recycling is one of the strategies adoptable after waste has occurred and it involves sorting of the waste materials into "recyclable and non-recyclables" during the construction activities or at the recycling site (Barros *et al*., 1998). The option of site sorting has been widely encouraged across the UK, as it eases recycling operations and ensures accurate separation of inert and non-inert materials (Poon *et al*., 2001). The strategy is not necessarily an approach for reducing waste in construction activities, but it proves valuable due to its tendency to divert waste from landfill sites. In addition, recycling as a waste management strategy ensures that waste materials are reprocessed to produce derivative materials, which replace the need for the use of virgin materials for materials production. It therefore saves the environment from pollution due to materials excavation, transportation and processing (Davidson, 2011; Treolar *et al*., 2003).

Peng *et al.* (1997) argues that substantial recycling operation, with respect to construction waste, has helped communities in freeing up large spaces in their landfill sites as construction and demolition usually generate large waste. Corsten *et al*. (2013) believe that an effective recycling operation saves an additional annual emission of 2.3MtCO_2 in Netherland. A typical Japanese building constructed of recycled materials would save at least 10% of energy need according to Gao *et al.* (2001). Other benefits in forms of job creation and economic gains are also claimed to the credit of recycling as a strategy for waste management. However, several pre-requisite are important to the success of recycling operation. A substantially large area of land of not less than 0.8 hectare, easily accessible site, experienced recycling specialists as well proper recycling equipment (Peng *et al*., 1997) such as screeners, crushers and wind-sifting are expected of a typical recycling site. Dedicated construction professionals available to adequately sort the waste materials play major part in successful recycling operations.

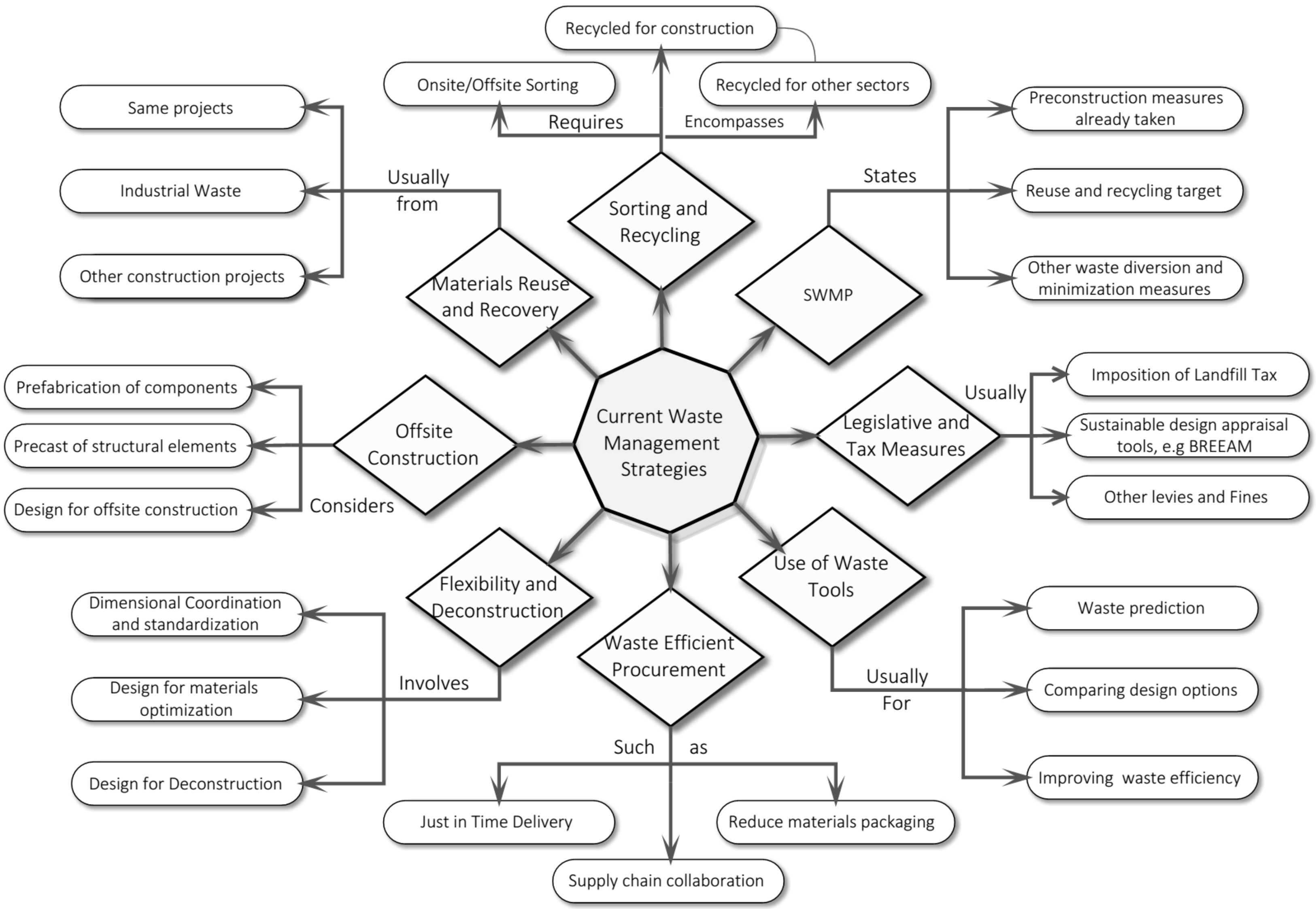

Figure I: *Summary of Existing Waste Management strategies*

2.2. Materials Re-Use

Materials reuse is an essential approach to diverting waste from landfill sites. Unlike recycling, materials reuse involves the use of the materials with little or no alteration to its physical state, and without any change to its chemical constituents (Guthrie and Mallet, 1995). In the Construction industry, material re-use has been adopted as a means of diverting own waste as well as domestic and other industrial waste from landfill. Construction demolition materials have been widely reused for land reclamation, road surfacing, and as constituents of concrete aggregates. Coal fly ash is also a valuable material, of industrial origin, being used to replace percentages of cement in concrete mix and rendering materials (Halliday, 2008). Materials leftover, off-cuts, excavated soil, etc., generated from construction sites have also found use in the same or other projects.

