Towards the Adoption of Zero Waste Concept in the Construction Industry: A Review of Existing Strategies

Department of Building Economics
University of Moratuwa, Sri Lanka.
kushiliyanage23@gmail.com, anulk15@yahoo.com, hmallawarachchi@gmail.com

Abstract

The construction industry, being the largest industry, generates massive quantities of Construction and Demolition (C&D) waste. Generation of C&D waste leads to issues related to environmental pollution, adverse health issues, economic issues, social issues, and undesirable landfill creations. Strategies such as the 3R concept (Reduce, Reuse, Recycle), and waste hierarchy are followed in the construction industry for C&D waste management. Although such strategies are applied to manage the C&D waste, C&D waste management is still in a primary stage. In order to eliminate C&D waste, the Zero waste concept emerged as a potential solution. Zero waste means the elimination of waste through redesigning the product lifecycle. Strategies such as eco-design, industrial symbiosis, closed-loop supply chain management, innovative technology, product stewardship, life-cycle assessment, and environmental management system (EMS) are employed to implement the zero waste concept in the construction industry. Although adopting zero waste concept in the construction industry has several benefits, only limited studies could be found on zero waste management in the construction industry. Therefore, this paper aims to review the available strategies to implement zero waste concept in the construction industry by critically reviewing the secondary data on waste management studies performed in the construction industry.

Keywords: Construction Industry, Construction and Demolition Waste, Zero Waste, Strategies

1.0. Introduction

The construction industry is considered a key economic driver in an economy with its considerable contribution to the gross national product along with employment and business opportunities (Sapuay 2016). However, the construction industry is also one of the largest polluters and faces the challenges regarding the reducing of construction waste generation (Banihashemi et al. 2018; Elgizawy et al. 2016). As defined by Kofoworola and Gheewala (2008), Construction and Demolition (C&D) waste mean the waste generated through new construction, demolition, and renovation activities of structures and buildings. C&D waste comprise of concrete, bricks, ceramics, and gypsum-based materials, wood, glass, plastic, electrical wiring, asphalt, tar and tarred products, metals soil and dredged soil, insulation materials, mixed C&D, and hazardous components (Elgizawy et al. 2016, Ghosh and Ghosh 2016; Hsiao et al. 2002). Although many researchers have attempted to manage C&D waste since the 1980s, still, it remains in a primary stage (Hao et al. 2007).

As depicted in literature, the lack of interest of contractors, poor knowledge in the designing stage, use of low-quality products and lack of expertise in material handling, and issues related to the delivery of materials has led to the generation of C&D waste (Kofoworola and Gheewala 2008). Poor C&D waste management has led to environmental impacts, health issues, land depletion, soil and water pollution, and economic impacts (Coelho and Brito 2012; Elgizawy et al. 2016; Lingard et al. 2000; Nitivattananon and Borongan 2007; Wahi et al. 2016; Wang et al. 2010; Yeheyis et al. 2013). In order to manage the C&D waste, various strategies, i.e., 3R (Reduce, Reuse, Recycle), waste hierarchy, client awareness, and zero waste concept are being followed (Ling and Nguyen 2013; Nitivattananon and Borongan, 2007; Zaman 2015). As Zaman (2015) mentioned, the Zero waste is a perfectionistic concept to address the critical waste issue in the society.

By challenging the traditional waste management method, zero waste concept converts waste into useful resources (Curran and Williams 2012; Ksiazek et al. 2016; Pietzsch et al. 2017). Further, Curran and Williams (2012) define Zero Waste as the redesigning of resources to reduce the harmful impacts to the environment through the emissions and to minimize resource wastage through a whole system approach. Thus, the implementation of zero waste concept
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offers benefits such as the optimum use of natural resources, reduction in environmental issues, improvement in the quality of life, and the use of renewable sources (Curran and Williams 2012; Kofoworola and Gheewala 2009; Osmani 2012; Zaman 2014). Strategies, for instance, eco-design, industrial symbiosis, innovative technology, product stewardship, life-cycle assessment, and environmental management system could be followed to implement the zero waste concept (Curran and Williams 2012; Song et al. 2015). Thus, the paper aims to review available strategies to implement zero waste concept in the construction industry.

