ANALYZING THE CAUSES OF DESIGN GENERATED WASTE THROUGH SYSTEM DYNAMICS

By

SIDRA MUZAFFAR

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School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology (NUST),

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SIDRA MUZAFFAR

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Dr. Khurram Iqbal Ahmad Khan
Supervisor
Department of Construction Engineering and Management
National Institute of Transportation, SCEE, NUST, Islamabad

THESIS ACCEPTANCE CERTIFICATE

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Signature: ______________________________

Name of Supervisor: Dr.Khurram Iqbal Ahmad Khan

Date:__________________________________

Signature (HOD): _______________________

Date:__________________________________

Signature (Dean/Principal): _______________

Date:_________________________________

This thesis is dedicated to my family and respected teachers!

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Abstract

During the last few years, with the increase in construction activities, a drastic rise in construction waste is predicted and notified. This has elicited a radical impact over the environment as well as economy. It is therefore necessary to come up with the waste minimization strategies that reflect the in-depth review of sources of waste. The purpose of this study is to understand the intricacy in behavior of design source' causative factors triggering the generation of construction waste through system dynamics. Via Conduction of pilot study and detailed survey, most important factors were identified and their interrelationships were determined respectively. System thinking approach was implied in order to address the complexities in design causes that generate waste. Four reinforcing and one balancing loops for CLD materialized through survey analysis. SD model was developed that contained two stocks regulated by most of the flows. The third stock "Design Generated Waste" was added to observe the combinatorial effect of both stocks. Simulation result shows the increasing trend of third stock over period of five years. This study has addressed the substantial causes of design source and their complexities of behavior comprising the causal relationship that is accountable for repercussions (i.e. waste) in the later stage. Future work can be performed by introducing a policy framework in the light of the developed model to control waste.

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List of Abbreviations

CDW	Construction & Demolition Waste
CLD	Causal Loop Diagram
SD	System Dynamics
C&D	Construction & Demolition
RIBA	Royal Institute of British Architects
CIRC	Construction Industry Review Committee
SPSS	Statistical Package for the Social Sciences
ANOVA	Analysis of Variance

Chapter 1

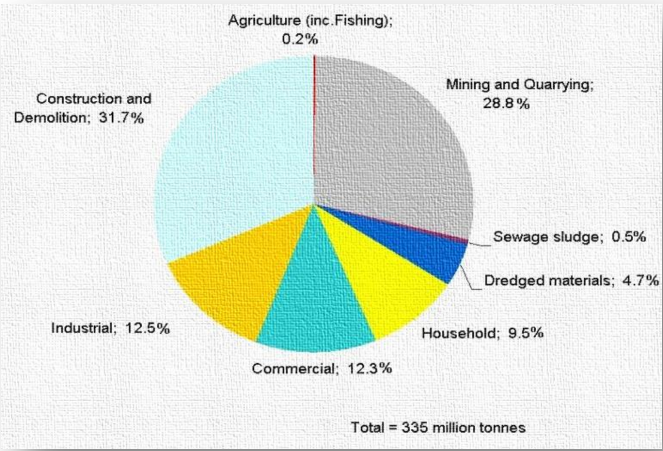
1. INTRODUCTION

1.1 Overview

Construction industry due to its dynamic nature and continuous development has brought with it major problems like waste. Koskela (1992) stated the definition of waste as any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of building(Mazlum and Pekeriçli, 2016).

The drastic increase of activities in the construction sector over the last few years has resulted in huge amounts of construction waste globally(Ghafourian *et al.*, 2018). The literature confesses that construction activities have been reported to produce about 20-30% of waste deposited in landfills(Craven, 1994; Poon, 1997). The CDW waste has been noticed to place a detrimental effect on the environment, economy, productivity, and society of a country(Ghafourian *et al.*, 2018).

Figure 1.1 Estimated Annual Aaste arising by Sectors



Carlos. et al (2002) emphasized that high levels of waste could result to consumption of the future availability of materials and energy. Carlos et al. (2002) further explained that in some building materials and components, large amount of non-renewable sources of energy is used, that are leading towards depletion steadily, such as timber, sand, and crushed stone(Nwachukwu *et al*., 2016). Furthermore landfill sites are exhausted and space for dumping waste is narrowing with the passage of time. (Nwachukwu *et al.*, 2016) This reveals the fact that the level of environmental importance, awareness and readiness to pursue the goal of sustainability in the country is considered to be very low(Al-Hajj and Hamani, 2011; Nwachukwu *et al.*, 2016).

Secondly, waste contributes to the construction projects as high as 15% additional cost (Tam *et al.*, 2007). According to consensus in literature, materials consume approximately 30 to 70% of construction cost. Bossink and Brouwers (1996) stated that wastage associated with material accounts for between 20 and 30% project cost overruns, it transpires an alarming situation how construction material waste is threatening the economic growth of the nation (Otali.M, 2013).

However, in the light of the present situation, with reference to the economic concerns and environmental awareness, where waste should be a significant matter of agenda, the study concludes that perception of the significance of waste is very little appreciated(Nwachukwu *et al.*, 2016). Other than this implication, where waste minimization and management should be a considerate and pressing issue (Osmani *et al.,* 2006), waste in the surveyed design and contracting companies is believed to be inevitable and is ignored(Akinade *et al.*, 2018).

The need of hour is to implement best waste minimization strategy to nip waste at the bud and this starts from the drawing board where waste is identified, evaluated and measured and then appropriate measures are taken to address them (Nwachukwu *et al.*, 2016). It is also generally accepted in the literature that the best attitude towards CDW management is via waste reduction from inception through detailed design. (Akinade *et al.*, 2018)

- Firstly this is because design based philosophy offers flexible and cost-effective approach to waste management before it occurs (Akinade *et al.*, 2018) via thorough source evaluation(Osmani, 2008; Dajadian, 2014; Akinade, 2018; Joseph, 2018).
- Secondly there exists a strong relationship between design and construction waste such that any approach deployed in the design process has effects not only over the design process but on the whole construction process (Osmani, 2008a; Sacks, 2009; Rahe, 2013; Mazlum, 2016).

The relationship lies within the nature of both design and construction, and thus, the consensus in the literature states that an extensive amount of construction waste is produced as a result of poor design(Chandrakanthi, 2002). Approximately 33% of construction waste generated onsite is related to design directly or indirectly(Mazlum, 2016). It is therefore not surprising that about one-third of construction waste could arise from design decisions(Osmani, 2006).

On the contrary, minimizing the construction waste is of low priority in the stages of strategic planning and design activities(Osmani, 2008; Mazlum, 2016). A study by Poon et al. concluded that at the time of selection of materials for construction, designers pay relatively little attention to the perception of waste minimization(Poon, 1997; Osmani, 2006). Further findings reveal that waste on-site is directly related to problems on which the site personnel have very little or no influence(Al-Hajj and Hamani, 2011).

Despite the fact that design process has ripple effect over construction process, much had been published in literature on ways to improve on-site waste management and recycling activities but very few efforts are seen addressing the effect of design practices on waste generation (Osmani *et al.*, 2008b). Hence, this study addresses an in-depth review and identification of the causative factors of waste generation right from the source-design stage so that their evaluation may help out in taking measures for reducing the generation of construction waste. In return, it will assist in abatement of pressure towards environmental and economic resources.

1.2 Level of Research Already Carried Out on the Proposed Topic

Much had been published on ways to address various issues relating to waste only when it has already been produced that accounts for the on-site waste generation. The current researches also express awareness about on-site waste minimization and its advantages to economy and environment. Moreover, the literature introduces models and techniques to help handle on-site waste. Plus, number of research studies related to the influence of legislature, predominantly the Landfill Tax, and its impact on the performance of the construction industry has also been published(M. Osmani *et al.*, 2008a). All the above mentioned literature discusses about the on-site waste management issues however, very few attempts are made to address the impact of design practices on waste generation (Osmani *et al.*, 2008b). Senami & Ejiga (2007) also manifested the inadequate, unorganized and unstructured approach towards addressing waste at source linked to design. Likewise, there are only handfuls of manuals available that accounts for management of CDW in design phase(Senami and Ejiga, 2007; Osmani, 2008) So there lies a need to fill this grey area by bestowing the similar awareness and attention to the design related waste- a proactive approach, that is given to the already generated waste.

1.3 Reason/ Justification for the Selection of Topic

Literature reveals 33% waste produced on site criticize the inefficiency of design directly or indirectly(Mazlum and Pekeriçli, 2016). It is definitely not surprising that design decisions contribute to one-third of construction waste (Osmani *et al.*, 2006) that impart major and negative consequences on both environment and cost(Baldwin *et al.*,2007). Hence, to minimize these negative outcomes, much improved inputs need to be explored and acknowledged. The need of hour is to focus on waste at source and nip the causes to further improve the waste reduction practices. As literature states that a key component in the development of cost-effective and robust waste minimization strategy is by appreciation of causes of the waste. Consequently, literature in the field discusses the waste that has already been produced, but very limited publications addresses waste at source, i.e., 'design waste'(Osmani et al., 2008). This further gives weightage to our contemplation towards sorting out the causes for the design that generate waste.

1.4 Objectives

- To identify the causes of design generated waste in construction sector.
- To identify the interconnectivity among variables.(Development of CLD)
- To develop SD model to understand the behavior of causes on the construction waste generation.

1.5 Methodology:

Methodology of research will be divided into three steps as follows;

- Study will be initiated by finding waste at source from the literature review. Frequency analysis on the basis of literature and respondent's score will help achieving the ranking of factors. After that shortlisting of factors will be done.
- Influence of one factor over another will be figured out and its validation will be done by expert opinion. After that an influence matrix will be developed that will serve as a basis for generating a CLD through VENSIM.
- Modelling of a SD will be done and its simulation validation will be done.

1.6 Relevance to National Needs

With the increasing commercialization, especially in the field of construction, reduction of ecological foot print on the environment has become one of our major concerns. Much attention is given to conserve resources from depletion. For this, alternative techniques and approaches are in phase of development to reduce man's continuous dependence on the non-renewable earth resources. Secondly, this era of economic recession has bewildered the whole world with the unbridled price hike. The situation unwelcoming and undesirable convinces to rethink and adopt economical and sustainable construction. This refers to the development of way of construction which must have minimum chances of waste generation and disposal should hardly be given a thought. The current situation demands thorough evaluation of the sources of waste generation for planning better waste minimization strategies. The study has identified that good waste management practice starts from the drawing board i.e. design where waste is identified, analysed and quantified. Following waste minimization practices in construction will help reducing pressure on economy and environment directly as well as indirectly. (Nwachukwu *et al.*, 2016)

1.7 Advantages:

"Doing the best at this moment puts you in the best place for the next moment." This quote of Oprah Winfrey vocalizes that if the contemporary problems are recast into proactive goals, it will help building up a better and healthy future. The current state of construction industry in which the valuable reserves convert to billions of tons of waste every year and crowd the landfill sites, this further worsens the environment and economy of a country. In this very time, designers and constructors should really give a thought to replan the ways of construction in a much better and proactive way to reduce the amount of construction waste produced. This would resolve the issue of sustainability in the construction sites for most of the countries. Non-renewable resources will be protected from depletion. Landfill sites will be saved from further exhaustion. Ultimately, it will emanate a positive impact on the economy and environment, and as a result, on the whole country.

1.8 Areas of Application:

Its major area of application is Construction Industry.

Chapter 2

2. Literature Review

2.1 Background

This chapter discusses the past work done related to the research being carried out. It also comprises the study entailing construction waste and its consequences on environment and cost, its categorization and origins of construction waste.

Further, connecting the related literature for research, this chapter enhances the knowledge about causes and origin of construction waste related to design and purpose behind use of the system dynamic model. The focus of this study is to analyze the causes of design waste in construction industry in developing countries.