2.3. Use of Waste Prediction Tools

In order to effectively manage waste in construction projects, different means of measuring and predicting likely project waste have emerged in the industry. It involves the use of different tools, usually at the design stage, to predict potential waste arising from construction process. NetWaste is one of the most popular tools used in the UK for waste prediction. It assists designers in estimating cost and quantities of waste from the project, and helps in selecting suitable strategy for improving waste effectiveness of the project (WRAP, 2008). Developed by the UK WRAP, NetWaste collects basic project information such as building volume and materials type in order to perform its waste evaluative function. Design Out Waste Tools for Building/Civil Engineers, DOWT-B/DOWT-CE are other tools developed by the same body for, identifying the potentials for designing out waste, recording design solution for waste mitigation, calculating the impacts of such solution, and comparing impacts of different design alternatives for Building and Civil Engineering projects (WRAP, 2010).

Other tools and approaches have been used for projecting construction waste outside the UK. A Spanish model for waste prediction was developed by Solís-Guzmán *et al.* (2009) based on data from 100 construction projects. Components and Global Index measuring waste per square metre and material types respectively were proposed by Jalali (2007). A Singaporean Model for waste score determination, BWAS, was also developed by Ekanayake and Ofori (2004). BWAS was developed for comparing different design scenarios for their waste effectiveness so that adequate mitigation strategies could be taken. These set of tools are employed during the concept and developed design stages of building delivery process.

2.4. Site Waste Management Planning (SWMP)

SWMP is a legislative requirement for construction activities in many nations. In the UK for instance, a legislative framework, SWMP regulation (2008), requires every project above £300,000 to produce SWMP before actual construction activities. Every maintenance, demolition, excavation, alteration, civil engineering project and decoration above the amount was required to produce SWMP before the regulation was repealed in December 2013. Until date, industry professionals are still expected to voluntarily produce SWMP for effective waste management or as a means of ensuring compliance with green certifications such as BREEAM and Codes for Sustainable Homes. Similarly, in Hong Kong, Site Waste Plan was introduced to construction industry in 2003, although it has since received negative feedback from industry practitioners, as it is believed to reduce productivity (Tam, 2008). Waste Management Plan is also an important requirement for planning approval of significant projects in Australia (Hardie *et al.*, 2007).

A typical SWMP involves statement of pre-construction strategies previously taken to ensure waste minimization as well as detail statement of proposed strategies for waste management during and after construction activities. The SWMP is typically aimed to, set waste diversion target, avoid flying tipping, ensure proper waste auditing and segregation, improve efficiency and profitability, and to ensure that adequate measure is taken for waste reduction, reuse and recycling. Usually prepared and managed by site waste managers, the plan proposes the proportion of waste to be reused and recycled, onsite area for waste storage, methods for waste sorting and reduction as well as the stakeholders that would be responsible for waste removal from site (Tam, 2008; McGrath, 2001; Mcdonald and Smithers, 1998).

2.5. Design for Flexibility and Deconstruction

One of the proven approaches to C&D waste management is to design the building for flexibility and deconstruction. A design is flexible if it is able to adapt to both external and internal change. This occurs when a design is optimized to the industry's standard so that its removed materials perfectly fit into another optimized project. During design, the elements of the building system are usually coordinated and standardised, preventing waste due to offcuts which is one of the major causes of waste in projects (Formoso *et al*., 2002). Industry practices submit that change is less costly at pre-construction stages, thus suggesting that dimensional coordination, as a design stage strategy, is an effective precautionary measure to ensure that waste is prevented during construction activities. It is clear that while materials reuse and recycling seek to manage waste after it occur, design coordination offers preventive measures, which is both environmentally and financially preferable. As such, standardizing design for waste efficiency through dimensional coordination tends to be a promising strategy for waste management.

Studies on Life Cycle Analysis (LCA) of building related waste suggests that demolition stage contributes a huge proportion (cf. Yeheyis et al., 2013; Blengini, 2009). A holistic attempt to reduce end of life waste is through the consideration of deconstruction during the design stage (WRAP, 2009). Deconstruction differs from demolition in that while the former involves careful dismantling of the building components in such a way that large proportion of the materials and components supports reuse and recycling; the latter gives little consideration to primary reuse of the building components. Adequate planning for the buildings' end of life, by considering deconstruction at the design and construction stages, would ensure that a large proportion of the materials and components is reused, thereby diverting substantial proportion of demolition waste from landfill.

2.6. Waste Efficient Procurement

Procurement stage is a very vital stage for waste management planning in construction projects. Several causes of construction waste such as packaging materials, double handling, and improper materials storage are all associated with procurement stage. Owing to this, different strategies have been used to ensure waste efficient procurement in the construction industry; these among others include Just in Time delivery (JIT), reduced packaging and improved collaboration between the supply chains.

2.7. Offsite Construction

Existing literatures identified some modern methods of construction as means of reducing waste generation in the industry. These include prefabrication and off-site construction (Tam *et* *al.*, 2005; Jaillon *et al.*, 2009; Lu and Yuan, 2013). Although it is noted that such technique as the use of precast materials might not be purposely done for waste reduction, evidence shows that they are highly effective for waste reduction. For instance, Jaillon *et al.* (2009) and Tam *et al.* (2007) suggests that waste minimization tendency of prefabrication and modular construction results in 52% and 84.7% respectively. This ensures that building elements are manufactured offsite, assembled onsite, while several factors that cause waste such as materials handling, poor storage as well as design changes have been entirely prevented.

2.8. Legislative and Tax Measures

Various legislative and tax measures have been imposed by governments towards diverting waste from landfill. One of such measures is the "Pay as You Throw" ((PAYT), which is a polluter pays principle through which governments have diverted substantial volume of waste from landfill across many nations. PAYT is a unit based pricing through which charges is paid per unit volume or weight of all waste disposed on landfill site, with ultimate aim of discouraging waste landfilling and encouraging waste reduction, reuse and recycling. Before the adoption of variable landfill tax, known as PAYT, other landfill penalties have been imposed without success. In the US for example, a fixed billing that does not vary with quantity of waste have been used; however, it did not show significant reduction in waste compared to the PAYT scheme (Skumatz, 2008). Evidences from other countries such as Greece, Sweden, Canada, Netherland, Switzerland, and the UK show that PAYT scheme substantially reduces burden on landfill sites (Dahlén and Lagerkvist 2010; Browna and Johnstone, 2014; Morris, 1998).

