A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach

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Abstract. This study shows that there is no systematic review of research progress in literature throughout the field of sustainable construction waste management by 3R (reduction, reuse, and recycling) A lifecycle approach, The need for processes, strategies, rating systems and policies for robust and efficient waste management is widely recognized. The paper aims to evaluate. A review of sustainable construction waste management in Malaysia to maximize the 3R and reduce the disposal of construction waste by implementing a sustainable strategy throughout project lifecycle. Managing landfill shortages and long-term negative environmental economic and social effects of sustainable waste disposal are now becoming crucial for the sustainability of public health and natural ecosystems. To make adjustments, causes and factors responsible for sustainable construction waste management and progress in moving towards sustainability, it is therefore important to define the existing waste management system and causative factors adopted by industries. It allows a major shift in waste management of Malaysia by improvising current technology for waste management in a much more sustainable way. Furthermore, this ongoing research would develop sustainable construction waste procedures to sustain environmental, economic and social development for a Malaysian construction project.

1. Introduction

The construction industry is a vital part of the economic backbone in many countries, the industry currently contributes 4% to the Malaysian Gross Development Product (GDP) and is expected to continue to contribute 5.5% of GDP by 2020[1]. Also, building products and processes have a significant impact on safety, health, and environmental aspects [1]. Since all human beings are directly affected by their processes and/or goods in modern societies, there is no uncertainty about the significance of the well-functioning construction industry [2].

As recorded by CIDB, over the past 30 years, the construction industry has consistently contributed an average of 3.8 percent. In addition, the Malaysian construction industry has grown rapidly and substantially improving. Subsequently, improper development planning may result in unsustainable urban development processes such as inefficient land use, pollution, and waste generation and Government involvement is necessary in order to tackle the roots of strong and inefficient [3]. The rising urban population is now becoming a driver of economic growth for developing nations, which
has a significant effect, particularly in the construction sector. This is because the construction industry plays a key role in meeting the basic needs of housing and infrastructure. The construction industry is critical in taking government policies to encourage sustainable development. Therefore, the implementation of a systemic approach to waste management is mandatory in order to achieve sustainable development although reducing waste [4]. The 3R strategy applies to reduction, reuse, and recycling, which is a three-fold grouping of waste management strategies and will be thoroughly used before being sent to disposal [5]. Waste reduction by 3R is one of the measures towards efficient waste management in the construction sector In Malaysia's construction industry, waste management by 3R is still in its infancy [6]. The principle of waste management was established not only in the basis of the 3R concepts of 'reduction, reuse, and recycling,' but should include the elements of re-imagination and re-design to optimize resource efficiency by reconsidering [7].

Coppola, et al. [8] mentions that Construction waste is defined as waste throughout construction, renovation and demolition, including design, acquisition, excavation or creation of land, construction of civil and buildings, clearing of sites, demolition, road work and renovation of buildings. As demonstrated by the double-digit growth, the construction industry in Malaysia has been quite robust over the past few years, and such growth is expected to continue in the future. The demands for large infrastructure projects, along with the construction of commercial buildings and housing development schemes, should produce a significant amount of waste building [9]. Various construction waste research works are carried out and the results show many negative impacts on a country's environment, social and economy [7,10,11]. Such results lead to a decrease in the efficiency of construction. Sustainable construction waste is suitable to avoid any possible negative impacts. Therefore, this paper addresses issues on the Review of Sustainable Construction Waste Management in Malaysia to maximize the 3R and reduce waste disposal by implementing a sustainable and thorough strategy across the whole lifecycle of the construction project. It also provides different criteria.

1.1. Construction waste-related issues

Construction waste is an influential global problem and is damaging to the performance overall of a project as well as to the community and nature can also be generated in various ways. The waste results in material time and cost expenses. The serious physical harm caused by construction activity is in the form of material waste such as concrete leftover collapsed debris, metal scrap, among others[1]. Studies indicate that waste material has a significant impact on the cost of the project and a positive impact on the environment. Illegal dumping at site is one of the ramifications of huge amounts of waste material [2]. Several countries are caught up in this problem of illegal dumping t site and it is completely necessary to understand the situation as it is tackled. Construction industries are highly concerned about the time and costs of the design.

