Chapter 26
Sustainable Techniques for Building Waste Disposal

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Abstract The building industry plays an important role in setting up the infrastructure needed for socio-economic sustainability. Owing to rapid urbanization, the substantial development of the construction industry has led to the formation of building material waste that has a negative impact on the environment, such as pollution of soil, air, and water. Building material (BM) waste consists primarily of inert and non-biodegradable materials such as concrete, plaster, metal, masonry, non-ferrous metal, paper and cardboard, mortar, bricks, roofing tiles, glass, paints, pipes, electrical fixtures, wood, plastics, etc. These waste products contain large concentrations of toxic materials that have a detrimental effect on the atmosphere and the health of humans. During the building process, various hazardous compounds are released into the environment. The conventional approach to waste disposal has long been to deposit BM waste in sanitary landfills, but this would not be possible in the years to come. It is necessary to control and manage the production of BM waste. Sustainable management of waste produced from construction is becoming increasingly compulsory to protect public health, minimize environmental burden and preserve existing natural resources. Extensive research has been dedicated to encouraging the safe management and disposal of waste building materials. This chapter addresses the sustainability of waste from construction materials and describes the related management and disposal techniques for the protection of natural resources and the environment, such as reduction, reuse, recycling, and incineration.

Keywords Environment · Hazardous · Waste · Sustainable · Building · Bioremediation

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26.1 Introduction

Building material waste is defined as the solid waste generated from the construction sector, including construction activities, material procurement, finishing, renovations, reconstruction, and demolition (Ajayi et al. 2017; Jamal et al. 2021). Construction activities have been on the rise to accomplish extensive property development, better public transport, and enhanced infrastructure for increasing urbanization and lead to more abstraction of natural raw materials, which results in a significant increase in the production of building material waste (Shooshtarian et al. 2020a, b). Building material waste is a highly heterogeneous material mixture that usually includes metals, concrete, asphalt, mortars, stone, gypsum wallboard, timber, plastic roofing, and cardboard (El-Haggar 2007). At least 30% of the total solid waste produced around the globe accounts for building material waste. Building material waste is caused by unnecessarily organized supplies or by unskilled laborer's mishandling of materials (Ginga et al. 2020).

Building material waste production has reached 3 billion tonnes worldwide, with India, China, and the USA contributing more than 2 billion tonnes (Akhtar and Sarmah 2018). Building material waste is categorized between non-inert and inert waste, where the non-inert waste is dumped at landfills and inert waste is usually disposed of in urban fillings as reclamation products (Poon et al. 2013). A significant factor of building waste is non-inert waste (timber and wood) (Wu et al. 2019a). Building material waste account for a significant part of the solid waste taking up landfills on a global scale and contribute to environmental issues. Limited landfill areas, water pollution, energy consumption and greenhouse gas emissions, waste materials produced from building demolition have become a major challenge to sustainable development (Bribián et al. 2011; Ding et al. 2016a).

Building material waste dumped into forests, streams, and vacant lots causes erosion, pollutes wells, water levels, and surface waters, attracts pests, creates fire hazards, and detracts from the beauty of natural areas. Building material waste containing toxic contaminants such as asbestos, heavy metals, persistent organic compounds, and volatile organic compounds (VOCs) is also much harder to disposal (Esin and Cosgun 2007). Every year, a huge volume of building waste is produced all over the world. Many investigations have demonstrated that waste management fees are an efficient solution that can minimize waste generation and increase the rate of landfill diversion (Wang et al. 2019).

The building industry accumulates a substantial volume of pollution that has a substantial effect on the atmosphere and the flow of energy (Sozer and Sozen 2020). Waste from the building sector faces enormous difficulties for sustainable waste management. This is not only due to the vast quantities of waste produced during building activities but also to the inherent toxins present in these materials (Amaral et al. 2020; Raskovic et al. 2020). In this chapter, we are proposed to discuss building material waste, their impact on the environment, human health, and various means and ways for the management and safe disposal of waste building material.