2.2 Definition of waste

In simple terms as put forward by the researchers, Waste is any substance discarded after use. Zaman and Lehmann (2013), redefined the definition of waste according to the modern society, waste is a symbol of inefficiency and a representation of misallocated resources.(Senami and Ejiga, 2007; Zaman and Lehmann, 2013)

With the emerging economic development and shifting ways of living in the 21st century, the quantity and intricacy of generated waste has increased, whilst industrial divergence has also contributed towards adding the substantial quantities of biomedical and industrially hazardous waste into the waste stream with extremely dreadful outcomes affecting human health as well as environment(European Commission, 2005).

The literatures in the waste studies disclose the principal sources that account for solid waste and are mentioned below namely as:

- Residential
- Industrial
- Commercial
- Institutional
- Construction and demolition
- Municipal services
- Process
- Agriculture

Attention must be paid to these sources with extreme compulsion so to reduce the amount of overall waste. This will give a smooth way towards sustainable development and healthy environment.

2.3 Construction and Demolition Waste:

The speedy increase of activities in the construction sector has brought about a huge amount of construction waste worldwide (Senami and Ejiga, 2007).Wastages in construction are said to be those physical materials supplied to the site for construction but were not used. The aforementioned statement seems to support Koskela (1992) definition about material waste as inefficiency that results from the use of resources in larger quantities than those considered necessary in the production of building (Mazlum and Pekeriçli, 2016). Ameh and Itodo (2013) cited in Carlos et al. (2002) consider material waste disposal as being inimical to the environment; and Oyegba (2013) contemplates waste as having direct influence on cost performance in construction and indirect repercussion over the environment (Formoso *et al.*, 2003; John and Itodo, 2013; Nwachukwu *et al.*, 2016).

Consequently, there emanates the issue of sustainability in the construction sites for most of the countries. This situates a ridiculously negative impact on the economy and environment, and as a result, on the whole country(Ghafourian *et al*., 2018).

2.3.1 Environmental Implications

Poon (2000) noted that among all types of solid wastes, construction waste accounts for substantially large portion of waste (Senami and Ejiga, 2007). While submissions from Carlos et al.(2002), Bossink and Brouwers (1996) further relate that every now and then, there is a usage of larger amount of non-renewable sources of energy in construction, that are in threat of exhaustion, such as timber, sand and crushed stone and this would inevitably result in the deprivation of future availability of materials and energy(Nwachukwu *et al.*, 2016). Furthermore, landfill sites are becoming exhausted as construction activities have been reported to produce approximately 20-30 percent of waste filling the landfill sites(Craven *et al.*, 1994; Poon, 1997). Furthermore, if these practices tends to continue in the way they are, probably in near future due to scarcity of landfill sites, use of landfill sites will be restricted due to probable health hazards(Nwachukwu *et al.*, 2016).

2.3.2 Cost Performance Implications

Moreover, as stated by Oyegba (2013), waste has a direct impact on cost performance of construction projects. Waste contributes to the construction projects as far as 15% additional cost (Tam, Shen and Tam, 2007). According to consensus in literature, materials consume about 30 to 70% of construction cost. Likewise, Bossink and Brouwers (1996) stated that wastage associated with material is responsible for cost overruns ranging between 20 and 30 percent, it transpires an alarming situation how construction material waste is threatening the economic growth of the nation (Otali.M, 2013). Secondly, in this period of economic recession, there is an issue of continuous price hike plus taxation fees associated with every item and service. The construction has to be sustainable in order to bear the economic pressure(Nwachukwu *et al.*, 2016). Apart from this, insufficiency of landfill sites would lead to the price escalation of waste disposal in the limited landfill spaces for the contractor (Nwachukwu *et al.*, 2016). According to Josephson and Hammarlund (1999), the shortcomings as a result of the design process encompass the largest category when measured in terms of cost(Mazlum and Pekeriçli, 2016).

Thus, it is strongly recommended to reduce the construction & demolition waste by thorough understanding of its origin and causes, and good management practices(Ghafourian *et al.*, 2018). Generally, the researchers have identified three major approaches for minimizing waste: reduction, re-using and recycling. Disposal should hardly be given a thought except when the three Rs have proved inappropriate for the waste generated.

Good waste management practice initializes from the drawing board where waste is identified, analysed and quantified and appropriate measures prescribed to mitigate them. However, in the light of the current situation in the country, with regards to environmental awareness and economic commitment to sustainable practices, the study observes that realization of the consequences of waste is very little appreciated(Nwachukwu *et al.*, 2016).

2.4 Categorization of construction wastes:

In the light of research, there exist different interpretations of multiple authors regarding categorization of CDW waste. For classification of CDW waste, many models have been presented to classify the types of waste. Senami et al.(2007) and Hamani et al.(2011) asserted that wastes can be classified by their state (solid, liquid or gaseous), by their characteristics or type of material (inert, combustible, bio-degradable, hazardous or nuclear) or by their sources (processing, household, emission treatment, C&D or energy conversion); various operational activities in a project; stakeholders of a project; life cycle of a project; as well as the construction industry(Senami and Ejiga, 2007; Al-Hajj and Hamani, 2011).

According to Ola-Adisa and Ojonugwa, the construction waste on site has been classified into two main types: direct waste and indirect waste. Direct waste is referred to loss of physical materials on site. Unlike direct waste, indirect waste is disparate in a sense that the materials are not lost physically, but the surplus and unwanted payment of part is expended. Some of the example of direct waste are as follow; site storage waste, cutting waste, delivery waste, conversion waste. Indirect waste includes cost incurred due to time overrun, substitution waste, operational waste, and negligent waste(Ola-Adisa *et al.,* 2015).

One approach introduced by Osmani et al. proposed that CDW waste can be divided into three categories

(a) Potentially valuable materials, including bricks and concrete

(b) Materials that can be recycled, example timber and glass

(c) Materials that are not easily recycled or that have discarding issues, example plaster and paints. (Osmani *et al.,* 2006)

Eventually, waste is observed in terms of what, when and where they occur to minimize it(Nwachukwu *et al.*, 2016). Therefore, a thorough understanding of the origins and causes of CDW needs to be required(Ghafourian, Ismail and Mohamed, 2018).

2.5 Origin of wastes:

Research studies related to construction waste often explore for the origins and causes of the construction waste. The terminologies 'source' and 'origin' are often used synonymously. It is revealed in literature that there are quite a number of approaches for classifying the primary origins and causes of CDW waste (Senami *et al*., 2007).

A deep knowledge of the origins and causes of CDW hence needs to be required to minimize the waste(Ghafourian, Ismail and Mohamed, 2018). Therefore, variety of different approaches by different authors associated to the origin of waste has been discussed below:

- Bossink and Brouwers(1996) categorized sources of construction waste according to the nature and technology of using materials into building products such as concrete, bricks and wood. (Bossink *et al.,* 1996; Nwachukwu *et al.*, 2016)

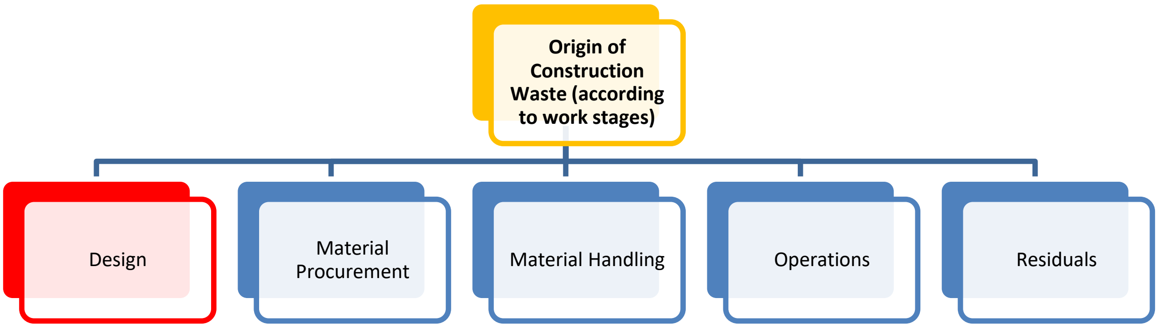
They further clarified that waste does not just originate from the application and use of materials in the construction site but it also emanates from the process preceding construction.

- Formoso et al. cited in Ghanim (2014) assorted waste according to its source stage in which the root causes of waste occur, such as material manufacturing, design, material supply, and planning as well(Nwachukwu *et al.*, 2016).

- Whereas Craven and Bernold cited in Osmani(2006) categorizes the waste sources of construction into design; materials procurement; materials handling; operations; residual (Craven *et al.*, 1994; Osmani *et al.*, 2006).
- A similar approach was taken by Serpell and Labra,(2003) and Ekanayake and Ofori(2000) cited in Osmani et al.(2006) who categorized construction waste according to design, operational, material handling and procurement sources. The authors revealed that design errors significantly accounts for a substantial amount of construction waste in the end. Similar breakdown is also presented by Ola. Adisa(Osmani *et al.*, 2006; Ola-Adisa et al., 2015).
- The research by Osmani categorizes the sources of construction waste from the beginning to the end of the life cycle using the work stages developed by the Royal Institute of British Architects (RIBA). This classification incorporates most of the sources already established in the literature and found the reason that though CDW waste is usually created at the stage of construction, the cause of the waste can be generated through all stages from in (Ghafourian *et al.*, 2018).
- Another research an approach similar to Craven and Ekanyake cited in Osmani(2006), was conducted by Masudi et al. (2011) that shows classification of waste sources into six stages namely: design, procurement, handling, operation and residual. (Nwachukwu *et al.*, 2016)
- Established in the literature work, Ghafourian(2018) also grouped the waste by main processes of a construction project mainly design, tender and contract, and construction as prescribed by the Work Stage developed by the Royal Institute of British Architects (Ghafourian *et al.*, 2018)

The reason behind the in-depth review of the sources of waste lies in the fact that further breakdown and simplification of the origin will help in extracting the corresponding causes that will help in effective management to reduce the waste. This is the reason why the study focuses on the design as a source of waste so the interpretation of the causes of waste can help find a better solution for waste reduction.

Figure 2.1 Origin of Construction Waste



2.6 Why chose "Design" as Source of Waste

Consensus in the literature shows that there exists a strong relationship between design and construction waste such that any approach applied over the design process will not only affect the design process but the whole construction process (Mazlum et al., 2016; Osmani et al. 2008a; Rahe et al., 2013; Sacks et al., 2009).

Design process is said to be notorious for its role at material waste generation (Mazlum *et al.*, 2016). Furthermore, the literature states that an extensive amount of construction waste originates as a result of poor design (Chandrakanthi, 2002; Al-Hajj, 2011). This foregoing seems to support the anecdotal fact that approximately 33% of construction waste generated onsite is related to design directly or indirectly(Mazlum *et al.*, 2016). It is therefore not a concealed fact that about one by third part of construction waste originates as a result of design decisions(Osmani *et al.*, 2006). A study lead by Saunders and Wynn (2004) revealed that improper design becomes one of the key causes of material waste(Saunders, 2004; Al-Hajj, 2011). This standpoint is also reinforced by Al-Hajj(2011), Osmani(2006), Ola-Adisa(2015), Nwachukwu(2016) and Akinade(2018). Another finding by Ofori in Al-Hajj & Hamani(2011) stated that waste produced on-site is right away related to the problems on which the site personnel have very little influence(Al-Hajj, 2011).

On the contrary, literature had been extensively published on various matters related to waste when it has already been produced but very few attempts are made to highlight the outcomes of design activities on waste generation(Osmani, et al., 2008b; Senami et al., 2007).

The need of hour is to implement best waste minimization strategy to nip waste at the bud and this starts from the drawing board where waste is identified, evaluated and measured. Thenceforth suitable measures are taken to address them (Nwachukwu *et al.*, 2016). Literature has also revealed that the best methodology to CDW management is waste reduction from inception through detailed design (Akinade *et al.*, 2018) that makes the major part of source reduction strategy.

2.7 Waste minimization through design:

The construction waste minimization is defined as "the process which avoids, eliminates or reduces waste at its source, or permits reuse and recycling of the waste for beneficial purposes in construction(Azkona, 1999; Senami and Ejiga, 2007).