Non-physical waste usually happens throughout the construction process. Like material waste, the unanimous of non-physical waste [3, 4], Currently, as in[5], time and cost overruns in construction projects have become a problem in Malaysia, due to the abandonment of many projects. These problems are caused by the poor financial management of developers, inaccurate design specifications, construction delays, lack of oversight and lack of oversight of existing rules.

1.2. Literature review

The basic understanding of the research topic was gathered from the literature review [9] stated that the literature review is the type of secondary data that is useful not only to find information to solve the research problems but also to have a better understanding and explanation of the research problems. It is an ongoing process which needs to be carried out throughout the research phases, while at the same time, researchers are always trying to seek for the latest publications. A literature review is important as it helps researchers in the following manner [9]. This paper aims to evaluate A review of sustainable construction waste management in Malaysia to maximize the 3R which is (reduce, reuse and recycle) minimizes the disposal of construction waste by realizing, thorough,
acknowledging sustainable complete strategy during the lifecycle of construction ventures which is from inception to completion.

1.2.1. Waste Management. According to [6] The use of waste products in construction is not only a rational response to improving the environmental management of manufacturing, but it is also a requirement and as such has been adopted by most construction companies in countries such as the Netherlands and Japan, where raw materials are practically lacking. The recycling of waste products can be used economically, not morally.

1.2.2. Causative Factors for Generation of Construction Waste. The interpretation causes at root the production of waste. The paper, therefore, discusses the causes and effects of various listed factors for construction waste management. Design, workers management, procurement site condition handling, and external factor set are the following categorized group. The list of the selected construction waste factors shown in the table. 1. The recognized factors have been exposed that total waste generation in a construction project is caused by a series of inter-related factors ranging from the design phase, over materials procurement, to the actual construction phase. Although, the waste generated on-site during construction activities for some identified factors. There is need for understanding the sustainable construction waste through the application of 3R in order to generate a sustainable solution [13, 14].

2. Sustainable construction waste management
Construction waste is a global issue that requires serious attention. One of the effective ways to control construction waste is to adopt sustainable construction principles as sustainable construction is not only focused on environmental issues but also on economic and social aspects.

It is therefore important to adopt sustainable waste management to address the overall step-by-step strategy as shown. Sustainability in construction waste can be seen as an achieving desirable and most suitable processes depending on the conditions and type of waste generation. As shown in Fig 1., this process can be translated into the hierarchy of waste management.

![Figure 1. Sustainable waste management hierarchy.](image)

2.1. Prevention
It also applies to reducing avoidance, which is the best way to manage waste[18]. This is the highest level of sustainability requires. Nonetheless, there are some issues that practitioners have to overcome primarily during the pre-construction phase[19, 20]. In order to prevent construction, designers need to take technical information about both the construction process into consideration during the design stage.

The prevention of waste, however, requires careful coordination between all those involved in the construction process. It is therefore important to have a very good relationship and contact with and within the building community, i.e. contractors, consultants and customers, in order to avoid any miscommunication or untoward incidents. Lack of communication and discussion can lead to incomprehension and the gene [21].
Table 1. Causative Factors for Generation of Construction Waste.