2.0. Research Method
A literature review helps to identify the knowledge gap (Webster and Watson 2002); hence, a systematic literature review is performed as the initial research process. Here, the required information is gathered by referring to journal articles, books, published and unpublished bibliographies, conference proceedings, industry reports, and documents that are specifically related to the construction industry, C&D waste, zero waste, and zero waste strategies.

3.0. C&D Waste
In a construction project, design and construction stages are significant as they are inter-related, and systematic waste management in one stage makes a direct impact over the next stage (Ding et al. 2018). Different authors have given different definitions for C&D waste and Table 1 shows the different definitions of C&D waste.

<table>
<thead>
<tr>
<th>Source</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Hsiao et al. (2002)</td>
<td>All wastes generated in construction works</td>
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<tr>
<td>Wang et al. (2014)</td>
<td>Waste of valuable natural resources.</td>
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<tr>
<td>Yuan and Shen (2011)</td>
<td>Solid waste generated in the construction sector is defined as the C&amp;D waste.</td>
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<tr>
<td>Shen et al. (2004)</td>
<td>Construction wastes are mixtures of inert and organic materials arising from all construction related activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork and building renovation along all stages in implementing a construction project.</td>
</tr>
<tr>
<td>Christensen and Andersen (2011)</td>
<td>Waste generated during the building, repair, remodeling or removal of constructions</td>
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<tr>
<td>Ghosh and Ghosh (2016)</td>
<td>Waste arising from the construction, repair, maintenance and demolition of buildings, structures and roadways</td>
</tr>
<tr>
<td>Kofoworola and Gheewala (2008)</td>
<td>The waste produced during new construction, renovation, and demolition of buildings and structures</td>
</tr>
<tr>
<td>Fatta et al. (2003)</td>
<td>The waste generated from various activities such as clearing of sites, and the building of new structures or infrastructure</td>
</tr>
<tr>
<td>Hsiao et al. (2002)</td>
<td>Construction waste is defined as legal and illegal construction activities encompassing new construction, addition, renovation, rebuilding, and repair as well as the associated demolition. Demolition waste is defined as legal reported demolition, demolition of structures under government requisition, demolition of structures destroyed by natural force, demolition of illegal structures, and illegal demolition.</td>
</tr>
<tr>
<td>Statistics Canada (2003)</td>
<td>Waste materials from the construction and demolition of roads, bridges and buildings</td>
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Osmani (2012) stated that attention is paid to waste minimization in the construction industry to enjoy the cost-saving benefits and overcome the environmental issues. Massive quantities of waste generate, starting from the raw material extraction up to the demolition and waste disposal, and the heavy use of raw materials for the construction industry results in unsustainability of the industry (Elgizawy et al. 2016). A considerable amount of C&D waste generates due to the rapid development in the construction industry (Osmani et al. 2008), and the 3R (Reduce, Reuse, Recycle) concept is being practiced to manage C&D waste management (Nitivattananon and Borongan 2007; Wang 2015). Ling and Nguyen (2013) identified training and supervision, management of subcontractors and workforce, material handling and control, procurement, communication, and documentation promotes C&D waste management.
3.1. C&D Waste Generation in Construction Industry

Based on how C&D waste is defined in each country, the amount of C&D waste generated vary among states (Kofoworola and Gheewala 2008). According to Elgizawy et al. (2016), most countries face real threats due to the large quantities of C&D waste generation, and developing countries pay high attention to C&D waste management (Yuan and Shen 2011). In Asian countries, C&D waste management is difficult as they are heavy, bulky, and a majority is unsuitable for disposal through composting or incineration (Nitivattananon and Borongan, 2007; Sapuay 2016).