In the UK, cost per tonnage of waste disposed have continuously been upwardly reviewed since it was imposed in 1996, up from £7 and £2 in 1996 (Read *et al.*, 1997), to £80 and £2.50 in 2014 per unit tonnage of active and inert waste respectively. This has made the industry to have a rethink of how waste is managed, especially as financial gains determines the industry's commitment to any waste management strategy (Al-Hajj and Hamani, 2008). As such, most construction firms have formed alliance with recycling and waste disposal companies who help in segregating and processing the waste to divert a substantial portion from landfill sites. Others have weighed the cost of landfilling against cost of other waste management strategies such as materials optimization, sorting and recycling, just in time delivery, low waste technologies, etc., thus selecting cheaper option for their project.

Meanwhile, apart from landfill tax, which is aimed at reducing waste to landfill, other legislative toolkits have raised the construction industry's awareness about waste management. These are not necessarily in forms of strategies, but they have helped in reducing C&D waste. Aggregate Levy introduced in 2001 by the UK government imposes a levy of £1.60, up by £0.4 to £2 per tonne since 2009. It was aimed at reducing consumption of virgin aggregates thereby encouraging reuse of recycled aggregates.

3. Methodology

Despite implementation of several waste management strategies within the construction industry, waste landfilling still remains a major practice within the industry, suggesting ineffectiveness of the existing waste diversion strategies. To tackle this conundrum, focus group discussion was used for collecting data for both epistemological and methodological reasons. Considering the epistemology, the concept of phenomenology is based on tenet that a particular situation could not be truly understood until all presuppositions and preconditions are suspended by a researcher (Holloway and Wheeler, 1996) in a bid to devise new meanings (Crotty, 1998). It recognises the researchers as interpreters of the participants' experience and actions, and it is concerned with the individual perception and account of the events under investigation (Edie, 1987), devoid of objective meanings imposed by the researcher (Smith and Coburn, 2007). The phenomenological approach therefore avail the researchers an opportunity to understand the efficacy of the existing waste management strategy from the practitioners point of view, devoid of every presuppositions. This is deemed suitable, as the approach is suitable in a situation where an important phenomenon has been poorly or wrongly conceptualised (Jasper, 1994; Van Manen, 1990).

From methodological point of view, the use of focus group discussion allows critical examinations of intersubjective opinions among the participants, throughout the course of encounter (Kvale, 1996). The approach helps in gaining in-depth understanding of the phenomenon (Wimpenny and Gass, 2000) by obtaining rich data from the different groups of construction and waste management professionals. The study involved four focus group discussions, carried out on different occasions with design and construction professionals grouped into four key teams, which were sustainability team, construction lean practitioners, designers/design managers and site waste managers. Sustainability team consists of construction professionals whose job roles is to advice, guide and ensure overall sustainability of build processes in their respective organisation. Lean practitioners are those seeking to employ lean thinking in design and construction activities while site waste managers are those professional whose consultancy service is to prepare and manage site waste management plans for construction companies.

All participants are from various design and construction firms ranging from small and medium to large organisation. All the participants are actively involved in project coordination and management of design and/or construction processes. None of the participants has less than seven years of experience in the industry, and their average years of experience is 12 years. Apart from two moderators for each of the focus group discussions, Table –I shows number of participants in each of the discussions.

Table – I*: Overview of the focus group discussions and the participants*

FG	*Categories of the Participants*	*Main Focus of the discussions*	*No of experts*	*Years of experience*
1	Designers and Design managers	• Designers approaches for designing out waste • Design management approach to prevent waste	**8**	**12 – 27**
2	Lean practitioners	• Lean thinking as a means of waste management • Strategies for preventing defects and reworks	**4**	**7 – 16**
3	Project/Site Waste Managers	• Factors contributing to low waste projects • Methods for reducing C&D waste	**7**	**10 – 12**
4	Sustainability Team members	• General discussions on waste preventive strategies • Project lifecycle waste reduction	**6**	**8 – 15**
		Total	**25**	

The four key teams were selected based on critical sampling because they are all responsible for day-to-day prevention and management of waste within the construction industry. This sampling technique was used based on assertion of Creswell (1998) that it allows logical generalisation of study and applicability of its findings to other cases (Creswell, 1998). However, participants were selected through a convenient sampling where researchers used their established network of contacts within the industry. This sampling technique gives the researchers an opportunity of purposefully selecting people that are considered information-rich for the study (Merriam, 1998). Within the field of construction management, other researchers that have employed the sampling technique include Oyedele (2013), Akintoye et al. (1998), Hodgson et al. (2011) and Spillane et al. (2012) among others.

The participants were informed of the need for understanding factors limiting effectiveness of the existing waste management strategies as well as the strategies required for improving waste management practices. The discussions were in two phases, each spanning between 40 and 45 minutes. Each of the first phase identified impediments existing waste management, while the second stage assisted in elucidating strategies for improving waste management practices. The discussions were recorded, transcribed and read several times to identify core themes in the different discussions, using thematic analysis (Morse, 1994). In order to uncover complex phenomenon and common themes that may be hidden in the large unstructured data, Atlas-ti qualitative data analysis tool was used.

4. Analysis and Grouping

This section presents findings on how participants reflect on the existing waste management strategies to identify their weaknesses as well as the strategies required for their improvement. To enhance further grouping and discussion of the findings, a Delphi technique was used. The technique is a widely used and accepted method of enquiry that is used to achieve convergence of opinion from people within a domain of expertise (Hsu, 2007). The benefits that accrue to a study employing Delphi technique include controlled feedback to participants, opportunity for reassessment of earlier judgement, anonymity of individual participants, and establishment of group consensus (Dalkey and Helmer, 1963). To build the group consensus, established impediments and strategies were sent to participants of the focus group discussions. After two iterative processes, limitation to existing waste management strategies were refined and further grouped into five major categories based on group consensus.