"the reduction of waste at source, by understanding and changing processes to reduce and prevent waste."(Kofi Agyekum, 2012)

Construction waste can be reduced using two main methodologies namely: through practices of source reduction and through strategies of improving on-site waste management. Source reduction strategy decreases or removes waste generation at the source of a process is known as source reduction. Unlike source reduction, on-site waste reduction strategy deals with waste that specifically arises due to on-site complications. For example an unskilled subcontractor worker consuming extra material than the amount required thus resulting in ruining up the goods ordered in required amount(Ghafourian *et al.,* 2018). The study aims to discuss on the source reduction strategy via design.

- The Construction for excellence report of construction industry review committee (CIRC 2001) endorsed that construction waste should be reduced throughout the design stage. This hence, obliges the design team to adopt waste reduction practices from inception through detailed design (Baldwin *et al.*, 2007).
- A consensus in the literature tells that the best tactic to CDW management is minimization through design. This is due to the fact that design offers flexible and cost-effective way to minimize waste before its occurrence(Akinade *et al.*, 2018).
- Shant and Daphene(2014) also posited that a potential scheme in minimizing waste is to design out waste or reduce the waste at source. Therefore, proper planning in the design stage will steer the way to such a perfection that little or no changes may be required at the later stages in construction(Dajadian et al. 2014).
- Findings by Nwachukwu also asserted that good waste management practice starts from initiation where waste is acknowledged and then appropriate measures are assembled to mitigate them(Nwachukwu *et al.*, 2016).
- Similar thinking is endorsed by Baldwin(2007) about efficiency of design process as major contributor towards waste minimization who further stated that expected waste generated during construction must be analyzed. Lending support to the former

statement, as the design process is multidisciplinary and iterative, the construction process must be redesigned to use alternative materials to minimize waste(Baldwin *et al.*, 2007).

- It is more resourceful if minimization of construction waste is addressed early in the design process. Owing to the nature of design process as integrative, multi-disciplinary and iterative, the design alterations in one discipline will inevitably cause rework for other disciplines personnel occasionally leading to unproductivity. Well-organized information flow between different design disciplines can improve the productivity and assist in reducing the reworks and abortive work promoting the reduction of construction waste.(Baldwin *et al.*, 2007)
- Ghanim (2014) and Gray (2013) noted that ascertaining the sources and forms of waste, and mitigating appropriate measures for the waste, forms an effective way of minimizing waste. Such set of activities makes the sound basis for developing a waste management plan, commended for every construction project. The plan will, in general manifest the peculiarities of project in terms of nature and extent of waste anticipated and then, will suggest ways to mitigate them(Nwachukwu *et al.*, 2016).

However, the increasing awareness of environmental and economic impacts demands the waste minimization and management to be a considerate and mandatory function of construction project management practices in the building (Shen *et al.*, 2002; Osmani *et al.*, 2006; Senami *et al*., 2007).

Consequently and unfortunately, there is no structured approach and insufficient effort to minimize the construction waste in the strategic planning and design activities of projects (Osmani *et al.,* 2008; Osmani *et al.,* 2008b; Mazlum *et al.*, 2016). This is mainly due to the reason that surveyed design and contracting companies believe that CDW waste is inevitable(Akinade *et al.*, 2018). Osmani et al. (2008) showed that waste management meetings are held by just 2% of construction project teams while the management goals are implemented by only 32% of them(Akinade *et al.*, 2018). This is due to the fact that material waste minimization is not interpreted as a means to save natural resources and achieve sustainable construction but as a monetary means to increase profit. Moreover, Architects show their willingness towards working with consultants and contractors to design out waste if and only if incentivized by clients, primarily if they are paid extra charges for waste minimization feasibility and implementation studies(Osmani *et al.* 2008a). This concludes the fact that for the introduction of systems of waste minimization in surveyed design and contracting companies, rather than charging penalties, rewards are demanded other than voluntary approaches(M Osmani, Glass and Price, 2008). On the other hand, waste minimization practices, instead of being a part of the core activities in building design process, is perceived as an ad hoc activity. Architects pointed out the existence of number of impediments in designing out waste; for example, unawareness of waste minimization, unknown root causes of design waste, clients' changing demands, and poorly defined responsibilities(M. Osmani, Glass and Price, 2008a). Therefore, there is apparently a huge demand for changing the attitude of whole construction team and mitigating the obstacles that are becoming hurdle in the way of waste minimization(Al-Hajj and Hamani, 2011). The significance of the designers should not be overlooked in this aspect(Senami and Ejiga, 2007).

Also, it is vital that the architect ensures the client knows about all levels of the waste management hierarchy to optimize the resources used on building projects. So as to reassure the practices of waste reduction and recycling, architects and engineers can develop pertinent language to incorporate in their specifications(Senami *et al.*, 2007). Accordingly, it must be the utmost responsibility of the architects and design engineers to ensure that waste is given high priority along with project time and cost during design(Akinade *et al.*, 2018). Designers should be motivated to advise stakeholders on the economic and environmental benefits of waste management, to initiate waste management strategies for other work stages, and synchronize the design practices with waste minimization practice(Akinade *et al.*, 2018). As according to Josephson and Hammarlund (1999), the shortcomings due to design process builds up the largest category when measured by cost(Mazlum *et al.*, 2016).

Thus, the research reports, cited in Osmani(2008c), have reinforced the education of waste minimization in the building construction industry, by including cost savings, and environmental issues and prescribed the use of recycled materials by presenting the basic 'three Rs' principle of waste (i.e. reduction, re-use and recycle)(Osmani *et al.*, 2008). One of the initial stage in reducing the sum spent on waste disposal is to reduce the amount of waste produced or made. The primary step in waste minimization strategy is good planning. Material standardization must be given a priority and materials should be ordered accurately. Also, it is vital that the architect ensures the client knows about all levels of the waste management hierarchy to optimize the resources used on building projects. So as to encourage waste reduction and recycling practices, architects and engineers can develop pertinent language to incorporate in their specifications(Senami *et al.*, 2007; Ola-Adisa *et al.*, 2015).

2.8 Causes of Design Waste:

Waste management should first consider different sources of waste and the causes of waste they generate, and then take best possible steps to minimize them from the root(Nwachukwu *et al.*, 2016). Among the three Rs' principle of waste hierarchy: reduction, re-use and recycle, reduction sets for a proactive goal towards waste minimization while, re-using and recycling indicates to have a reactive approach when the waste has already been generated. Disposal should be considered as the last option when the three Rs have failed to prove recuperative for the waste generated(Nwachukwu *et al.*, 2016). This study focuses on the principle "Waste Reduction" i.e. a proactive technique. Thus, the interpretation of the causes of design waste can help find a better solution for waste reduction.

Figure 2.2: Three R's of Waste Hierarchy

Additionally, design waste is defined as "the waste arising from construction sites owing directly or indirectly to the design process"(Osmani *et al.*, 2006). Similarly, 'design waste' is also defined as ''the waste arising from construction sites both by acts and/or omissions on the part of the designer, including opportunities to reduce waste lost by not using reclaimed materials'(Osmani *et al.*, 2008).

In addition, Ghafourian(2018) brought this phenomenon into notice that many of the reasons for waste are inter-related and thus, a thorough understanding of sources is needed to integrate the causes to be better understood and managed for an effective process of waste management (Ghafourian *et al.*, 2018). Ghafourian research further states that many researchers have discovered a number of factors leading to construction waste such as quality, cost, delay, and the lack of safety procedures, transportation that is unnecessary, nonsuitable methods of management, improper equipment, and weak construction(Ghafourian *et al.*, 2018).

Table 2.1: Factors causing Design Waste

S. No.	Factors Causing Design Waste	References
1	Negligence of material standardization	(Al-Hajj and Hamani, 2011), (Ola-Adisa, Sati and Ojonugwa, 2015), (Alshboul and Ghazaleh, 2014)
2	Poor design leading to change at advance stage	(Alshboul and Ghazaleh, 2014), (Ola-Adisa, Sati and Ojonugwa, 2015), (M. Osmani, Glass and Price, 2008b)
3	Lack of support from senior management	(Wang, Li and Tam, 2015), (M. Osmani, Glass and Price, 2008a), (M. Osmani, Glass and Price, 2008b)
4	Lack of training	(Wang, Li and Tam, 2015), (Al-Hajj and Hamani, 2011), (Osmani, Price and Glass, 2005)
5	Waste accepted as inevitable	(Alshboul and Ghazaleh, 2014), (Akinade *et al.*, 2018), (Al-Hajj and Hamani, 2011), (Senami and Ejiga, 2007), (Jose et al., 2018), (Wang, Li and Tam, 2015)
6	Lack of government and legislation policies	(Al-Hajj and Hamani, 2011)
7	Erroneous contract document	(Nwachukwu *et al.*, 2016), (Ola-Adisa, Sati and Ojonugwa, 2015), (Senami and Ejiga, 2007)
8	Inefficient information flow	(Ola-Adisa, Sati and Ojonugwa, 2015), (M. Osmani, Glass and Price, 2008b), (Senami and Ejiga, 2007)
9	Inaccuracy in quantity surveys	(Ola-Adisa, Sati and Ojonugwa, 2015), (Ghafourian, Ismail and Mohamed, 2018), (Jose et al., 2018)
10	Inexperienced designers	(Ghafourian, Ismail and Mohamed, 2018), (Alshboul and Ghazaleh, 2014),

		(M. Osmani, Glass and Price, 2008b)
11	The interference of the owner during construction	(Alshboul and Ghazaleh, 2014)
12	Designer's concerns about aesthetics and building's appearance	(Mazlum and Pekeriçli, 2016), (Alshboul and Ghazaleh, 2014)
13	Client's induced last minute changes	(Osmani, Glass and Price, 2006), (Mazlum and Pekeriçli, 2016), (Senami and Ejiga, 2007), (Senami and Ejiga, 2007)
14	Poorly defined individual responsibilities	(Akinade *et al.*, 2018), (M. Osmani, Glass and Price, 2008b), (Wang, Li and Tam, 2015)
15	Design changes and revisions	(Mazlum and Pekeriçli, 2016), (Senami and Ejiga, 2007), (Nwachukwu *et al.*, 2016)
16	Ineffective use of qualified source	(Mazlum and Pekeriçli, 2016)
17	High expectations from unqualified sources	(Ghafourian, Ismail and Mohamed, 2018), (Mazlum and Pekeriçli, 2016)
18	Lack of self-evaluation of the organization	(Mazlum and Pekeriçli, 2016)
19	Problems with client relations	(Mazlum and Pekeriçli, 2016)
20	Selection of low quality materials and products	(Ghafourian, Ismail and Mohamed, 2018), (Jose et al., 2018)
21	Lack of influence of contractors	(Ghafourian, Ismail and Mohamed, 2018)
22	Over-ordering of materials	(M. Osmani, Glass and Price, 2008b), (Senami and Ejiga, 2007), (Osmani, Price and Glass, 2005)
23	Building complexity through emergence of variety of design specialties	(Senami and Ejiga, 2007), (Osmani, Price and Glass, 2005), (Repository, 2000), (Ghafourian, Ismail and Mohamed, 2018)

2.9 System Dynamics:

System Dynamics approach was first introduced by Professor Forrestor of Massachusetts Institute of technology that became a separate subject in 1950s. It was extensively used in the field of economics, Social Sciences and Natural Sciences.(Yu-jing, 2012)

Before jumping to the final decisions, one must consider number of possibilities. Combinatorial and interconnectivity of various problems build up a dynamic complexity. Complex systems take into account the broader aspect of variables interdependency by taking into account the correlations existing among them. A fundamental principle of system dynamics states the behavior and characteristics of the whole system in the dynamic complexity (Sterman, 2001). Around the world, there are many areas of applications where System dynamics is used. The most popular among them is the policy making(Duggan, 2018).