3.1.1. C&D Waste Management in Developing Countries

The regional and national policies and laws and regulations available in Asia are inadequate for C&D waste management (Nitivattananon and Borongan 2007). In Indonesia, it is identified the involvement of stakeholders such as clients, suppliers, construction managers, foremen, and laborers are necessary for waste minimization (Nitivattananon and Borongan 2007). Similarly, Malaysia produces a large amount of C&D wastes due to the development of major infrastructure projects, commercial buildings, and housing programs (Begum et al. 2010), and the authors have stated a compelling necessity to reduce C&D waste in the Malaysian construction industry. Moreover, Nitivattananon and Borongan (2007) report countries such as China, India, Sri Lanka, Thailand, and Vietnam lack specific C&D waste regulations to manage waste. However, as per Ghosh and Ghosh (2016), cities such as Chennai, Mumbai, Kolkata, and Bangalore in India have initiated C&D waste management through the introduction of C&D waste handling rules.

Although information related to C&D waste in the entire country is unavailable in Brazil, specific cities such as Sao Paulo, Rio de Janeiro, and Salvador generates an average of 0.49 kg per inhabitant/day (Nunes et al. 2006). The authors have stated that out of the generated C&D waste in Brazil, a larger portion is not recycled due to the lack of recycling centers. According to Kofoworola and Gheewala (2008), C&D waste is considered a part of Municipal Solid Waste in Thailand, and the rapid urbanization generates a huge amount of C&D waste. Subsequently, as per Ghosh and Ghosh (2016), nearly 600 million tons of C&D waste get made annually in China, and it is considered as 30 to 40 percent of the total urban waste. Authors have further stated that 500 to 600 tons of waste get generated through the construction of a 10,000 m² building, whereas the destruction of a 10,000 m² old building produces 7,000 to 12,000 tons of demolition waste.

3.1.2. C&D Waste Management in Developed Countries

Since 1994, Austria and Denmark have reported average recycling of 76% and 90% respectively (Agamuthu 2008). Christensen and Andersen (2011) have stated that in Denmark, building waste comprises of concrete, mortar, and tiles, which are nearly 62-93%, and during the renovation, almost 26% of waste generated from wood and other combustibles. In Germany, C&D waste management practices are being followed and starting in 2002, with proper legislative instruments and treatment methods, disposal of C&D waste into landfills was banned (Agamuthu 2008). Ghosh and Ghosh (2016) have further stated that in 2002 and 2003, C&D waste generated in Germany is 63.2% and 61.0% respectively. Italy, in 2001, disposed 67.1% of the generated waste to landfills, incinerated 8.7%, and recycled the remaining portion (Marchettini et al. 2007).

In Taiwan, C&D waste generation accounts for 1.2 to 1.9 million tons per year, and reuse 64% to 80% of waste (Lai et al. 2016). The C&D waste accounts for 33-65% in landfills of the USA, Canada, UK, and Hong Kong and they follow 3R initiatives within their countries (Agamuthu 2008). In the UK, more than 50% of the C&D waste is landfilled (Ghosh and Ghosh 2016). Here, 51.2% (27.4 million tons) of C&D waste is directly disposed to landfills, and 39.6% (21.2 million tons) exempted from licensed disposal and applied to land modeling of the construction projects (Lawson et al. 2001). Further, the authors have mentioned that 9.2% (5 million tons) of C&D waste produces graded products.

In the USA, C&D waste ranges from 20 to 30 kg/m², which is approximately 500 kg/person/year on a per capita basis (Peng et al. 1997). The authors have further stated that nearly 31.5 million construction waste is produced, and the demolition waste is almost equal to the double amount of the generated construction waste in the USA. According to Ghosh and Ghosh (2016), the USA produces 170 million tons of waste per year, from which, 48% is recovered. In the
USA, recycling the C&D waste is a challenging issue since the secondary market for recycled materials is still in an adolescent stage (Peng et al. 1997).

According to Yeheyis et al. (2013), C&D waste accounts for one-third of the solid waste stream in Canada, where nearly 9 million tons of C&D waste get generated, and 27% of the total municipal solid waste disposed to landfills are from the C&D waste. The authors have further stated that Canadian C&D waste recycling rate is low, and an integrated and comprehensive C&D waste management plan needs to be implemented within the country. The recycled or reused C&D waste in Canada is comparatively lower than other developed countries (Ghosh and Ghosh, 2016), and according to the findings, concrete is the largest C&D waste generated in the construction industry in Canada, which is nearly 52%.