The five major categories of the impediments to existing waste management strategies are:

A. End of Pipe Treatment;

***B.** Externality and Incompatibility of waste management Tools with Design Tools;*

***C.** Failure of Waste Management Strategies to Offer Holistic Solutions*

***D.** Perceived or Unexpected Expensiveness of Waste Management*

***E.** Culture of Waste Behaviour within the ACE Industry.*

Similarly, suggested strategies for improving waste effectiveness of the construction industry were consensually grouped under six categories, which are:

1. Design Stage Implementation

2. Whole life consideration

3. BIM compliant solutions

4. Economic Viability of Waste Management Strategies

5. Improved Legislative Provisions

6. Applied Research and education.

Tables II and III presents findings of the focus group discussions as well as the categorisation of the impediments from Delphi interview techniques. A – E in Table –II represents the above categorization of the impediments

Table II: *Existing Waste Management Strategies and Impediments to their Effectiveness*

	Waste Management Strategies	**Limitations**	**Focus Groups**				**Category**
			1	**2**	**3**	**4**	**A – E***
1	Sorting and Recycling	• Extra labour/man-hours is needed for successful sorting exercise	✓		✓		**D**
		• Substantial site space is required, and it cannot be done in confined sites			✓		**C**
		• Recycling consumes substantial energy for transportation and recycling				✓	**D**
		• It is an end of pipe treatment rather than waste preventive measure	✓	✓	✓	✓	**A**
		• It costs time, money and interfere with other site operations			✓	✓	**D**
		• It cannot even tackle all waste categories as some are not recyclable	✓	✓		✓	**C**
2	Materials Reuse	• It is not adaptable for all waste streams		✓			**C**
		• It is an end of pipe treatment	✓	✓	✓	✓	**A**
		• Uncertainty about lifecycle quality of reused materials prevents its use	✓			✓	**E**
3	Use of Waste Prediction tools	• Most prediction tools lack provision for actual waste reduction/minimization	✓				**C**
		• Building information are input manually, and this discourages its use	✓			✓	**B**
		• Incompatibility with drawing tools discourages their wider acceptability	✓		✓		**B**
		• Extra man-hours/efforts are required as they are external to drawing tools	✓	✓		✓	**D**
		• Not realistic in complex design with irregular shapes	✓				**C**
4	Site Waste management Plan (SWMP)	• Only being used as a means of fulfilling legal requirements or BREEAM points			✓	✓	**E**
		• No standard benchmark as it is done based on individuals' instinct	✓			✓	**C**
		• It requires additional man-hours/specialist			✓		**D**
		• No solid follow up on original plan				✓	**E**
5	Design for Flexibility and Deconstruction	• It requires added expertise as well as dedicated planning which are unpaid for	✓	✓	✓		**D**
		• Deconstruction is more expensive than demolition			✓	✓	**D**
		• It does not offer immediate benefits to project teams	✓	✓			**E**
6	Waste Efficient Procurement, e.g. JIT	• Measures such as JIT increases transportation cost			✓	✓	**D**
		• It sometimes delay projects			✓		**D**
7	Offsite Construction and Other MMC	• More expensive than in-situ mode of construction			✓	✓	**D**
		• It requires more careful planning which counts on project cost	✓		✓		**D**
8	Legislation and Tax Measures	• It gives little attention to design stages which is key to waste reduction	✓			✓	**C**

******A = End of Pipe Treatment;* **B** = *Externality/Incompatibility of waste management Tools with Design Tools;* **C** = *Failure of Waste Management Strategies to Offer Holistic Solutions;* **D** = *Perceived or Unexpected High Cost of Waste Management;* ***E.*** *Waste Behavioural Culture*

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Table III: *Requisite for Reducing Waste Intensiveness of Construction Industry*

	Major categories of the Strategies	Identified Measures for Improving Effectiveness of Waste Management Strategies	Focus Groups			
			1	2	3	4
1	**Design Stage Implementation**	• Increasing implementation of waste management solutions right from design stage			✓	✓
		• Optimization/standardization of designs to achieve waste effective solutions	✓	✓		
		• Early collaborative waste management arrangement among project teams			✓	✓
		• Design changes should be limited to the design stages		✓		✓
		• Waste management software solutions should be implementable within design platform	✓			✓
2	**Whole Life Consideration**	• Waste management solutions should cover all stages of project lifecycle than construction stage		✓		
		• Waste prevention should be given adequate consideration as much as end of pipe treatment options	✓		✓	✓
		• Flexibility should be considered while planning/specifying design and construction techniques		✓		✓
		• Deconstruction should be planned at design/construction stage to reduce end of life waste		✓	✓	✓
3	**Building Information Modelling (BIM) Compliance**	• Improve use of BIM and Integrated Project Delivery (IPD) will enhance project's waste effectiveness	✓			
		• As the industry shifts towards BIM, waste management tools should be made BIM compatible	✓			✓
		• Capability of Waste prediction/management tools to automatically capture building information	✓			
4	**Economic Viability**	• Waste preventive/management measures should be made cheaper than allowing waste to occur		✓	✓	
		• Economic benefits of adopting waste management strategies should be more pronounced			✓	
		• Increasing cost of waste landfilling could make waste prevention more economical and accepted	✓			✓
		• Easily implementable strategies devoid of causing project delay should be encouraged			✓	✓
5	**Legislation Drives**	• Increased stringency of waste management regulations		✓		✓
		• Consideration of design stage in future waste management regulations	✓		✓	✓
		• Inclusion of waste management in project sustainability appraisal tools and building control process	✓			✓
		• Award of more points to waste effectiveness of construction projects	✓		✓	✓
6	**Research and Enlightenment**	• More research into impacts of different design and construction practices on waste output		✓		
		• Cost benefits analysis of various low waste building techniques should be illuminated			✓	✓
		• Increased education of design and construction professionals about waste preventive measures	✓	✓	✓	✓

5. Impediments to Existing Waste Management Strategies

As presented in Table – II, effectiveness of existing waste management strategies is limited by different factors. These sets of impeding factors are discussed under five major categories.