26.2 Sources and Causes of Building Material Waste

Building waste typically refers to debris created by practices such as construction, destruction, and reconstruction, and describes what involves building waste from country to country (Hoang et al. 2020). There are many interrelated sources of building waste existing (Ekanayake and Ofori 2004). Based on the particular building methods used, the forms and composition of onsite waste generated are extremely variable (Osmani 2011). The building material waste is produced during the project from the pre-construction stage, construction stage, and the final finishing stage. In general, the building waste in the industry can be categorized in many divisions as shown in Fig. 26.1.

The major components of the building waste include cement concretes, bricks, steel, stone, wood/timber, and cement plaster, whereas the minor components include iron plastic conduits, pipes, glass, tiles, etc. (Shrivastava and Chini 2005).

Excessive cement mix or leftover mortar after work of building operation is overdue to rejection caused by the change in plan or incorrect quality of work, etc. Concrete is considered as waste in 2 forms: reinforced (building structural elements) concrete and non-reinforced (foundations) concrete (Ponnada and Kameswari 2015). Concrete, substances that make it an affordable material and easy to manufacture anywhere, is found in organic granules, cement, and water. About 12% cement, 80% bulk aggregates, and 8% water is used in conventional concrete (Barbuta et al. 2015).

During demolition, large quantities of bricks and brickwork mixed with cement, mortar, or lime are produced as trash. During the demolition of old buildings, the stone is produced as waste material. Metal waste is produced from tubes, transmission lines, and light sheet material used throughout the air vents, cords, and plumbing fixtures, and structural concrete. Various waste materials include plastic, glass, paper, etc. (Ponnada and Kameswari 2015). A fraction of demolition waste was analyzed by Briere et al. (2014) and found that 52.8% of the most efficient waste was classified as

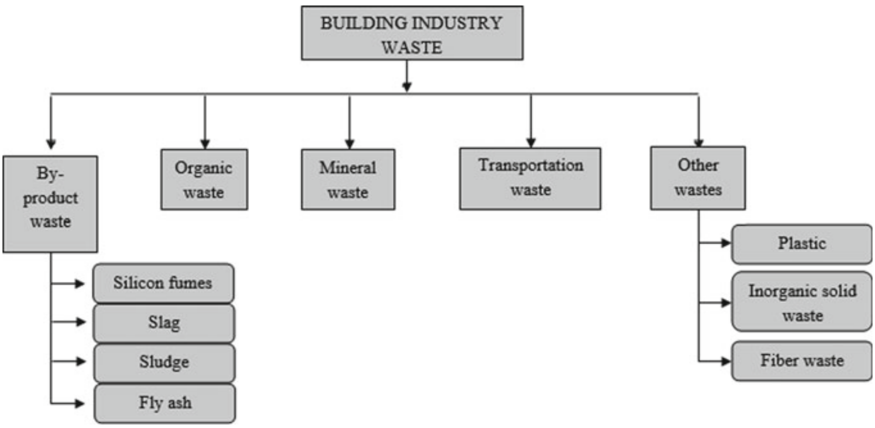

Fig. 26.1 Building material waste

masonry, 26.4% reinforced concrete, 9.3% mixed inert waste, and the other 11.5%. The key causes of waste in construction were categorized into six categories: design source, procurement, material handling, operation or service, residuals, and other sources (Gavilan and Bernold 1994; Bossink and Brouwers 1996; El-Haggar 2007).

26.3 Impact of Building Material Waste

Buildings are liable for the exploitation of resources and emission of pollutants in the environment (Feng and Lam 2021). As a result, the building sector has thus become a global target for reducing environmental impacts and curbing the depletion of resources (Hossain and Thomas 2019). In both urban and dynamically developing cities in the world, construction companies are booming (Hasan et al. 2021). Rapid urbanization has boosted unlimited construction in both developed and developing nations. Building material waste has been extensively produced which resulting in catastrophic and tragic effects in terms of economic standards and environmental conservation on urban health and longevity (Aslam et al. 2020). Improper management of building material waste affects our environment due to water, soil, and air pollution and have hazardous impacts on our ecosystem's flora and fauna, it is also responsible for social along with public health issues which can cause health problems, improper working and human safety and can have economic impacts because of loss of raw materials, resources and use of fuel supply during waste transportation (Asgari et al. 2017).