The construction industry has developed in Greece over the past decades, and with the C&D waste generation, materials such as wires, glass, and frames of doors and windows are being reused while some quantities of waste ended up in landfills (Fatta et al. 2003). Out of 13,458 tons of Municipal Solid Waste (MSW) in Hong Kong, C&D waste accounts for a quarter of the MSW in 2011 (Ghosh and Ghosh 2016), and hence construction waste management policies are introduced to handle the C&D waste issue. Moreover, the authors highlighted that nearly 7890 tons of C&D waste was landfilled in 1999, and after introducing two off-site waste sorting facilities from the off-site Construction Waste Sorting (CWS) program, nearly 5.11 tons of C&D waste is handled in the two off-site CWS facilities during 2006 to 2012. Also, Nitivattananon and Borongan (2007) report that infrastructure projects in Hong Kong have caused a significant increase in C&D waste generation over the past decades. Australia generates nearly 5 million tons of C&D waste within a year (Nitivattananon and Borongan 2007) and C&D waste management practices are followed in Victoria, Queensland, South Australia, Western Australia, Tasmania, and Australian Capital Territory (Ghosh and Ghosh 2016). In the European Union (EU), C&D waste accounts for 855 million tons per year which are 33.3% of the total EU waste; and out of the generated C&D waste, nearly 75% of the waste gets landfilled (Ghosh and Ghosh 2016).

In order to manage the generated C&D waste in the construction industry, strategies such as 3R (Reduce, Reuse, Recycle), waste reduction at source, Waste Minimization Design (WMD), client awareness, use of Building Information Modelling (BIM) tools along with Revit, Archi CAD, training and supervision, material handling, and communication are used (Akinade et al. 2016; Baldwin et al. 2009; Bossink and Brouwers 1996; Ling and Nguyen 2013; Pitt et al. 2009; Nitivattananon and Borongan 2007). The strategy of Zero waste concept is identified as the correct solution to eliminate C&D waste in the construction industry (Song et al. 2015; Zaman 2015).

### 3.2. The Concept of Zero Waste

“Zero Waste” is an idealistic concept to address the critical waste issue in society. It is an ambitious goal to handle waste and is considered an innovative waste management approach (Zaman 2014, 2015). With the application of the zero waste concept, products are redesigned in a manner in which they can be reused, and the zero waste concept challenges the traditional waste management views (Curran and Williams 2012; Song et al. 2015). Furthermore, zero waste concept ensures waste is managed through reuse, recovery, or recycling in an eco-friendly manner (Zaman 2014).

Among the many articles on C&D waste management, none published from 1995 to 2014 focuses on the C&D waste documentation for zero waste (Zaman 2015). As per Osmani (2012), achievement of the zero waste target in the construction is highly challenging. However, with the maximum use of raw materials and renewable resource usage through the implementation of zero waste concept, the construction industry can achieve sustainability (Curran and Williams 2012). Thus, zero waste could be identified as the key strategy to eliminate C&D waste from the construction industry.
In a linear economy, recyclable materials are not directed into the production process, and it causes long-run issues from the perspective of sustainability (Curran and Williams 2012). Hence, authors have declared, zero waste can be implemented with the rejection of one-way linear method and using a circular closed-loop system. Elgizawy et al. (2016) have further elaborated that the cradle-to-cradle approach should be used for the efficient use of materials. Figure 1 presents the linear and circular resource flow.

![Figure 1: Linear and circular resource flow](source)