5.1 End of Pipe Treatment

Current approaches to tackling waste are usually categorised into four, which are reduce, reuse, recycling and disposal in order of environmental and economic preferences (Faniran and Caban, 1998). However, most waste management techniques are down the hierarchy and lacks platform for preventing waste occurrence (Osmani, 2012). Focus group discussants opined that:

> *"While many waste management strategies already exist, we are also improvising for some others. Government is also forcing us to adopt some of them… However, it seems that most of these strategies are only meant to address waste after it has occurred".*

A major impediment to waste efficiency of the construction industry is that widely used waste management strategies fall into categories of end of pipe treatment which are, by definition, not waste preventive measures, but ways of managing waste after it occurred. Across all the focus group discussions, the participants put similar argument against materials reuse and recycling which are the most common approaches to waste management.

> *"How would you think that reuse and recycling solve waste and environmental problems when they proffer solution to waste after it occurs? Recycling needs waste transportation, which in itself a means of pollution…..if you have been to recycling site, you would realise that it is a polluting activities.*

> *"The success of all these end of pipe treatments depends on whether or not the secondary materials make their way back to construction sites".*

> *"It is unfortunate that most of the approaches are offering solutions after waste has occurred…. In my own view, waste is only well managed if it is not generated in the first place".*

Apart from the argument that waste recycling is only a means of treating waste after it occurs rather than preventing or minimizing it, successful recycling operation requires dedicated sorting arrangement which requires cost, time, site space, labour and dedication among the professionals (Teo and Loosemore, 2001; Poon *et al.*, 2001). The consensus that waste is best tackled at design stage where cost of change is minimal (Faniran and Caban, 1998; Ekanayake and Ofori, 2004; Osmani, 2012) suggests that the end of pipe treatments have limited tendencies of reducing construction waste. In addition, Oyedele *et al.* (2014) claim that, there is low acceptance of recycled products as designers rarely consider them during specifications. This further suggests that reuse, recycling and other end of pipe waste management measures have little tendency of reducing waste generated by construction activities. Although, the end of pipe treatments are believed to be contributing towards waste diversion from landfill sites (Sassi and Thompson, 2008), a holistic approach to reducing C&D waste is expected to consider minimization techniques (Wang *et al.*, 2014).

5.2 Externality/Incompatibility of Waste Management Tools with Design Tools

The use of waste prediction tool is perceived as an innovative approach to tackling construction waste from holistic perspective (Solís-Guzmán *et al*., 2009). It involves the use of different tools, usually at the design stage, to project likely quantity of waste, and sometimes their causes, so that the industry practitioners would act towards minimizing the waste by using alternative design, plan for waste reuse and recycling, among others. However, apart from being that some of the tools in use only predict waste without information about their likely causes and predictive measures, the tools work based on manual input of project information (Jalali, 2007). Its effectiveness therefore relies on the extent of accuracy of the input data. Despite its perceived benefits as a means of predicting and preventing construction waste, it is limited by externality and lack of compatibility with design tools and manual input of building information. Designers argue that:

> *"Waste prediction tools offer excellent approach to waste management. However, their main problem is that they are not compatible with design tools. You waste a lot of time on waste, while manually entering the information"*

This was further buttressed by another participant who opined that:

> *"You know, most of our activities are time bound, nobody is interested in doing something that would waste time…assuming we can do it within the design platform, it would be awesome to predict likely waste before actual construction"*

This suggests that as this strategy proves requisite to effective waste minimization at source, more efforts is needed to improve mode of capturing building information. Further waste management solution is not only expected to be compatible with design tool, its ability to automatically capture building information would enhance its effectiveness and acceptability.

5.3 Failure of Waste Management Strategies to Offer Holistic Solutions

As echoed by the focus group discussants, a major problem leading to waste intensiveness of the construction is the failure of the waste management strategies to tackle waste at holistic level. By the nature of existing waste management strategies and studies, they usually address stages of project delivery processes as a static stage rather than developing one stop approach capable of assisting throughout the project lifecycle stages. The discussants argued that:

> *Apart from doing some of these things to gain BREEAM point, the industry is more interested in things that could help in both design and construction. How well have we benefited if we can only manage waste after it occurred? We definitely need something that could help us reduce waste and therefore increase profit"*

> *"Even, waste management tools are not useful beyond the design stage. Most of the strategies are only meant to address little portion of the problem. In my own view, they are not holistic enough"*

It was established by the focus group discussants that most of the existing waste management strategies are not applicable on every types of projects, sites and materials. For instance, while recycling as a strategy becomes irrelevant with certain types of materials, site based sorting of waste is not feasible in the case of confined sites. Despite the perceived relevance of waste prediction tools, the discussant argue that it offer little or no solution to waste reduction. Again, waste management legislation, which is known to be driving waste reduction in industry (Yuan, 2013), also has limited provision for reducing waste through design (Osmani *et al*., 2008). All these suggest that most of the existing waste management strategies lack holistic framework for effective diversion of waste from landfill.

This corroborated earlier submission by Yuan *et al*. (2012) and Hao *et al*. (2007) who suggest that waste minimization strategies are usually implemented on static perspective while there is need for dynamic and interdependent approach to determining effective waste management strategies. Notwithstanding the interrelationship and interdependency of every stages of building delivery stages (Sterman, 1992), existing practice in C&D waste management research often results in scattered findings, as researchers usually concentrate on each stage of project delivery processes. This results in stage based solutions to C&D waste management. Thus, there is need for more holistic approach that considers all materials types as well as every stage of project delivery process.

5.4 Perceived or Unexpected High Cost of Waste Management

Rather than landfilling, construction professionals are more likely to adopt waste management strategies in as much as it presents economic cases (Al-Hajj and Hamani, 2011; Oyedele *et al.*, 2013). However, this study suggests that a major barrier to implementing waste management strategies is due to its perceived cost and time impacts on project costs. Although, penalty is being paid for waste landfilling, focus group discussants illuminates that they sometimes compare cost impacts of waste landfilling to potential impacts of waste management on project duration and cost. They suggest that while some increases design and construction cost as they require extra man-hours, others interfere with site activities and could potentially result in project delay, which in turns increases project cost (Enshassi *et al.*, 2009). The discussants stated that:

> *In a situation whereby the cost of appointing waste management experts is more than the cost of landfilling, what do you do? I bet you will definitely prefer to landfill your waste.*

> *We mix up our waste on most sites because you need dedicated people and ample site space to sort waste into recyclable and non-recyclable. However, we have waste management company that take everything away from the site…, I think they separate them and sell back some of the waste to us.*

> *Although Just in Time delivery could reduce waste generation, but it is cheaper to deliver your materials in bulk. If you use JIT, you will pay multiple transportation fees and sometimes, your materials would be delayed.*

The experts opined that C&D waste has not been properly addresses because nobody is interested in paying for it.