| Group                        | Causes of Construction Waste                                                                 | References                        |
|------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------|
| Design                       | • Last minute client requirements                                                            | Migilinskas, et al. [7], [8, 9]   |
|                              | • Frequent design changes                                                                   |                                   |
|                              | • Design errors                                                                             |                                   |
|                              | • Frequent design changes                                                                   |                                   |
|                              | • Slow drawing distribution                                                                 |                                   |
|                              | • Interaction between various specialists                                                   |                                   |
|                              | • Erroring contract documentation                                                           |                                   |
|                              | • Lack of design information                                                               |                                   |
|                              | • Inexperience designer                                                                    |                                   |
|                              | • Design errors                                                                             |                                   |
|                              | • Incomplete contract                                                                      |                                   |
|                              | • Complicated design                                                                       |                                   |
|                              | • Poor design quality                                                                      |                                   |
|                              | • Poor coordination of parties during design stage                                          |                                   |
| Procurement                  | • Congestion of the site                                                                    | [9, 10]                           |
|                              | • Interference of other crews at site                                                       |                                   |
| Management Factors           | • Late information drift amongst parties                                                   | Migilinskas, et al. [7]           |
|                              | • Poor of quality information                                                              |                                   |
|                              | • Lack of coordination amongst parties                                                     |                                   |
|                              | • Inappropriate methods of construction                                                     |                                   |
|                              | • Rework                                                                                    |                                   |
|                              | • Lack of environmental information                                                        |                                   |
|                              | • Lack of influence of contractors                                                         |                                   |
|                              | • Lack of knowledge about construction                                                     |                                   |
|                              | • Communication problems                                                                   |                                   |
|                              | • Resources problems                                                                       |                                   |
|                              | • Non-availability of equipment                                                            |                                   |
|                              | • Outdated equipment                                                                       |                                   |
|                              | • Lack of waste management                                                                 |                                   |
|                              | • Poor supervision                                                                         |                                   |
|                              | • Poor site management                                                                     |                                   |
|                              | • Poor controlling                                                                        |                                   |
|                              | • Poor planning                                                                            |                                   |
| Construction Operation/      | • Poor workmanship                                                                         | [9, 11, 12]                       |
| Project Management           | • Improper project planning                                                                 |                                   |
|                              | • Poor supervision                                                                         |                                   |
|                              | • Poor site conditions                                                                     |                                   |
|                              | • Reworks Due to Errors                                                                    |                                   |
|                              | • Leftover from cutting and shaping                                                        |                                   |
|                              | • Inadequate knowledge                                                                    |                                   |
|                              | • Materials off-cuts                                                                       |                                   |
| Site Condition               | • Unforeseen ground conditions                                                             | Wijesiri, 2011                    |
|                              | • Difficulties accessing construction site                                                  |                                   |
|                              | • Leftover materials on site                                                               |                                   |
|                              | • Poor site condition                                                                      |                                   |
|                              | • Waste resulting from packaging                                                           |                                   |
|                              | • Lighting problem                                                                        |                                   |
| Handling                     | • Poor Materials Storage                                                                   | [13, 14]                          |
|                              | • Poor Materials Handling                                                                  |                                   |
### Table 1. (Continued)

| External Factors | • Effect of weather | • Antiacceleration | • Accidents | • Unpredictable local conditions | • Effect of weather | • Antiacceleration | • Lack of legislative enforcement | • High level of Vandalism | • Damages caused by third parties |
|------------------|---------------------|-------------------|------------|---------------------------------|-------------------|-------------------|---------------------------------|------------------------|----------------------------------|
|                  |                     |                   |            |                                 |                   |                   |                                 |                        | [15, 16]                          |
| Workers          | • Workers' mistakes during construction | • Incompetent workers | • Poor workmanship | • Inappropriate use of materials | • Workers' mistakes during construction | • Worker's no enthusiasm | • Insufficient training for workers | • Inventory of materials not well documented | • Too much overtime for workers | • Workers' mistakes during construction | • Lack of experience | • Incompetent workers | • Poor workmanship | • Damage caused by workers | • Shortage of skilled workers | • Lack of awareness among workers | • Poor attitudes of workers |
|                  |                     |                   |            |                                 |                   |                   |                                 |                        | Migilinskas, et al. [7], [17]                      |

#### 2.2 Minimization

Minimization and elimination in the management of construction waste were rated in the second most desirable way. Reducing waste generation factors may perhaps be helpful in the construction industry. These steps reduce environmental destruction and the cost of construction. Also, minimizing the use of resources from the start of projects and reducing transportation work [22].