Curran and Williams (2012) have defined zero waste as a whole-system approach that aims to ‘eliminate’ rather than ‘manage’ waste. Further, all discarded materials that are designed to become resources for others to use are also defined as zero waste (ZWIA 2015). Zaman and Lehmann (2011) defined zero waste as the recovery of all resources from waste materials, and the zero waste challenges the traditional waste management system within which, at the end of the product life, is considered as waste (Zaman 2014). The author states waste is transformed into a resource through zero waste and redirected to the production process holistic zero waste management systems. Further, the author explained zero waste management get created as a result of design integration and waste management philosophies. The implementation of zero waste promotes high recycling levels, valuation of resources that are generated from waste, prevention of waste, and changes in behaviors (Pietzsch et al. 2017). Table 2 shows the development of the zero waste concept over the past years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Country</th>
<th>Milestones/Events</th>
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<tbody>
<tr>
<td>1970</td>
<td>USA</td>
<td>The term “Zero Waste” was coined by Paul Palmer</td>
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<tr>
<td>1986</td>
<td>USA</td>
<td>The National Coalition against Mass Burn Incineration was formed</td>
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<tr>
<td>1988</td>
<td>USA</td>
<td>Seattle introduced the Pay-As-You-Throw (PAYT) system</td>
</tr>
<tr>
<td>1989</td>
<td>USA</td>
<td>The California Integrated Waste Management Act was passed to achieve 25% waste diversion from landfills by 1995 and 50% by 2000</td>
</tr>
<tr>
<td>1990</td>
<td>Sweden</td>
<td>Thomas Lindhqvist introduced “Extended Producer Responsibility”</td>
</tr>
<tr>
<td>1995</td>
<td>Australia</td>
<td>Canberra passed the “No Waste by 2010” bill</td>
</tr>
</tbody>
</table>
| 1997 | New Zealand | • The Zero Waste New Zealand Trust was established  
|      | USA     | • The California Resource Recovery Association (CRRA) organized conference on zero waste |
| 1998 | USA     | Zero waste was included as guiding principles in North Carolina, Seattle, Washington, and DC |

Table 2: Key milestones of zero waste concept development
Source : Zaman (2015)
To remove the environmental threats caused as a result of human consumption and unsustainable behaviors, product design, and waste management principles are considered within the zero waste philosophy (Zaman 2014). The authors emphasized, to extend the lifecycle of the product in a zero waste product design, products are designed in a way they can either be reused or repaired. The authors also stated that pollution of the natural environment is avoided through the zero waste management process, as waste is recycled and recovered. Moreover, zero waste encourages the diversion of waste from incineration and landfills (Curran and Williams 2012). Figure 2 illustrates the historical development of waste management up to zero waste system.

![Figure 2: Schematic waves of innovation management system](image)

Source : Zaman and Lehmann (2011)

In the schematic waves of the innovative waste management system, open dumping is the first wave still practiced in low-income countries; uncontrolled landfills are considered as the second wave while composting is the third wave (Zaman and Lehmann 2011). The authors stated the fourth wave focuses on recycling and controlled landfill, whereas the fifth wave focuses on waste-to-energy technologies such as incineration, pyrolysis-gasification, and plasma arc. Finally, the sixth wave of innovation focuses on sustainable waste management system through zero waste, and include the recovery of resources from waste, sustainable resource consumption, and cradle-to-cradle closed-loop design systems.

### 3.3. Zero Waste Strategies

Effective strategies are a need for implementing the zero waste concept (Zaman 2014). Zero waste system comprises four levels, i.e., design, manufacturing, application, and recycling and disposal (Song et al. 2015). According to Curran...
and Williams (2012), different strategies can be followed to implement zero waste in the construction industry. Out of the identified strategies, the authors have selected Eco-design, Industrial Symbiosis, Closed-loop supply chain management, Innovative technology, Product stewardship, Life cycle assessment, and Environmental Management System as the key strategies to implement the zero waste concept.

- **Industrial Symbiosis (IS)**

Industrial Symbiosis is identified as a part of industrial ecology concept (Curran and Williams 2012). Yazan et al. (2016) have stated that more attention is paid towards the waste reduction in the production economies. The authors further reported IS has forced to provide waste as a primary resource to other companies, which will ultimately reduce the adverse environmental impacts near industrial areas.

- **Life Cycle Assessment (LCA)**

Measurement of impacts throughout the entire life cycle, starting from the raw material extraction up to end disposal of the product helps to identify the environmental effects of the product, and also to have sustainable production and consumption patterns (Curran and Williams 2012).

- **Eco-Design**

Eco-design could be defined as, starting from the origin of the product, thinking about the entire life cycle and environmental impact reduction, throughout the product life (Vallet et al. 2015). As per Bhamra (2004), Eco-design is defined as the integration and balancing of the existing design practice considering cost, quality, and functionality. In order to manage ecological issues related to the types of C&D waste, the client and design team awareness is needed (Ball 2002). Also, sustainable construction techniques and materials are required for the eco-friendly construction industry (Torgal and Jalali 2012), and in the ecosystem, waste is designed out of the system to achieve real waste reduction (Curran and Williams 2012).