> *You know we get contract through competitive bidding. If you say because you want to design for deconstruction or reduce waste through some techniques, and then raise your price, you might end up not getting any contract.*

Offsite construction reduces waste significantly because of its involvement of design freeze, which prevents reworks. But you cannot use offsite construction only because you want to reduce waste because you have to pay premium for it

All these statements suggest a strong belief that waste management is more expensive than waste landfilling. In line with the experts' opinion, previous studies also suggested that some waste preventives measures tend to be more expensive. For instance, Dantata *et al.* (2005) posit that deconstruction is about 17-25% more expensive than deconstruction. Durmus and Gur (2011) also argue that while planning for deconstruction, which is waste effective than demolition, careful planning and additional time would be spent by the designers. Although waste minimization tendency of prefabrication and modular construction could be up to 84.7% (Tam *et al.,* 2007), financial premium is expected to be paid as it is more expensive than in-situ construction.

5.5 Waste Behavioural Culture within the ACE Industry

Teo and Loosemore's theory of waste behaviour posit that there is a prevailing culture of waste behaviour within the construction industry (Teo and Loosemore, 2002). The theory suggests that while top managers usually perceive waste as trivial issues, the operatives always opine that waste is an inevitable problem of the managers. Although this was not directly raised by the discussants, some of their response suggests the belief. For instance, a discussant claims that:

"I think a lot has to be done by Government if SWMP is to achieve its desired goal. Since it has no standard benchmark, we produce it for every site as required by law. Ask me about its implementation and effectiveness; it is absolutely used for ticking boxes… We however take its implementation serious only when we want to use it for achieving BREEAM points"

"It is the government that is more sincere and committed to environmental management, the main motivation for waste management and other policies within the industry is the financial gains, and sometimes, to gain desired BREEAM or other assessment points"

This opinion was also echoed by Ikau *et al*. (2013) and Osmani *et al.* (2008) who reiterated that a major reason for waste intensiveness of the construction industry is that workers believe that waste is inevitable, thereby giving less attention to its management. This means that without legislation as a driver of waste management behaviour, culture of waste behaviour within the industry means that construction industry is likely to remain waste intensive.

6. Requisites for Improving Waste Diversion Rate

Reducing waste in landfill sites remains a pressing challenge facing the construction industry. Evidence shows that more than a third of waste in global landfill might be of construction origin (Solís-Guzmán *et al*., 2009). By devising appropriate requisites capable of improving effectiveness of waste management strategies, it is certain that environmental problems associated with increasing waste generation would be prevented. In addition, substantial financial savings could be made from effective waste management.

By corroborating findings in Table – III with extant literatures, measures capable of improving C&D waste management are discussed under six headings, which are design stage implementation, whole-life consideration, BIM compliance, economic viability, legislative drivers, and research and enlightenment. The six broad factors describe basic requisite measures needed to be considered in order to reduce waste intensiveness of the construction industry. Figure II summarizes and depicts the requisites for improving waste intensiveness of the construction industry.