System Dynamics is a methodology that is favorably used for sustainable processes and allows the specialists to streamline the real world complexities into simulations and consensus systems (Barranquero, *et al*. 2015). It is run through a simulation system in computers which develops a structure model for system thinking. System is the thing that is needed to be investigated while the model depicts the side of the actual system for the problem being researched.(Yu-jing, 2012)

For system causal association among variables, a causal loop diagram (CLD) is developed with the conception of balancing and reinforcing feedback loops. The influence of one design cause over the another will help building out a causal loop diagram in this research(Tegegne et al., 2018).

Waste management researchers have also developed SD models to quantify and assess waste reduction potential(Dangerfield et al., 2010). Another research by Yuan and Wang demonstrated the economic effectiveness of construction waste management using a system dynamic approach (Yu-jing, 2012). This research also intends to address the complexities in design causes that generate wastes using system dynamic approach.

Chapter 3

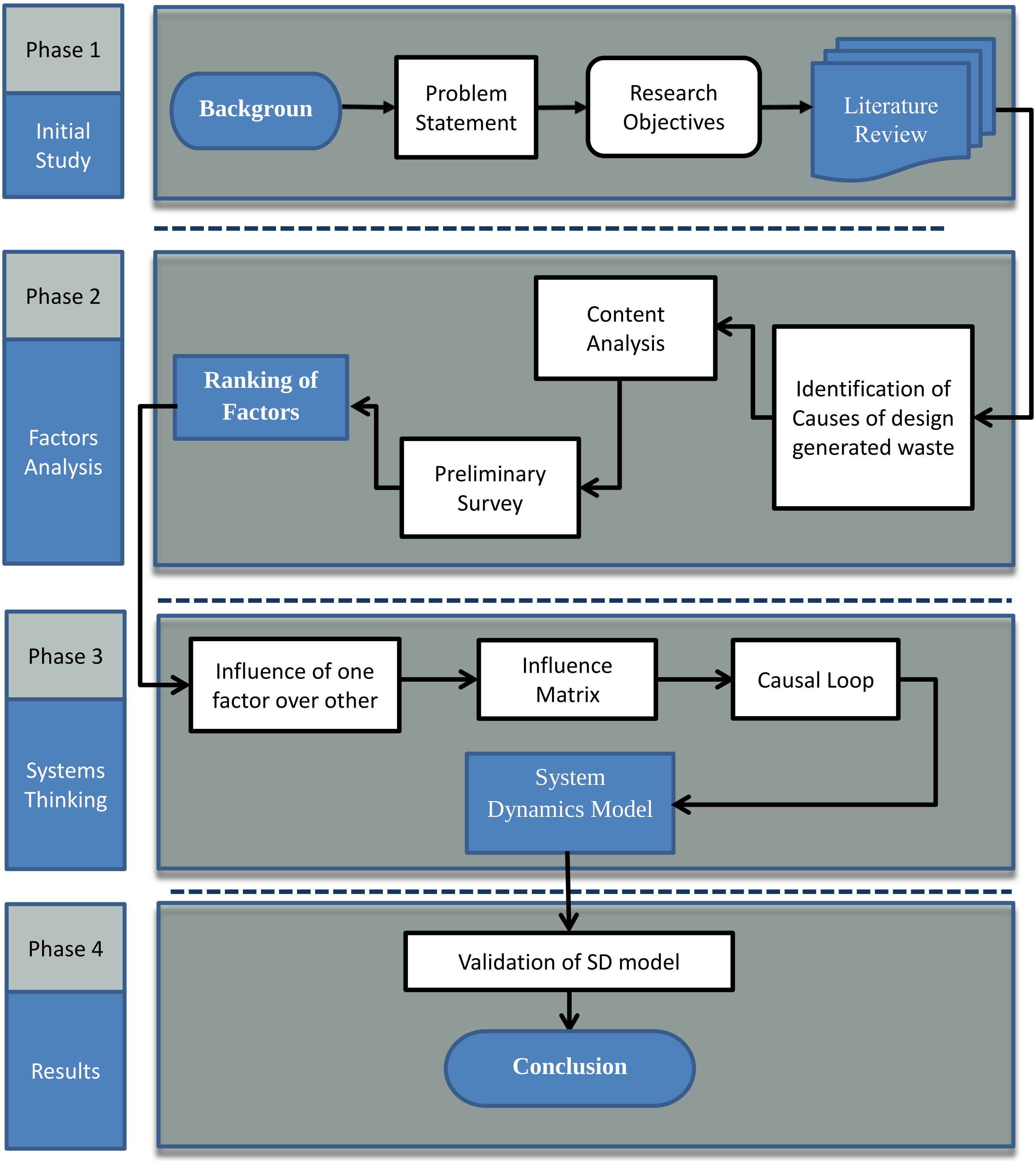
3. Research Methodology:

Searching for knowledge scientifically to solve a problem (research gap) is referred to as research. Research Methodology is said to be an art of exploring the hidden facts. It is usually a well-defined, organized and structured way of following series of steps to achieve and answer research objectives carried out by the scientists (Saunders, Lewis and Thornhill, 2009).

This research intends to follow a certain sequence of steps, techniques and procedure required to accomplish the above mentioned objectives in Chapter 1.Literature review, Content analysis, preliminary field survey, combination of particular SPSS tests, detailed field survey, influence matrix, and then system thinking approach is implied.

A four stage research methodology as shown in Fig 3.1 below has been developed. The details will be discussed in the subsequent section:

Figure 3.1 Research Framework



3.1 Research Gap Analysis:

Search for the research gap started by scrolling through the research articles that appeared in recent publication year. Going through the background of waste management, it was realized that despite the extensive work in waste management, area of design is still under research. Previous studies focus on the reactive approaches to waste management with the little emphasis on the work of proactive approach. Possible methods and strategies were identified to develop a system thinking model for addressing the complexities in design that leads to generate waste.

3.2 Literature Review:

An extensive literature review was conducted to identify factors causing design generated waste. Content analysis was piloted to observe the researchers' data in an organized and structured form(Antwi-afari *et al.*, 2018) which used contextual importance(qualitative scores) and frequency of appearance(quantitative scores) as a basis for computations of results. Normalized scores for literature were then determined to rank the identified factors.

3.3 Preliminary Field Survey:

An appropriate literature review technique shall be adopted along with the participation of experts from the field(Ullah, 2016; Ahmad, 2018). A mandatory approach was implied that promoted the participation of field experts in the form of online questionnaire survey form. The questionnaire survey form was generated through Google$_{TM}$ docs and was sent to the targeted respondents of developing countries to determine the importance of each factor in field.

3.4 Data Analysis:

After getting a reasonable number of responses from the field survey, results were compiled and tested for further analysis. Statistical Package for Social Sciences was used for testing the reliability of responses and the extent of agreement of respondents(Bonett and Wright, 2015). Cronbach's alpha reliability analysis and Concordance analysis tests were done respectively.
The statistical verified data was then put forward for factor analysis that helped to deduce the most important factors. Ranking and shortlisting of factors was done by taking collective scores of respondents and literature giving the weightage of 60 and 40 respectively with the combined significance of 50 percent(Nazia *et al.*, 2019).

3.5 Detailed Field Survey:

To determine the interconnectivity and combinatorial effect of the variables(factors), level of influence (causal strength) and relationship (polarity) of contributing factors in construction waste will be needed to be explored. A detailed questionnaire survey will be disseminated nationally and internationally to the field experts on the basis of which influence matrix and causal loop diagram shall be developed. This account for the broader aspect of variables interdependency by taking into account the correlations existing among them (Sterman, 2001).

3.6 Model Development:

System dynamics model with the software of Vensim will be developed via information extracted form causal loop diagram about the influence of one factor over the other and positive/negative polarities. In a model based methodology, validity of a model is an utmost aspect as the validity of results analytically depends upon the validity of the model(Barlas, 1996). Structural and behavioral verification tests will be conducted within this respect. After that, results and conclusions will be drawn.

Chapter 4

4. RESULTS AND DISCUSSION

4.1 Content Analysis:

First most step was the identification of factors via extensive relevant literature review. For the required purpose, Emerald Insight, Science Direct, Wiley, Google Scholar and various online libraries forums were frequently used. Total of 20 papers were studied from which 98 factors were extracted. Owing to the similar meanings and context, many factors were synonymously used in place of others or were merged respectively. The number of overall factors was decreased to 23. Semi qualitative analysis was then done to analyze the literature associated importance of each factors. Frequency of appearance of factor in the research article as quantitative score was simply noted as "one" in the spreadsheet for each associated research article and contextual importance used as qualitative score were assessed using a 3-point Likert(5 as High, 3 as medium, 1 as Low). Qualitative and quantitative scores were then multiplied to elicit the literature score. This score was further normalized to scale the data for factor analysis in the next step. Literature studies tell about the research trends carried out in the past. It is considered to be a secondary data. This is the reason why it is deemed necessary to collect primary data that is done through preliminary field survey in the study.

Table 4.1 Ranking of Factors based upon Literature Score

Sr.	Codes	Factors	Literature Score	Normalized Score	Ranking
1	**F2**	Substandard design at advance stage	0.7	0.135	1st
2	**F15**	Design changes and revisions in design stage	0.7	0.135	1st
3	**F8**	Inefficient information flow	0.5	0.097	2nd
4	**F1**	Lack of attention paid to standardization of material in market	0.4	0.077	3rd
5	**F5**	Waste accepted as inevitable	0.4	0.077	3rd

6	**F7**	Erroneous contract document	0.35	0.068	4th
7	**F10**	Inexperienced Designers	0.35	0.068	4th
8	**F3**	Lack of support from senior management	0.3	0.058	5th
9	**F13**	Client's induced last minute changes	0.3	0.058	5th
10	**F23**	Building complexity through emergence of variety of design specialties	0.18	0.035	6th
11	**F17**	Client's biased behavior towards inexperienced human resource	0.15	0.029	7th
12	**F20**	Selection of low quality materials and products	0.15	0.029	7th
13	**F9**	Inaccuracy in quantity surveys	0.15	0.029	7th
14	**F22**	Over-ordering of materials	0.12	0.023	8th
15	**F12**	Designer's concerns about aesthetics and building's appearance	0.1	0.019	9th
16	**F4**	Lack of training	0.06	0.012	10th
17	**F19**	Problems with client relations	0.05	0.010	11th
18	**F14**	Poorly defined individual responsibilities	0.04	0.008	12th
29	**F6**	Lack of government and legislation policies	0.03	0.006	13th
20	**F18**	Lack of self-evaluation of the organization	0.03	0.006	13th
21	**F11**	The interference of the owner during construction	0.01	0.002	14th
22	**F16**	Ineffective use of qualified	0.01	0.002	14th

		source			
23	**F21**	Lack of influence of contractors	0.01	0.002	14th

4.2 Preliminary Questionnaire Survey:

This research has two staged data collections: Preliminary field survey that is considered to be the part of pilot study and the detailed questionnaire survey that helped in developing causal loop diagram and system dynamics model. Thus to get primary data, it was deemed necessary to carry out an international survey. For this purpose, Google$_{TM}$ Docs was used that was divided into two sections.(Shen, Zhang and Long, 2017)

- First section comprises of demographic and professional information about the respondents: qualification, field of experience, job description, professional experience, country of origin and details about prioritization of waste minimization through design.
- Second section consists of multiple choice grid, that inquired respondents according to their knowledge, approximately how much the causes of design have contributed towards the construction waste. It was recorded on the 5 points ordinal Likert scale data.