Therefore, waste minimization is important for sustainable practice. In this similar scenario due to scarcity of land happens in Singapore. The authorities in the country’s construction field, taking minimization manner for achieving sustainability and lessen the usage of land [23]. The need for contractors to promote this sustainable initiative and play their optimum role in enhancing it.

#### 2.3. Reuse

Waste reuse is positioned fourth in the hierarchy of waste management. Similar steps are being taken by some developing countries like Germany and Hong Kong to reduce waste disposal in landfills. The government in Germany very well sponsored the recycling operation.

Review of lightweight concrete raw material demonstrates the country's contribution to sustainability [24]. In the meanwhile, the government has supported recycling aggregates of concrete and paving blocks in the case of Hong Kong [25]. Nevertheless, even after receiving formal accreditation, the demand from construction companies to use the recycling items remained high. In addition, the Korean government's policies require recycled aggregates to be used in construction.

Government regulatory incentives provide for minimum requirements for the use of recycled aggregates in construction projects [26].

#### 2.4. Recycle

It also applies to reducing avoidance, which is the best way to manage waste[18]. This is the highest level of sustainability requires. Nonetheless, there are some issues that practitioners have to overcome primarily during the pre-construction phase[19, 20]. In order to prevent construction, designers need to
take technical information about both the construction process into consideration during the design stage.

The prevention of waste, however, requires careful coordination between all those involved in the construction process. It is therefore important to have a very good relationship and contact with and within the building community, i.e. contractors, consultants and customers, in order to avoid any miscommunication or untoward incidents. Lack of communication and discussion can lead to incomprehension and the gene [21].

2.5. Recovery
Recovery that is described as removing materials or components from the waste stream in a way that preserves its original reuse nature in the same way as it was created [22]. The amount of waste that ends up in a landfill can be rising with recovery. In Germany, the process of incineration has helped to recycle metal waste.

After the distillation and burning process, this recovery tool can cut off harmful heavy metal in 1-ton waste up to 2 to 3 kilograms. Therefore, from taking space to landfill, this approach effectively solved the problem [48]. Nonetheless, the government should support this process even though the establishment of the recovery plant will result in a sum of money.

2.6. Disposal
Disposal is the last choice and the lowest criteria for sustainable waste management can be marked. Many countries, however, dispose of construction waste in landfills. The Department of National Solid Waste Management in Malaysia, for instance, revealed that there are about 289 landfills in the country [24].

Furthermore, Solid Waste Management and Public Cleansing Corporation (PPSPPA) and the Construction Industry Development Board (CIDB) keep promoting recycling and Industrialized Building Systems (IBS) to reduce landfill waste. However, the way to dispose of is not a good option since the role of sustainable waste management is to reduce waste management.

3. Construction waste management Life Cycle
A shut circle approach to sustainable construction waste management can provide value at every phase of a structure life cycle. Figure 2 demonstrates a systematic procedure for construction waste management depends on the closed-loop approach. Waste management will be discussed according to a ‘cradle to cradle’ approach. social or environmental perspective, likewise reduce the problems of settling the gradually increasing solid wastes by partaking better innovation in sustainable waste management [25].

![Figure 2. Systematic process for construction waste management through life cycle of a building.](image-url)
3.1. Stage 1: Objective
Developing the waste management plan and setting the waste management policy at an early stage is essential [26]. In connection to this, the prerequisite for good practice in construction waste management should be introduced at the outset of a project.

SAID [27] Proactive waste management plans begin with setting specific objectives by the project owner/client, which should be understood by the project team. The main objectives in achieving the effective waste management plan must be clear and ought to be incorporated in the project brief by the owner/client.

3.2. Stage 2: planning, design, and procurement
The prerequisite set by the client/owner will create a key opportunity for the project team to consider and implement the waste minimization plan [27]. The project team must be able to deliver what is stated in the project brief. An overall methodology to achieve waste minimization begins during programming and planning. Involvement of the project team at the early phase is crucial in ensuring that the waste management plan can be sustained throughout the building life cycle [28].