- **Closed-Loop Supply Chain Management**

According to Krikke et al. (2004), closed-loop supply chains comprise of reverse and forward supply chain. Authors elaborate that loops can be closed through reusing the whole product, components, or materials. Moreover, Morana and Seuring (2011) stated that closed-loop supply chain deals throughout the product lifecycle. The supply chain of the construction industry could be explained under four roles as focus on the impacts of the supply chain on on-site activities, focus on the supply chain and to reduce costs in logistics, lead-time, and inventory, focus on transferring activities from the site to earlier stages of the supply chain, and finally, focus on the integrated management and improvement of the supply chain and the site production (Vrijhoef and Koskela 2000).

- **Product Stewardship / Extended Producer Responsibility (EPR)**

Management of impacts of a product throughout the life cycle of the product until the disposal is identified as the product stewardship (Zaman and Lehmann 2011). Further, authors have elaborated, once the consumer stops using the product, the producer has to take back the product in product stewardship. According to Zaman and Lehmann (2011), EPR is also identified as a product stewardship principle and take-back principle. Authors have stated that in the innovative packaging and product design, EPR is a vital tool to reduce waste generation in the production process, and EPR takes responsibility for each action and work. EPR is a strategy used in the recycling process (Chavan 2014). Accordingly, through the EPR, the manufacturer is responsible for the entire lifecycle of the product, and the manufacturer is liable for the take-back, recycle, and final disposal. EPR model comprises of four responsibilities as informative, physical, financial, and liability (Manomaivibool 2008), and EPR is an important tool to reduce and avoid major waste volumes during the production process of the product (Lindhqvist 2000).

- **Environmental Management System (EMS)**

EMS helps to achieve environmental obligations and performance goals by identifying problems and solving the problem with the systematic management of environmental activities of the organization, and the plans, schedules,
implementation, and monitoring of events take place to improve the environmental performance through EMS (Curran and Williams 2012).

4.0. Conclusion

C&D waste is a persuasive issue that needs to be addressed since the construction industry is considered a leading contributor to solid waste generation. C&D waste comprises of rubble, sand, cement, timber, plastic, brick, concrete, tile, aluminum, steel, paper, and cardboard. The generated C&D waste triggers health, environmental, and social and economic issues, and hence, strategies such as the 3R concept, WMD, waste reduction at source, waste hierarchy, and zero waste are being followed.

Zero waste concept is considered one of the idealistic methods to manage the generated C&D waste as a resource. In order to adopt zero waste concept, strategies such as eco-design, innovative technology, product stewardship, life cycle assessment, and industrial symbiosis are being followed. Development of a framework for adopting zero waste in the construction industry will be the final outcome of this research project.

5.0. Acknowledgement

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7.0. Biographies

K.L.A.K.T. Liyanage is a M.Sc. Research Student attached to department of Building Economics, University of Moratuwa. She is a B.Sc. (Hons) in Facilities Management graduate of the same department. Her research interests include Waste Management, Risk Management, Supply Chain Management, Sustainable Development, Occupational Health and Safety and Lean Management.

Ch.QS. Dr. K.G.A.S. Waidyasekara is a Senior Lecturer, Department of Building Economics, University of Moratuwa. She obtained her PhD in 2016, MSc in Civil Eng. in 2006 and BSc Hons (QS) in 2002 from University of Moratuwa. Her research interests are Sustainable construction, green buildings, renewable energy, and quantity surveying practice.

H. Mallawaarachchi is a Lecturer attached to the Department of Building Economics, University of Moratuwa. She obtained her Master of Philosophy (MPhil) in Sustainable Built Environment from the Department of Building Economics, University of Moratuwa in year 2016. Further, she has obtained her B.Sc. (Hons) in Facilities Management degree from the same department in 2011. Her research interests include Sustainable Development, Carbon Footprint, Green Buildings, Productivity and Waste Management.