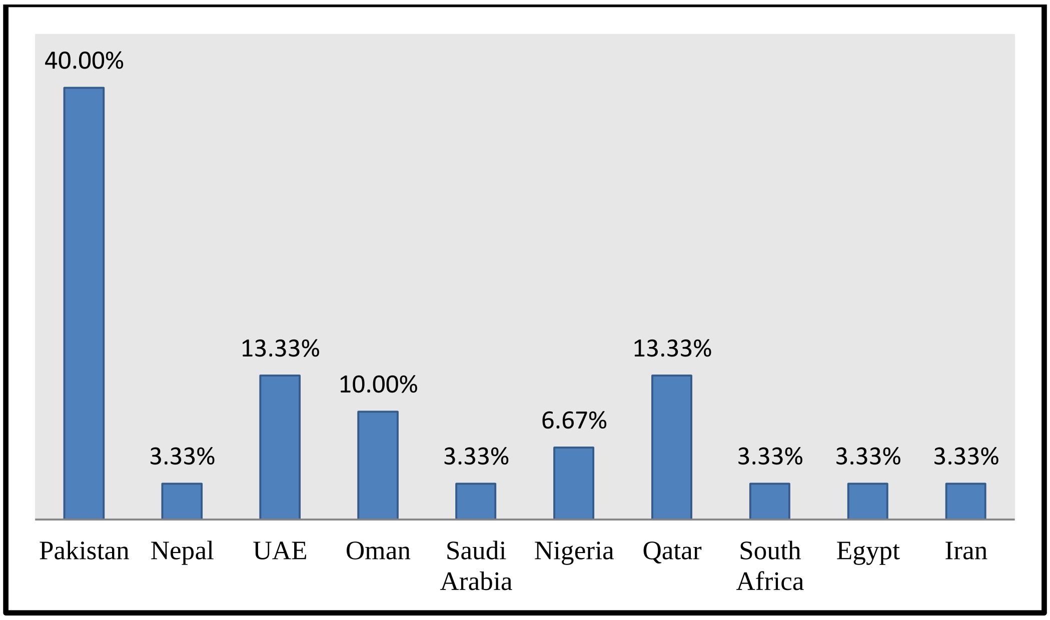
Online professional forums like Linkedin and ResearchGate were used to disseminate the survey form to targeted respondents. The main focal area was the developing countries. This is the limitation of this research. It took three to four months to collect the data. A total of 30 samples were collected from 10 different developing countries as shown below in table. Almost half of the survey was filled by the experts having experience of above 15 years. According to the commonly accepted rule, with a sample size of 30 or above, the central limit theorem holds true(Albert Ping Chuen Chan, 2015). Most of the responses were from the professional experience of above 15 years that further proves the validation of the research.

Table 4.2 Respondents' Data

Total Respondents=30			
1) Professional experience			
Sr.	**Experience**	**Number**	**Percentage**
1	0 to 1	0	0.00%
2	2 to 5	4	13.33%
3	6 to 10	4	13.33%
4	11 to 15	7	23.33%
5	Above 15	15	50.00%

2) Organization type			
Sr.	**Organization type**	**Number**	**Percentage**
1	Client	3	10.00%
2	Contractor	12	40.00%
3	Consultant	13	43.33%
4	Specialty Contractor	2	6.67%

Figure 4.1 Origin of Responses



4.3 Data Analysis

Measurement level of responses recorded in a 5 point Likert scale is ordinal. Parametric statistics would not yield meaningful result unless and until they are normalized (Bishop and Herron, 2015). Tending to the nature of this data type, some of the non-parametric tests were implied(Golparvar-fard *et al.*, 2006) using the Statistical Package for Social Sciences(SPSS) in the beginning to see the consistency among the data recorded and agreement between the respondents regarding variables.

4.3.1 Cronbach's Alpha Test:

Cronbach alpha reliability test was conducted that measures the consistency of responses in a set of survey. Cronbach Alpha test value came out to be 0.915 that means there is high reliability of used scale. The threshold value for checking reliability is 0.7.(Polat *et al.*, 2017)

Table 4.3 Reliability Test Results

Reliability Statistics	
Cronbach's Alpha	N of Items
.915	23

Table 4.4 Representation of Cronbach's Alpha Values

The relationship between the Cronbach's alpha value and internal consistency.

Cronbach's alpha value (α)	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable

4.3.2 Concordance Analysis:

Concordance analysis test was performed to check whether the data collected is in an agreement (H_a) or not (H_o). This was done via SPSS and also checked through megastats add-ins tab in excel. The Kendall's coefficient of concordance (W) came out to be 0.077. There are two ways of checking the data on the basis of which the decision is taken whether to accept the null hypothesis or to reject it(Golparvar-fard *et al.*, 2006):

1. First is by checking the value of sigma whether it lies above or below the level of significance that is 0.05. The lower value will tend to push our decision towards rejecting the null hypothesis. This case also shows the value of sigma or p-value to be 0.0004.
2. Second is by checking the calculated chi square(X^2) value with table value of chi square. The table value for Chi square is 33.92 lower than the calculated chi square(X^2) i.e. 51.123 in below table. So the null hypothesis is rejected.

This means that in either situation null hypothesis is rejected. This implies that there is a good degree of agreement among the respondents in prioritizing the causes of waste(Golparvar-fard *et al.*, 2006).

Table 4.5 Concordance Test Results

N	30
Kendall's W[a]	.077
Chi-Square	51.123

df	22
Asymp. Sig.	.0004

After conducting both the tests, factor analysis was run to shortlist the factors for systems thinking in future. Before that the respondent score data was also normalized on a scale of 0-1. This was done to make the data compatible for further analysis. Different weighting ratios of 50/50, 60/40, 70/30 and 80/20 of respondent normalized score and literature normalized scores were calculated respectively taken to determine the collective score.

4.3.3 ANOVA:

The results of the weighting criteria were then tested using ANOVA. The data tested through ANOVA is now a scale data hence it is appropriate for parametric tests (Mircioiu and Atkinson, 2017). The P-value/Sigma value was 1 that signifies the null hypothesis exists and the difference between the means of the data is not significant.

Table 4.6 ANOVA Results

Groups	*Count*	*Sum*	*Average*	*Variance*
80/20	23	0.996525	0.043327	0.000144
70/30	23	0.994788	0.043252	0.000224
60/40	23	0.99305	0.043176	0.000335
50/50	23	0.991313	0.043101	0.000478
40/60	23	0.989575	0.043025	0.000652
30/70	23	0.987838	0.042949	0.000858
20/80	23	0.9861	0.042874	0.001095

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.67E-06	6	6.12E-07	0.001133	1	2.157914
Within Groups	0.083281	154	0.000541			
Total	0.083284	160				

4.3.4 Shortlisted Factors

Decision of 60/40 ratio finally posited 8 most important factors ranked in order with the cumulative impact of 50 percent to encompass maximum influence(Nazia *et al.*, 2019). 60/40 weight criterion was selected as to allow a balanced amalgamation between field respondents and literature score. Pertaining due importance to the recent data, primary data was specified more weight than the secondary(Nazia *et al.*, 2019).

Table 4.7 Shortlisted Factors

Sr.	Code	Shortlisted Factors	Weightage (60/40)	Cumulative Score
1	F15	Design changes and revisions	0.0820	0.0820
2	F2	Substandard design at advance stage	0.0750	0.1569
3	F8	Lack of interdisciplinary coordination	0.0665	0.2235
4	F10	Inexperienced designers	0.0619	0.2854
5	F1	Negligence of material standardization	0.0588	0.3442
6	F5	Waste accepted as inevitable	0.0588	0.4030
7	F7	Erroneous contract documents	0.0549	0.4579
8	F13	Client's induced last minute changes	0.0511	0.5090

4.5 Detailed Field Survey

An international detailed questionnaire survey was carried out in order to determine level of influence (causal strength) and relationship (polarity) of one factor over the other that is creating complexities and then contributing to construction waste. The survey comprised of two parts: Former section was devoted to demographic such as, qualification, experience, field of work; (Wong *et al.*, 2016) and the latter part includes questions regarding causal strength and relationship among factors. Causal strength for each question was recorded among the level scales-Low, Medium and High. Respondents were demanded to choose between direct and indirect to determine polarity. This was facilitated using the GoogleTM Docs forum (Shen, Zhang and Long, 2017).

4.5.1 Sample Size Calculation

Decision of appropriate sample size was made by using a simple formula prior to the collection of data:

$$n = \frac{(z^2 * p * q)}{MoE^2} \qquad \textit{Equation 1}$$

Where n=sample size, z = z-score for required confidence level, p = proportion being tested, q=1-p, MoE=Margin of Sampling Error (Dillman, 2014)

For 95% confidence interval, used as convention in most of the studies(Goodman and Berlin, 1994), z-value is 1.96, p-value and q value are taken on the basis of 50/50 split i.e. the probability of getting 50% answers as “yes” and the rest 50% as “no”. Desired Margin of sampling error is taken as ±10%(Dillman, 2014).

$$n = \frac{(1.96^2 * 0.5 * 0.5)}{0.1^2} = 96$$

Substituting the values, sample size came out to be 96.

4.5.2 Data Collection

The data was collected from various developing countries. Professional Online forums like LinkedIn and Research gate and social networks like Facebook were made into use for this purpose. The survey conducted was held in bidirectional flow to cover every perspective in order to achieve the most meaningful relationships. Out of 152 responses, 134 responses were considered while rest of the responses being erroneous and incomplete was discarded. The data collected, covered 35 developing countries. Most of the respondents were with the experience of more than 5 years. The respondents’ data is represented below:

Table 4.8 Respondents’ Data

Total Respondents=134			
1) Professional experience			
S. No.	**Experience**	**Number**	**Percentage**
1	0 to 5	3	2.24%
2	1 to 5	20	14.93%
3	6 to 10	43	32.09%
4	11 to 15	30	22.39%
5	16 to 20	15	11.19%
6	21 and above	23	17.16%
2) Highest Academic Qualification			
Sr. No.	**Qualification**	**Number**	**Percentage**
1	Doctorate	9	6.72%
2	Masters	63	47.01%
3	Bachelors	62	46.27%