3.3. Stage 3: Construction
Rowe [28] The construction phase of a project will produce the greatest impact to minimising waste produced. The waste management plan developed during the early phase must be adopted on site. Policies related to waste management on site include monitoring and record keeping of wastes leaving the site, which must be formulated and reviewed periodically considering the developments during construction. Designated locations where wastes are dumped in separate compartments enable recycling because fewer efforts are needed to separate wastes when these are indiscriminately dumped [29]. Contractors should be encouraged to develop and propose new methods of construction to reduce the production of waste. Meetings and reports regarding waste management and minimisation on site should be held every week or every month, depending on the levels of involvement [30].
- the contractor alone is involved;
- the contractor and the consultant are involved; or
- all parties involved in the project.

3.4. Stage 4: Occupancy
Developing the waste management plan and setting the waste management policy at an early stage is essential [26]. In connection to this, the prerequisite for good practice in construction waste management should be introduced at the outset of a project.

Proactive waste management plans begin with setting specific objectives by the project owner/client, which should be understood by the project team [27]. The main objectives in achieving the effective waste management plan must be clear and ought to be incorporated in the project brief by the owner/client. Management of solid waste generated during occupancy ought to emphasize more on environmental solutions to achieve and maintain long-term sustainability goals that cover occupancy [30]. The project team should design the building with efficient waste management systems based on building type, geography, occupancy and other special circumstances of each individual building and its occupants. Currently, several green rating tools, for example as Green Building Index (GBI), Green RE, Malaysia Carbon Reduction and Environmental Sustainability Tool (MyCREST), can be used as a reference in managing waste during occupancy [17].

3.5. Stage 5: Operation and maintenance
Long-term optimization inactivity and maintenance of the finished building is an important part of the waste management plan [31]. However, the waste management plan developed at the design, the stage should be adequate with the waste management plan execution.
3.6. Stage 6: Renovation and demolition
Potential waste that generated during renovation and demolition ought to be considered at the beginning stage. Such consideration should include proper management based on the aims to maximise the potential usage and profit. Identifying opportunities and actions that will divert waste materials from disposal are important [32]. In this way, a waste diversion plan should be discussed among professionals at the planning stage, which should cover all the possibilities of waste.

4. Conclusion
The paper discussed construction waste issues and challenges, which in many countries has become a growing concern. Currently, illegal dumping, population growth, 3rd application in a trial stage has become a major problem in dealing with physical construction waste. The paper often underlined causal factors as well as maximizing the 3R and reducing waste disposal by implementing a sustainable and detailed strategy throughout the lifecycle of the construction project that can be mitigated sustainably to manage construction waste.

The waste management model should be embraced as a way forward to make the construction industry look greener to integrate sustainability into the management of building waste. Finally, this ongoing research will create a framework for constructing waste to sustain Malaysia's environment economy and social development.