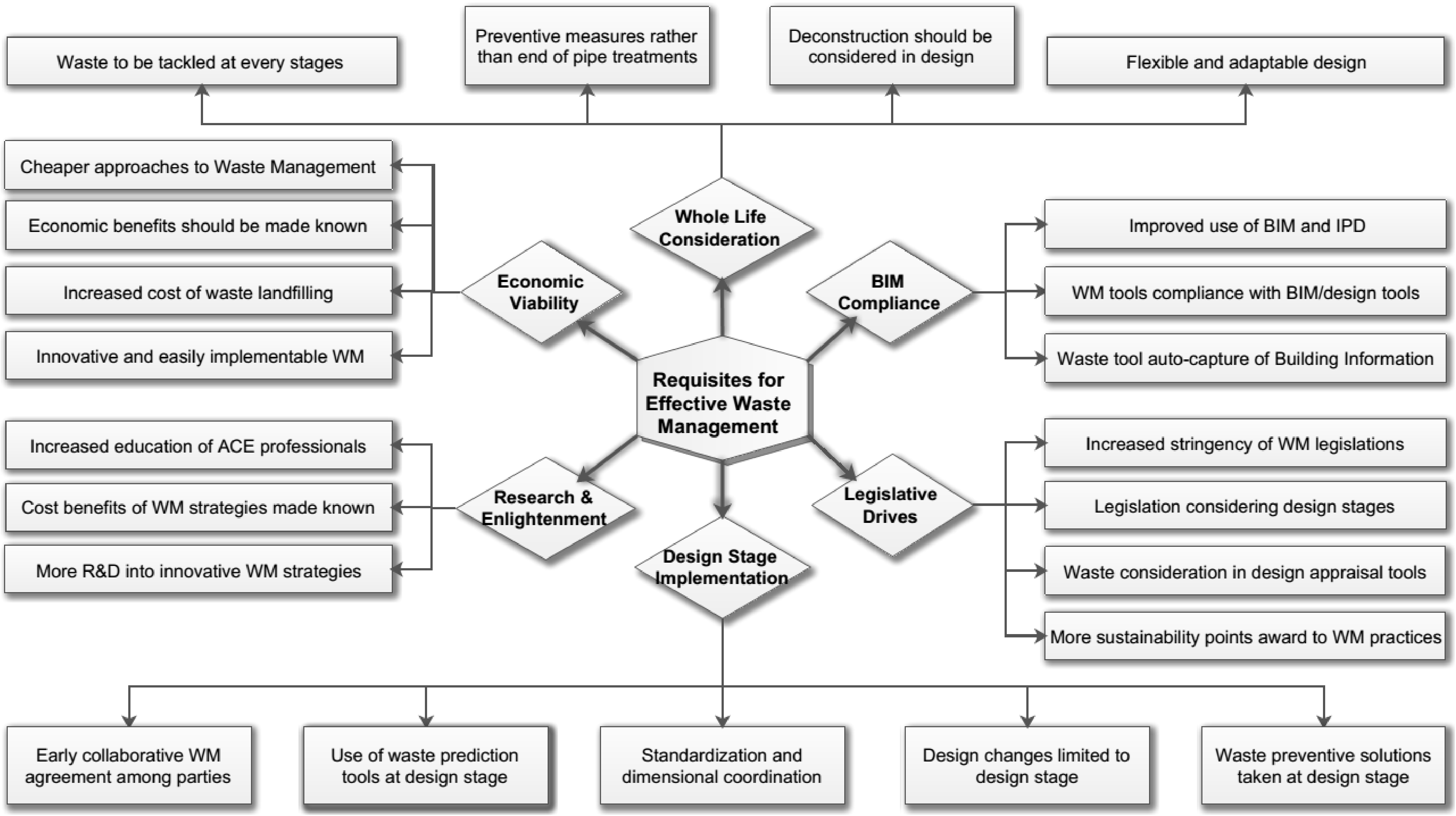

Figure II: *Requisites for reducing waste intensiveness of the construction industry*

6.1 Design Stage Implementation

Design stage is a very crucial point for waste preventive measures in construction activities. It is no news that change is cheaper at design stage when there would be no need for any reworks that could otherwise lead to materials and time wastage. Osmani (2012) noted that according to Innes (2004), about 33% of construction waste occurs because of design related factors. This implies that attempts to tackle waste at design stage would result in substantial reduction in waste. UK government funded WRAP also claim that waste could be designed out in construction projects using some set of tactics known as waste spectrums. These according to WRAP involve design for reuse and recovery, design for offsite construction, design for deconstruction and flexibility, design for materials optimisation, and waste efficient procurement (WRAP, 2009).

To reduce waste intensiveness of the construction industry, the industry's experts strongly believe that design stage is a decisive point. The discussants equally opined that:

> *"A good area which we should be looking into if we are really sincere about waste management is in the aspect of design"*

> *"If we want to reduce waste, we need to ensure that our design dimensions are coordinated and the overall design is optimized for waste efficiency"*

> *"By limiting design changes to the design stage, we would be able to prevent waste generation to a great extent"*

Waste management strategy is expected to be implementable at early design stage where designers would have the best opportunity to optimize their design and compare different design alternatives for waste efficiency. Other discussants suggest that:

> *Existing waste minimization strategies at design stage only allows waste prediction on a platform external to design tools. Many of the tools even lack functionality for supporting waste minimization techniques. It will be excellent if we can implement the waste management simulation within the design platform. We need something like what Revit calls energy simulation, which could be done along with design*

These assertions suggest that a platform that allows waste prediction and benchmarking, design optimization, and tendency for setting waste target in user interactive and decision support manner would adequately assist in reducing. In addition, design stage should be more recognised in waste management practices rather than current practices that usually adopt end of pipe measures in tackling waste.

6.2 Whole-life Consideration

Causes of waste have been linked to all stages of project delivery process, ranging from design to completion. Although the actual waste occur onsite during construction activities, various pre-construction operations such as design errors, scheduling mistakes, lack of dimensional coordination, etc. have been pointed out as major causes of waste (Faniran and Caban, 1998; Ekanayake and Ofori, 2003; Coventry et al, 2001). However, existing practices show that different strategies are adopted at various stages of building delivery activities. For instance, waste management tools such as WRAP NetWaste are used for waste predictive measures at design stage without capability to assist onsite during construction activities. Existing Site Waste management tools such as the US Waste Spec and the UK SmartWaste only consider onsite waste, suggesting inadequacy of current solutions in tackling preconstruction causes of waste. The respondents suggest that:

> *Large volume of waste comes from deconstruction and refurbishment; we seriously need to plan for demolition if we are targeting sustainability in our waste management.*

> *A large portion of C&D waste comes from building renovations, repartitioning and so on. There is need to adapt our designs to future change in building use so that little waste will be generated from them.*

> *When we are planning to reduce waste, every stage of building delivery processes and even end of life should be considered all together*

The above assertions suggest that the industry practice is expected to shift from addressing waste management from one aspect of project lifecycle. It means that there is need to adopt measures capable of mitigating all waste causative factors at design, procurement and construction stages. By so doing, it would mean that waste causative factors have been prevented during preconstruction activities while framework for managing construction and post construction waste is also set. As such future waste management solutions is not only expected to consider all stages, its capability to predict, monitor and prevent waste is expected to be a build on most present-day waste management strategies which proffer solutions after waste has occurred. This becomes needed, as the best strategy for waste management is to prevent its occurrence (Faniran and Caban, 1998).

6.3 Building Information Modelling Compliance

The adoption of BIM is becoming commonplace within the construction industry. This is not only because of its collaborative facilities, but also because of the industry's shifts towards its adoption, as influenced by governments' leads. BIM is a technologically enhanced approach that enhances digital representation, storage, management and sharing of building information in a way that allows access to the projects database throughout its lifecycle. The process aspects of BIM gives it more popularity than its software technology (Eadie *et al.*, 2013), and its ingenuity is based on its ability to generate adequately coordinated project information that augments information management and collaboration (Race, 2012; Eastman *et al.*, 2011).

According to the focus group discussants, the main challenge of existing waste management tools, such as NetWaste in the UK, is manual input of project geometry and lack of compatibility with basic design tools. These results in extra efforts to predict and prevent design related causes of waste.

> *With the current yearning for BIM and IPD, increasing project collaboration will reduce waste generation significantly*

> *If the waste management tools are BIM compatible and are able to capture building information automatically, then there is nothing stopping their use.*

The participants imply that future waste management tools are expected to be BIM compliant as the industry practice shifts towards whole BIM adoption. Such tools are expected to provide framework of operation within BIM design platform, and compatibility with several other BIM tools for other design related functions. This would ensure that waste output is easily simulated as an integral part of building design, with intent of comparing different options. Equally, to ensure efficient waste prediction and prevention, as well as its wide adoption within the industry, such tool would automatically map its material database with existing BIM database.