Figure 4.2 Field of Work

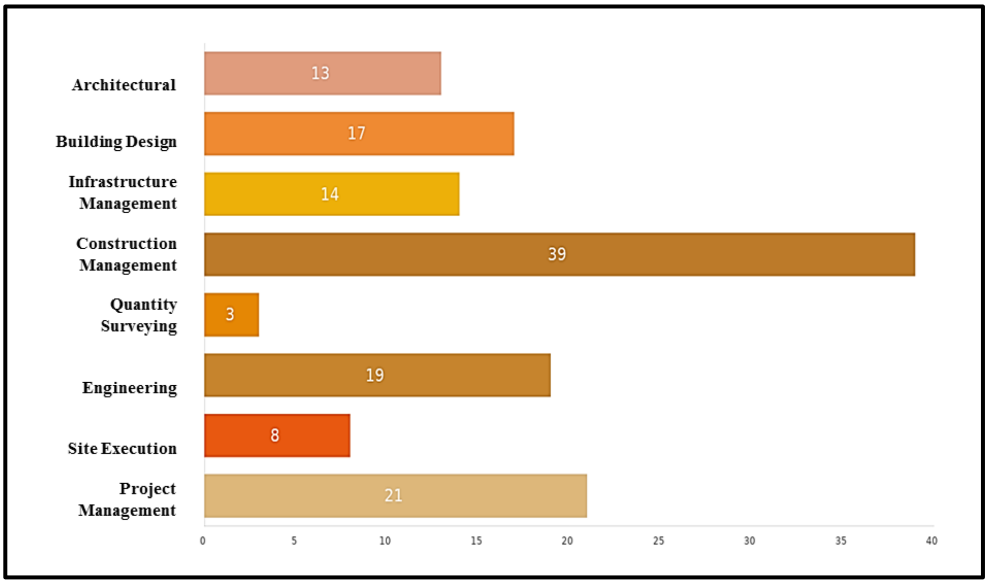


Figure 4.3 Organization Type

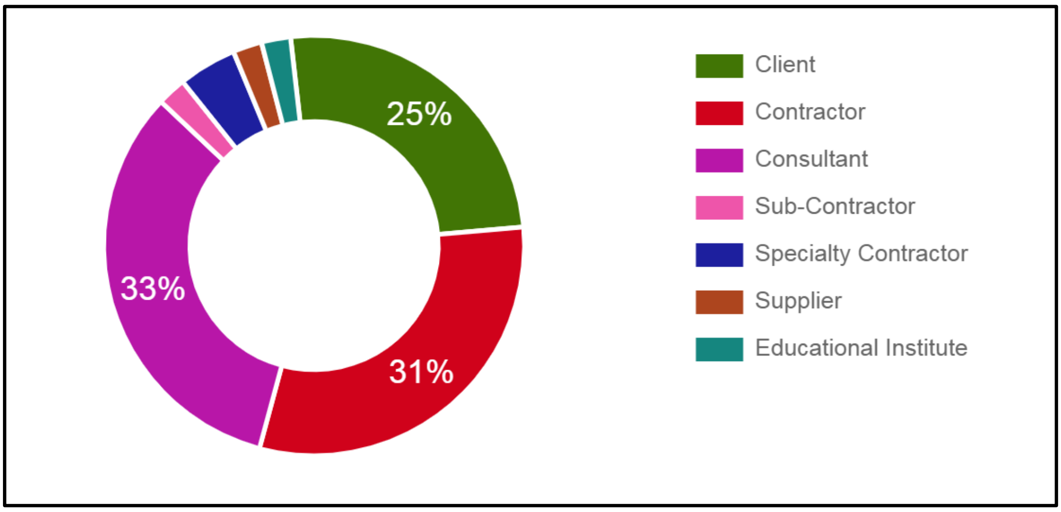
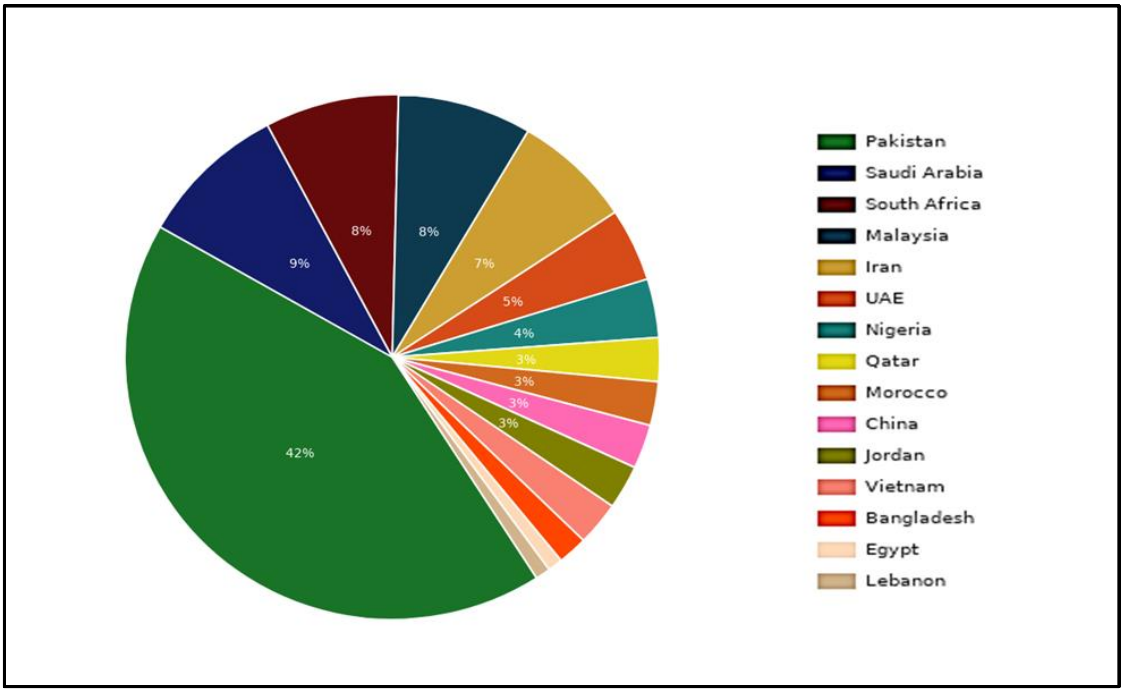


Figure 4.4 Origin of Responses



4.5.3 Detailed Data Analysis

After the collection of 134 responses from 35 different developing countries, the data was compiled and statistically tested for Cronbach's alpha reliability test via SPSS before proceeding to analysis.

Table 4.9 Reliability Test Results

Reliability Statistics	
Cronbach's Alpha	N of Items
.895	56

Out of 56 relationships, 12 relations were shortlisted by field experts. Causal strength was achieved by taking the mean value of the responses recorded in the form of Likert scale- Low:1, Medium:3, High:5) (Boone *et al.*, 2012). The interrelationships with the mean score value above 3.5 were taken into account for further analysis(Sourani *et al.*, 2015). The values were then further normalized(Patro and sahu, 2015). Polarity was determined referring to higher number of counts among the categories- "Direct" and "Indirect"(Abdul Rahim *et al.*, 2008). This served as a basis for developing the influence matrix which further assisted in creating a causal loop diagram.

Table 4.10 Interrelationship Chart

Impacting Factor	Impacted Factor	Polarity	Influenced value	Normalized
Waste accepted as inevitable	Inexperienced designer	Direct	0.76	0.104
Client's induced last minute changes	Design stage changes and revisions	Direct	0.75	0.102
Inexperienced designer	Waste accepted as inevitable	Direct	0.72	0.098
Inexperienced designer	Client's induced last minute changes	Direct	0.72	0.098
Inexperienced designer	Lack of interdisciplinary coordination	Inverse	-0.77	-0.105
Inexperienced designer	Negligence of material standardization	Direct	0.75	0.102
Lack of interdisciplinary coordination	Design stage changes and revisions	Direct	0.75	0.102
Negligence of material standardization	Design stage changes and revisions	Direct	0.79	0.107
Design stage changes and revisions	Erroneous contract document	Direct	0.73	0.099
Design stage changes and revisions	Substandard design at advance stage	Direct	0.73	0.100
Erroneous contract document	Client's induced last minute changes	Direct	0.71	0.097
Substandard design at advance stage	Waste accepted as inevitable	Direct	0.70	0.096

4.5.4 Influence Matrix

The results interpreted in interrelationship chart provided a basis for the formation of influence matrix. The matrix shows the impact of variable "y" over the variable "x" in the form of a feedback structure (Beck, *et al.* 2012).

Table 4.11 Influence Matrix

Influence Matrix	A1	A2	A3	A4	A5	A6	A7	A8
A1	**1**		0.76					
A2		**1**				0.75		
A3	0.72	0.72	**1**	-0.77	0.75			
A4				**1**		0.75		
A5					**1**	0.79		
A6						**1**	0.73	0.73
A7		0.71					**1**	
A8	0.70							**1**

A1 = Waste accepted as inevitable, **A2** = Client's induced last minute changes, **A3** = Inexperienced designer, **A4** = Lack of interdisciplinary coordination, **A5** = Negligence of material standardization, **A6** = Design stage changes and revisions, **A7** = Erroneous contract document, **A8** = ubstandard design at advance stage

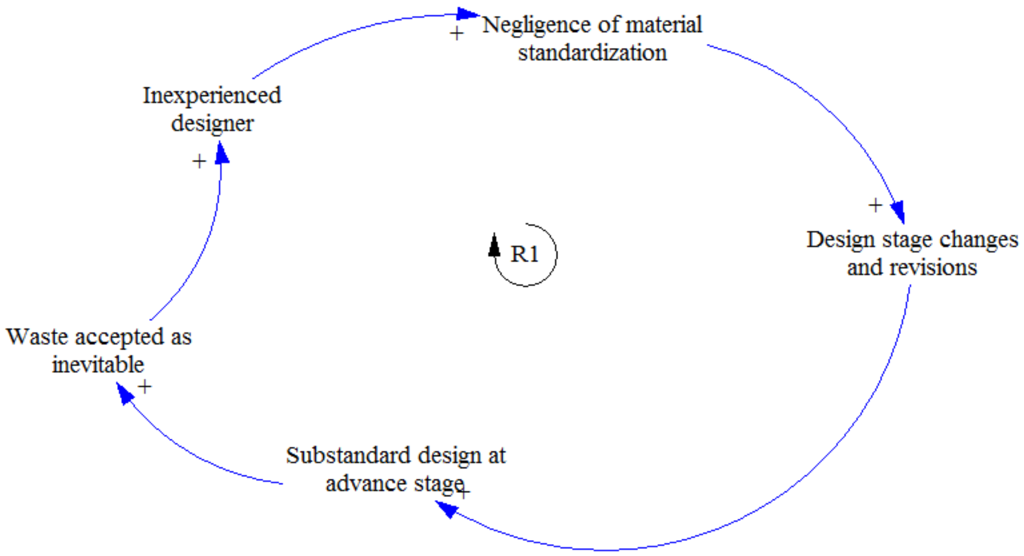
4.5.5 Causal Loop Diagram

The influence matrix assisted in creating an understanding of the dynamics of factors in a highly interconnected environment by developing a causal loop diagram. The Causal Loop Diagram demonstrates 4 reinforcing and 1 balancing loops-R1, R2, R3, R4 and B1. The combination of interconnected loops provides an illustration of a rational and logical complex structure that is entirely accountable for triggering the construction waste.

4.5.5.1 Reinforcing Loop R1

According to the figure 4.5, if the top management system accepts the "waste" as an outcome of the construction process, this will cause to hire more inexperienced designers for designing. The employment of inexperienced designer will lead to the consequence of negligence in material standardization. Due to which, design changes and revisions will take place. This will affect the advance stages of construction badly. The substandard design at advance stage will systematically evidence the concept of waste acceptance in construction as inevitable.

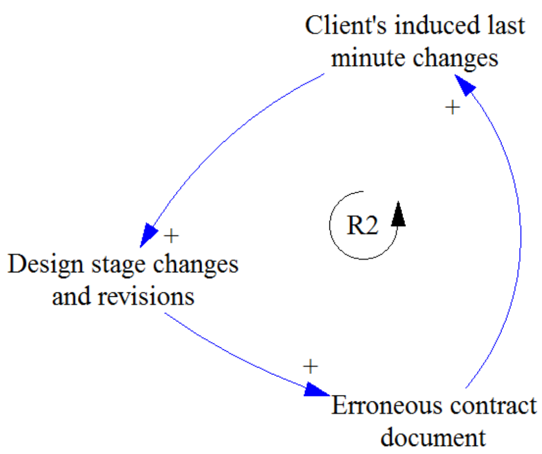
Figure 4.5 Reinforcing Loop 1



4.5.5.2 Reinforcing Loop R2

The reinforcing loop in figure 4.6 illustrates that the clients induced last minute changes will ultimately induce design stage changes and revisions. The changes will certainly lead to formulation of erroneous contract document.

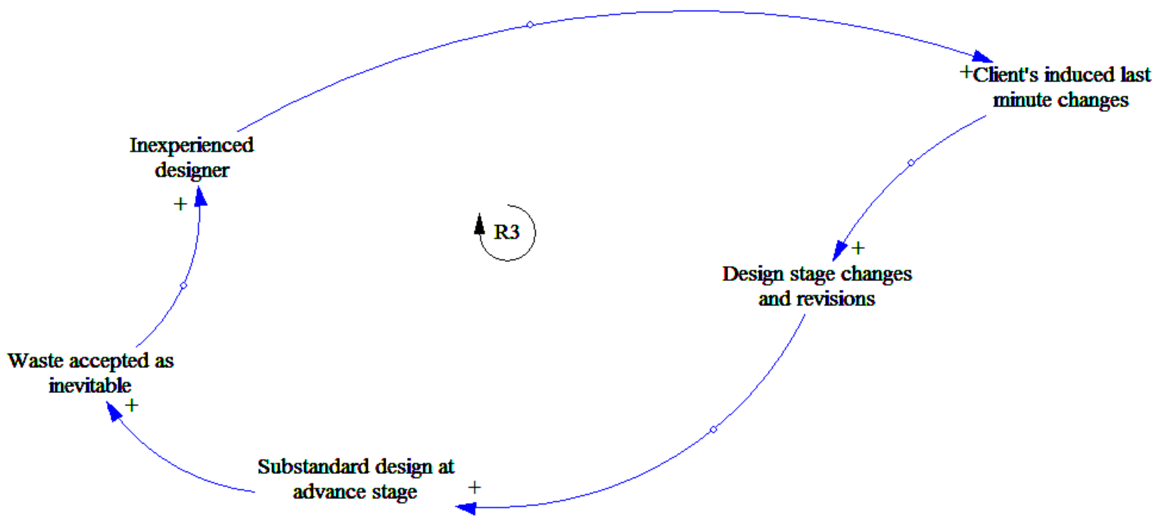
Figure 4.6 Reinforcing Loop 2



4.5.5.3 Reinforcing Loop R3

Figure 4.7 demonstrates that appointment of inexperienced designers during design stage will increase the number of changes clients will make at last stages. This will lead to changes in design. The chances of substandard design at advance stage will eventually increase. This will actuate the affirmation of the point that waste will always produce as a result of construction. The thought of waste to be as inevitable leads to non-serious behavior of top management in selecting designers that leads to increase in engagement of inexperienced designer.