References
[1] M Behera S Bhattacharyya A Minocha R Deoliya and S J C Maiti 2014 Materials 68 501-516
[2] S Nagapan I A Rahman and A. Asmi 2012 Construction waste management: Malaysian perspective in International Conference on Civil and Environmental Engineering Sustainability (IConCEES), Malaysia vol. 2 299-309
[3] A H Memon I Abdul-Rahman and I J L S J Memon 2014 Life Science Journal 11(6) 417-424
[4] N Rao and B R J O R Reddy 2018 International Journal of Advances in Applied Sciences 5(23) 174-179
[5] E Elizar 2019 Correlation Model of Construction Waste Cause Factors to Cost and Time in Infrastructure Project in Third International Conference on Sustainable Innovation 2019–Technology and Engineering (IcoSITE 2019).
[6] K Joseph 2007 Electronic waste management in India–issues and strategies in Eleventh international waste management and landfill symposium, Sardinia, 2007.
[7] D Migilinskas V Popov V Juocevicius and L J P E Ustinovichius 2013 Procedia Engineering 57 767-774
[8] S Ajayi 2017 Design, procurement and construction strategies for minimizing waste in construction projects (Dissertation: University of the West of England)
[9] W Lu and H Yuan 2011 Waste Management 31(6) 1252-1260
[10] A A Najafpoor A Zarei F Jamali-Behnam M Vahedian-Shahroudi and A. Zarei 2014 Iranian Journal of Health and Sciences 2(3) 49-54
[11] D-W O 2018 The identification of non-value adding activities associated with site management in the Nigerian construction industry (Dissertation: Cape Peninsula University of Technology)
[12] S O Ajayi L O Oyedele M Bilal O O Akinade H A Alaka and H A Owolabi 2017 Waste Management 59 330-339
[13] A Bakshian I Srour G Chehab M El-Fadel 2015 Resources, Conservation, and Recycling 100 70-80
[14] I A Rahman N S M Akhir A H Memon and S Nagapan 2015 InCIEC 2014 (Springer) p 199
[15] S Nagapan 2014 Structural Modelling of Cause and Effect Factors of Construction Waste Generation in Malaysian Construction Industry (Dissertation: Universiti Tun Hussein Onn Malaysia)
[16] S O Ajayi L O Oyedele O O Akinade M Bilal H A Alaka HA Owolabi 2017 Renewable and Sustainable Reviews 73 1333-1341
[17] S. O. Ajayi L O Oyedele O O Akinade M Bilal K O Kadiri 2016 Journal of building Engineering 5 185-193
[18] G B Zamri N K A Azizal S Nakamura K Okada N H Nordin N Á Othman F N Md Akhir A Sobian N Kaid A. Har 2020 Journal of Cleaner Production 118 96
[19] M Li H Yu and P Liu 2018 Automation in Construction 91 284-292
[20] H U Imad M A Akhund T H Ali A R Khoso and F. H. Siddiqui 2018 International Journal of Civil and Environmental Engineering 12 9(1) 17-81
[21] S Makieva E Giacomini J Ottolina A M Sanchez E Papaleo and P. J. I. Viganò 2018 Int J Mol Sci 19(9) 2477
[22] S Nagapan I A Rahman A Asmi A H Memon and I Latif 2012 Issues on construction waste: The need for sustainable waste management in 2012 IEEE Colloquium on Humanities, Science and Engineering (CHUSER) IEEE 325-330
[23] C J Circo 2007 Penn State Law Review 112 731
[24] O C Aja and H Al-Kayiem 2013 Journal of Material Cycles and Waste Management 16(4) 693-710
[25] I Baek 2015 A study on the sustainable infrastructure of the Songdo City Project: from the viewpoint of the metabolic flow perspective (Dissertation: Stellenbosch University)
[26] A Adeyemi D Martin and R Kasim 2017 Journal of Engineering and Applied Sciences 12(6) 1365-1376
[27] M Z Said 2018 The Relation between Risk Management throughout Project Lifecycle and the Success of Construction Projects in the UAE, The British University in Dubai
[28] D Rowe 2002 Teaching Sustainability at Universities 79-103
[29] T T Bgwoni 2015 The role of community based organizations in solid waste management. A case of Masvingo urban, Zimbabwe (Degree dissertation: Midlands State University)
[30] A Martos R Pacheco-Torres J Ordóñez and E Jadraque-Gago 2016 Renewable and Sustainable Energy Reviews 57 479-495
[31] I J Onuoha G U Aliagha and M. S. Rahman 2018 Renewable and Sustainable Energy Reviews 90 814-823
[32] L. Ng and R Kenley 2018 Preliminary Evaluation of Synergizing BIM and Malaysian Carbon Reduction and Environmental Sustainability Tool in Sustainability in Energy and Buildings 2018: Proceedings of the 10th International Conference in Sustainability on Energy and Buildings (SEB’18), vol. 131 p. 218: Springer