6.4 Economic Viability

A major driver for adopting waste management strategy is the economic cases it presents. Al-Hajj and Hamani (2011) and Oyedele *et al.* (2013) suggest that contractors are more likely to adopt waste minimization strategy if its implementation results in more financial gains than leaving waste to occur. Tam (2008) claims that waste management planning is less adopted in Hong Kong construction industry as it is believed to reduce productivity rather than increasing profit. Industry practice suggests that contractors compare cost of waste minimization to cost of waste landfilling, thereby adopting cheaper option for each project. It was argued that:

> *With almost yearly increases in landfill tax, more people are finding alternative solutions. If the trend continues, waste landfilling could become something of the past, especially as money almost matters.*

> *Most people are just aware of environmental benefits of landfilling; there is more need for emphasis on its economic benefits. A lot of cost goes into material waste. This include its original cost, transport cost, labour spent on it, and the landfill tax. People need to know that cost of waste is more than landfill tax*

Apart from making waste management appealing by raising penalties for waste landfilling, the above assertion advocates effective demonstration of economic benefits of existing waste management strategies. It also reinforces the general belief that waste is not being management due to its perceived high cost. As such, for any waste management strategy to be adequately adopted and effectively used, such strategy would not only be easily implementable, it must have cheaper cost of implementation, which presents more financial gains than cost of waste disposal.

6.5 Legislative Drives

One of the major factors that shape the construction industry is the national and regional legislation. As planning approval is required before any physical construction activities, it means that the project has to fall within the framework provided by the legislation. In the UK construction industry for example, compliance with the provision of Code for Sustainable Homes has become a requirement for all residential building construction. This has continued to drive sustainable building practices as the code becomes more stringent. Before the compulsory SWMP was repealed (in December 2013), it has been the industry's standard to prepare and monitor detailed SWMP for all projects over £300,000. These practices suggest relevant impacts of legislation in driving sustainable practices within the construction industry. Participants in the focus group discussions suggest a number of measures through which legislation could further assist waste management practices.

> *By including waste management capacity in sustainability assessment tools such as BREEAM and Code for Sustainable Homes, people will take it more serious*

> *If we are to overcome the problem of waste in construction, more stringent legislation and penalties for improper waste management practices are expected from the government*

> *To the best of my knowledge, waste management legislations addresses mainly the construction stage, other stages need to be considered as well*

Buttressing the above assertion, Osmani (2012) argues that waste management legislation has been practically non-existing with respect to design stage, despite being that major causes of waste are design related (Faniran and Caban, 1998). As the legislation is expected to continuously drive future waste management strategy, more stringent legislation and fines are not only expected, waste preventive standard is also expected to be set for design stage.

6.6 Research and Enlightenment

Inadequate knowledge of effective waste management practices as well as poor understanding of the cost benefits of waste preventive measures was stressed by many respondents during the focus group discussions. The participants illuminate this is some of their assertions quoted below:

> *There is need for more research and education on innovative waste management techniques as well as waste management tools capable of assisting in both design and construction*
>
> *Unlike sustainable technologies such as PVC and others, lifecycle cost benefit of using low waste construction techniques such as prefabrication is not known. We need more education and more awareness about this as well, and I think it would assist decision-making*

The need for research into impacts of different design options and techniques on waste management was illustrated in the above quotation of discussants' expressions. In addition, it was clearly stressed that by enlightening design and construction professionals on different waste management and preventive measures, substantial waste could be diverted from landfill sites. This position is also corroborated by a number of existing studies. While suggesting management measures capable of enhancing waste management practices, Yuan (2013) similarly identified research and development, major stakeholders' awareness and improvement of operatives. Osmani *et al.* (2012) equally identified education programmes as a potential way of improving waste management practices. Thus, increasing awareness and education are indispensable to improving waste effectiveness of the construction industry.

7. Conclusion

Owing to its contribution of substantial portions of global waste to landfill, effective management of construction related waste is an important requisite for the global sustainability agenda. In a bid to prevent pollutions and enhance financial gains, several waste management strategies and policies have been developed. However, construction industry remains waste intensive. This study identifies impediments to existing waste management strategies as well as requisites for reducing waste intensiveness of the construction industry. Using series of focus group discussions, this study shows that the reason for ineffectiveness of the existing waste management strategy is due to its treatment of waste after it has occurred rather than proffering waste preventive solutions. In addition, existing waste preventive solutions put unpaid burdens on design professionals, as the tools are external to design tools and require extra efforts, which discourages their use. It is noted that apart from a culture of waste behaviour that is prevalent within the construction industry, most of the existing waste management strategies are either expensive or incapable of providing holistic solution to tackling C&D waste. All these point to the reasons for ineffectiveness of existing waste management strategies and subsequent waste intensiveness of the construction industry.

To reduce waste intensiveness of the construction industry, this study suggests that a number of measures are requisites. This includes increasing implementation of waste preventive measures at design stage, consideration and planning for whole life waste including waste from renovation and end of life, improved compliance of waste management tools with design tools as well as their BIM compliance, cheaper approach to waste management, increasing stringency of waste management legislation and fiscal policy, and research and enlightenment.

The study has implications for practices for both construction professionals and policy makers. At the industry level, waste preventive strategies are expected to be collaboratively adopted at the preconstruction stage, especially as the design stage is very decisive in determining waste effectiveness of a construction project. Rather than the prevailing practices that are concentrated on construction stage, whole project lifecycle as well as buildings' end of life are to be considered. Similarly, as the industry shifts towards full BIM adoption, waste management solutions are expected to be BIM compliant in such a way that waste preventive measures becomes integral part of project delivery process. To cap it all, improving waste management skills and awareness of the design and construction professionals is indispensable to achieving waste effective projects. At policymaking level, legislative approach to waste management should not only consider construction stage, it is expected to set minimum waste preventive standard for design. This is due to the strong emergence that legislation drivers and economic viability of any strategy enhance its adoption in construction industry. As such, for waste management strategy to be well adopted, it would either be legislation driven or more financially viable than landfill tax and other associated cost of waste disposal.

As this study is limited to qualitative data as well as UK context, other studies employing quantitative data could determine generalizability of its findings. Its transferability to other nations could also be determined. As a number of measures has been explored by this study, it is expected that future studies quantitative identify the actual measures that are critical to reducing waste intensiveness of the construction industry.

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