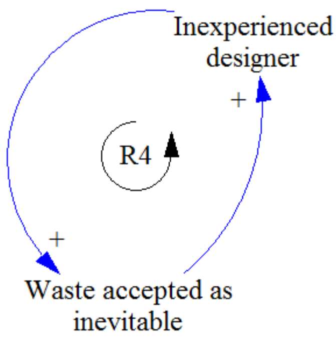
Figure 4.7 Reinforcing Loop 3



4.5.5.4 Reinforcing Loop R4

Figure 4.8 shows if the top authority admits to accept the consensus that waste will be produced during construction, it allows the engagement of more inexperienced designers during design. Conversely, this will reassure the prevailing concept about waste to be generated during construction process.

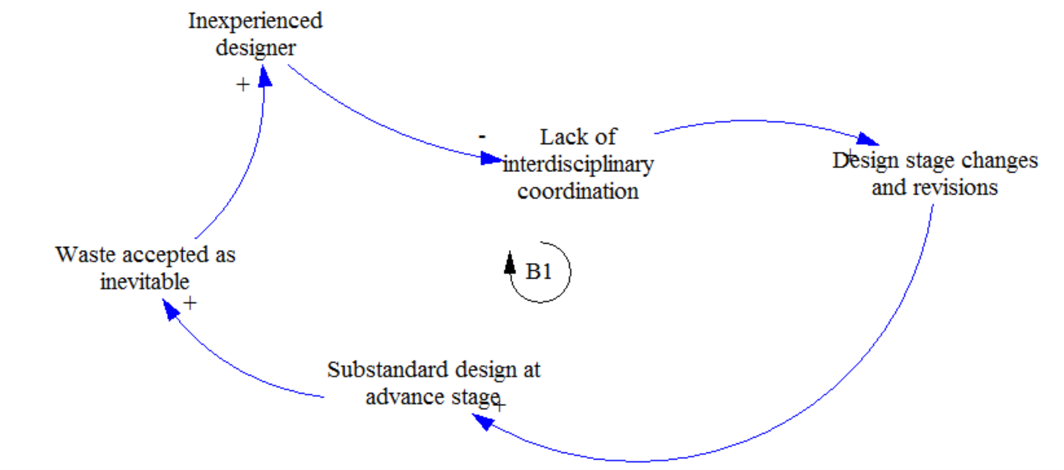
Figure 4.8 Reinforcing Loop 4



4.5.5.5 Balancing Loop B1

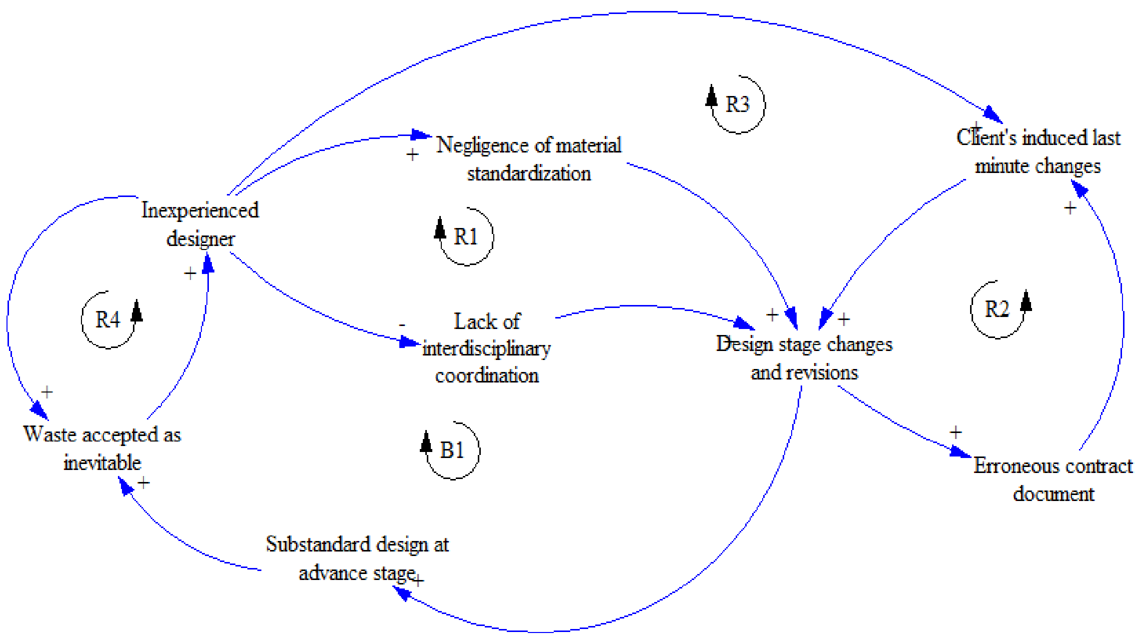
Figure 4.9 indicates the increase in appointment of inexperienced designer if the top management system agrees on the waste production point as inevitable. This will reduce the interdisciplinary coordination. Lack of interdisciplinary coordination will lead to design stage changes and revisions. More the changes are in the design stages, more substandard design will be produced at advance stage. This will further trigger the concept of waste to be produced as a result of construction.

Figure 4.9 Balancing Loop 1



All the factors, on the basis of relations, thus connect each other in an endless chain creating a dynamic and logical consolidated diagram known as Causal Loop Diagram.

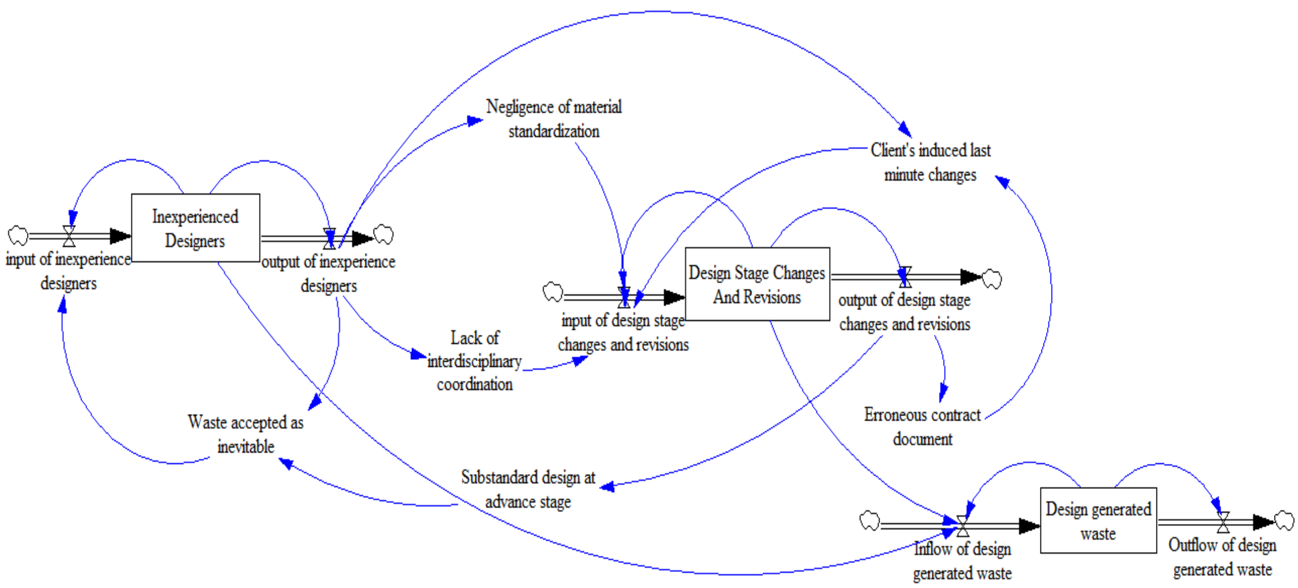
Figure 4.10 Causal Loop Diagram



4.6 Model Development

To visualize and study complex behavior of the causes on the construction waste generation, a stock and flow diagram was developed using the software "Vensim" and readily converted to system dynamics model. The qualitative methodology has been chosen for the development of system dynamics model because this methodology is said to be easy to understand and enables policy making for decision makers(Dhawan, *et al.* 2011). The two variables "Inexperienced designer" and "Design stage changes and revisions" that can be regulated by flows are stocks in this dynamic model (Beck, *et al.* 2012). Another stock "Design Generated Waste" was added to examine the combined effect of the two stocks over "Design Generated Waste". This model thus leads to the accomplishment of thesis goal towards sorting out the causes for the design that generate waste.

Figure 4.11 System Dynamics Model



The feedback collected in detailed questionnaire survey helped in development of equations in the model. The equations were established using the normalized field score to connect the system mathematically.

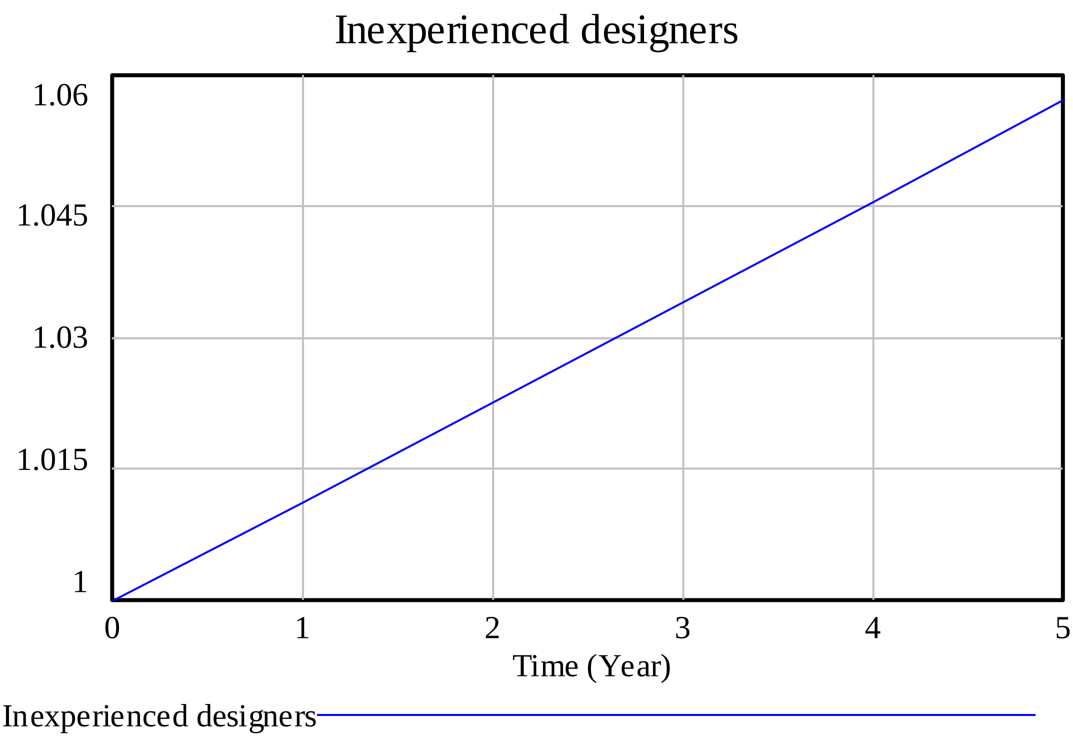
1. Inflow of inexperience designers $= (0.104 * A1) + (1 * A3)$ *Equation 2*
2. Outflow of inexperience designers = $(1* A_3)$ *Equation 3*
3. Inflow of design stage changes and revisions = $(0.102*A_2) + (0.107*A_5) + (0.102*A_4) + (1*A_6)$ *Equation 4*
4. Outflow of design stage changes and revisions = (A_6*1) *Equation 5*
5. Inflow of design generated waste = $A_6 + A_3$ + (1*Design generated waste) *Equation 6*
6. Outflow of design generated waste = (1*Design generated waste) *Equation 7*

4.6.1 Simulations results and discussions

Simulations were run to understand the dynamic behavior of the complex system over the period of five years. Rather than focusing on all the variables, simulation results will highlight the intrinsic nature of the network putting emphasis on the stocks that represents the whole system dynamics through its effects(Barranquero, *et al.* 2015).

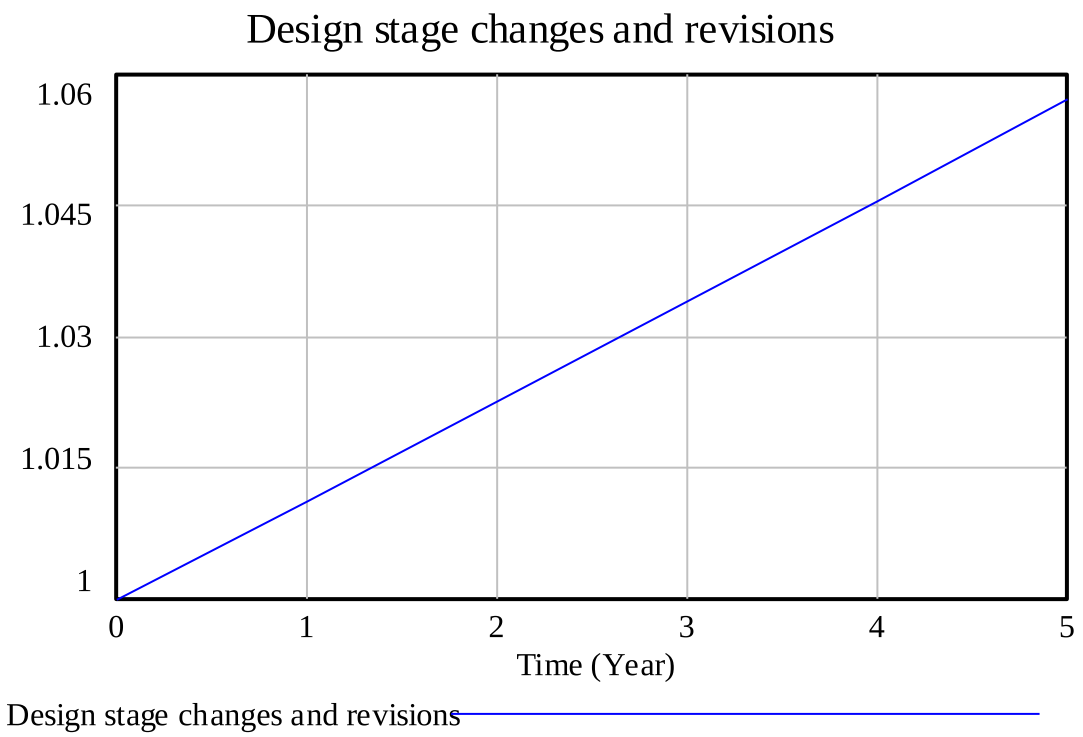
The behavior of graph in figure below shows the increase in hiring of inexperienced designers over the number of years. This is due to the integrated effect of variables influencing the behavior of stock. The simulation result shows that with the passage of time, the trend of inexperienced designers seems to be increasing. Due to the increase in stock trend, there will be rational effect on the subsequent variables in the loop.

Figure 4.12 Simulation Graph (Inexperienced Designers)



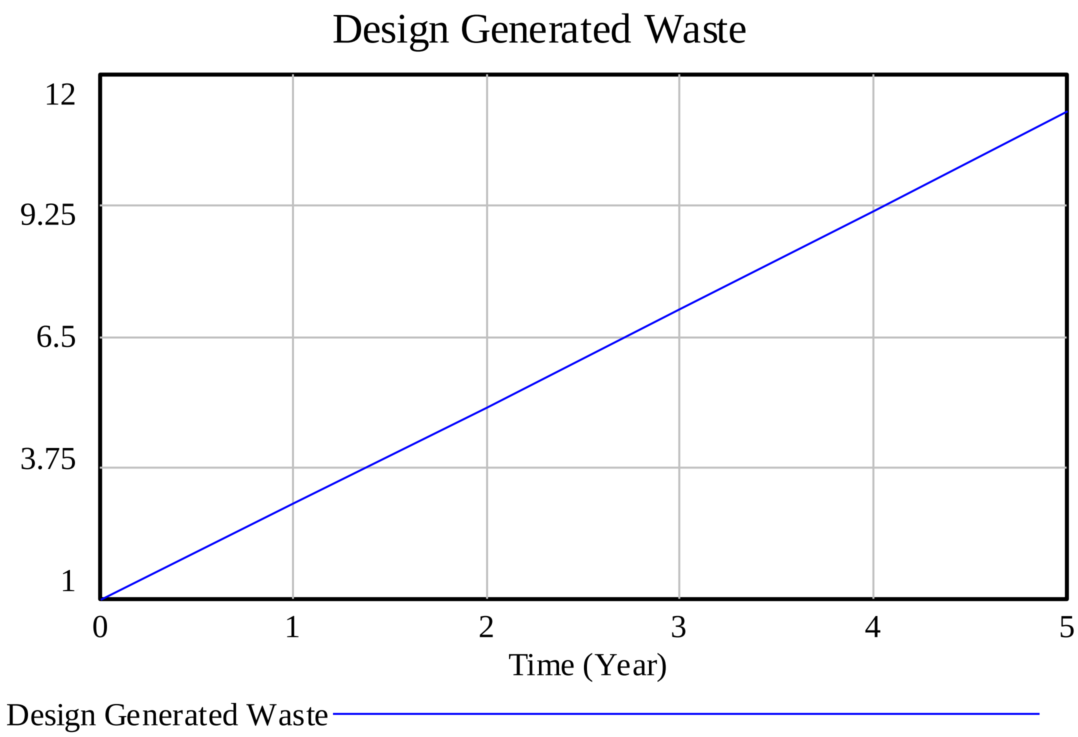
The figure below is the graphical representation of simulation results for Design stage changes and revisions. Likewise inexperienced designer, the trend of this stock is noted to be increasing over the years. The escalation in the trend is likely to affect other succeeding variables that will inevitably lead to the generation of design waste.

Figure 4.13 Simulation Graph (Design Stage Changes and Revisions)



The graphical representation of "Design generated waste" over the period of five years as a result of simulations shows the linear increase over time. The Design generated waste is minimum at the start but increases linearly as it reaches to the end of five years tenure. Simulation thus shows the combinatorial effect of the two stocks-Inexperienced designers and Design stage changes and revisions on "Design Generated waste" over the course of time. Hence, it transpires an alarming situation of waste generation after each and every year. The government or the authoritative committee must come forward holistically with the proactive solutions to tackle this problem.

Figure 4.14 Simulation Graph (Design Generated Waste)



4.6.2 Model Validation

Model validation is considered to be a very important step in system dynamics methodology. There exists a strong relationship between the validity of a model and its "purpose"(Barlas, 1996). Purpose of the model is not fulfilled unless the model is verified. As mentioned earlier, the main purpose of the model is to study the behavior of integrated variables over the "Design Generated Waste". Therefore, the step to model validity is established to prove it vital for its core purpose. Some of the tests used to validate the model are- Boundary adequacy test, Structure verification test and Parameter verification test(Qudrat-ullah and Seong, 2010).

4.6.2.1 Boundary Adequacy Test

Boundary adequacy test was conducted to check whether the important conceptions in addressing the problem are endogenous to the model, and also if the behaviors of the model change significantly when boundary assumptions are relaxed(Sterman, 2000). The system dynamics model includes all the variables extracted through an extensive literature review and were then verified via expert opinion. Thus, the variables were found endogenous to the model. Plus, the behavior of the model did not change with the varying boundary conditions.

4.6.2.2 Structure Verification Test

The purpose of this test is to verify whether the structure of model is consistent with relevant descriptive knowledge of the system (Sterman, 2000). The interconnected variables in the multiple loops represent the structure of the model. In this particular model, all the variables are identified through a detailed literature review and the field experts then authenticated the existence of interrelations amongst variables. This assisted in development of a logical and meaningful causal loop diagram. Therefore, the model structure closely represents the actual system in the industry.

4.6.2.3 Parameter Verification Test

The system was connected mathematically based on the responses collected from the field that proved to be empirical evidence for the sound model structure(Sterman, 2000).

Chapter 5

5. CONCLUSIONS AND RECOMMENDATION

The construction industry has proved to produce huge amount of construction waste globally that has elicited a drastic effect over the environment as well as the economy. The literature has revealed to cater this pitfall by considering the waste minimization strategies from inception-design stage (Akinade *et al.*, 2018).

This study targets the identification of causative factors of waste generation right from the source-design stage that is creating complexities. The system thinking approach assisted in widening the perspective on complex issues of design generated waste combining long-term effects as well as side effect. In return, this will enable decision makers to propose sustainable solutions to the problems (Beck, *et al.* 2012).

Initially an extensive literature review was conducted to identify factors causing design generated waste. A total of 23 factors were extracted. A pilot study was conducted in which the respondents were allowed to rank the 23 factors on the basis of their contribution towards waste generation on Likert scale (1 to 5).

Secondly the statistical verified data was then put forward for factor analysis that helped to deduce the most important factors. Ranking and shortlisting of factors was done by taking collective scores of respondents and literature giving the weightage of 60 and 40 respectively with the combined significance of 50 percent (Nazia *et al.*, 2019). 8 most important factors were shortlisted through this analysis.

Then, a detailed bidirectional questionnaire survey was circulated to the targeted field respondent in order to find the causal strength and relationship of one factor over the other. A total of 12 most influential relationships, that have influenced value >3.5, materialized through data collection. On the basis of which, a meaningful causal loop diagram was developed. There were 4 reinforcing and 1 balancing loop in Causal loop diagram.

In the end, system thinking approach was opted to see the integrated effect of variables on the behavior of stocks that is the main area of concern. Hence, stock and flow diagram was developed using software VENSIM® followed by the assignment of mathematical equations to each stock and flow. Normalized influenced scores were used to develop the equations. There were two stocks: **Inexperienced designers** and **Design stage changes and revisions** that are regulated by the flows. The stock "**Design Generated Waste**" was added and the rest of the two stocks were merged over it in order to observe the combinatorial effect of causes of design waste. Simulation was run for the model over five years' time period. The graphical representation of the two stocks shows the linear increasing trend over the period of five years. The similar trend is followed by the subsequent stock i.e. Design generated waste. This eventually depicts that waste specifically generated by design will continually increase year by year which will henceforward eventuate a disconcerting situation for the environment and economy globally. The developed model thus achieves the target to address the complexities of design based causes for waste minimization in the construction industry.

According to Nwachukwu 2016, the best waste minimization strategy is to maneuver a proactive approach that starts from the drawing board where waste is identified, evaluated and measured and then appropriate measures are taken to address them. The substantial research has thrown light over the whole background map that is accountable for the repercussion (i.e. waste) in the later stages. It means the design waste causes has been identified, evaluated and measured in this respective study. Future work can be performed by introducing a framework of appropriate measures and policies that can help control the waste in the light of the developed model. Current study was based on design stage, further studies could be done for other stages of construction. Field validation is also further recommended. System dynamics approach is recommended for construction industry practitioners as it helps to deal with the complexity issues.

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