26.3.1 Impact on Environment

Traditionally, the building industry is environmentally unfriendly. Soil pollution, water contamination, and landscape erosion are among the environmental effects of building material waste (Fadiya et al. 2014). The rapid increase in building construction activities has resulted in large amounts of waste generation causing environmental change and pollution (Rani 2017). The construction industry consumes 35% of generated energy and releases 40% of CO_2 into our environment. This sector is the largest consumer of raw materials resulting from natural resources and these activities result in producing material waste that harms the environment (Luangcharoenrat et al. 2019). Building material waste comprising of hazardous substances like heavy metals and organic pollutants could result in leaching if not treated properly before disposal, which will be toxic to the atmosphere and cause contamination to the water, soil, and air (Huang et al. 2017).

A huge quantity of waste is produced due to building activities accounting for 20–30% of total solid waste of which 70–80% is concrete and masonry, thereby causing detrimental effects to both human life and the environment (Gupta 2018). Due to the continuous increase of building material waste, there is a shortage of landfill space which in turn causes pollution in the atmosphere because of illegal dumping in the world i.e., China, Malaysia, Hong Kong, and Israel (Yu et al. 2013). Building material waste landfilling's not only consumes limited landfilling resources but also contributes to an increase in energy consumption, greenhouse gas emissions, cause public health issues, and environmental contamination (Chen et al. 2017a, b; Mah et al. 2018; Zhang et al. 2019). These wastes are contributing to the global warming phenomena leading to an increase in temperature and weather extremes, further causing heat waves and poor air quality (Marzouk and Azab 2014).

Building material waste contributes to air pollution and water pollution mostly occurring from the transportation of waste, greenhouse gas emissions, and leachates released from the wastes in landfill areas (Yahya and Halim Boussabaine 2006). Sulfates present in gypsum drywall in building material debris are mainly responsible for causing harm to the environment and the excess of chemicals above the limit in water can cause a cathartic effect on humans (Jang and Townsend 2001). Improper disposal of building material waste limits any land reclamation job which could have taken place on large surfaces along with contributing to the contamination of air with toxic gases such as CO_2 and CH_4, two of the main factors responsible for the greenhouse effect at the planetary level (Iacoboaea et al. 2010). Other chief pollutants in construction activities are mostly particulate matter 10 (PM 10) and 2.5 (PM 2.5), N_2 and SO, and volatile organic compounds (VOCs) which attributes to 23% of air pollution present in cities, 50% of climate change through greenhouse gas emission, 40% of pollution in drinking water, 50% of landfill pollution and 50% of Ozone depletion (Jain et al. 2016).

26.3.2 Impact on Public Health

Building material waste is a major part of industrial waste. This waste is heterogeneous and comprises a large degree of building materials, but even considerable amounts of hazardous chemicals are included (Trankler et al. 1996). The building material waste has been disposed of in the sanitary landfills. Due to improper disposal of waste, heavy metals (HMs) such as Cd, As, Pb, Ni, Cr, Cu, and Zn gets leached into the water bodies, which poses a grave threat to the ecosystem and public health and can cause health problems like ulcers, liver damage, diarrhea, cancer, respiratory disorders, and cardiovascular disease, through unintended utilization of the heavy metals (Yu et al. 2018). The main constituents of building materials such as calcite and gypsum are responsible for causing respiratory tract infection and inflammation in the mucus membranes of the eyes, and their inhalation in form of these ultra-fine particles e.g. PM 2.5, could potentially lead to toxic respiratory effects (Oliveira et al. 2019).

Informal workers i.e., recyclers were also found to be suffering majorly from body pain due to lifting of heavy loads, back pain due to constant bending down, long working hours, and improper working conditions (Gutberlet and Baeder 2008). Dust is the fourth highest emission in percentage resulting from building activities impacting the environment directly by contributing to the direct visual, image, and health of the ecosystem and public health (Estevez et al. 2003). Some of the additional risks of handling building material waste involve asbestos removal whose fibers upon inhalation could be the causative agent for cancer and other lung diseases (Duan and Li 2016). The improper management of the building material waste affects the community's health and causes various adverse health effects and disorders associated with pollution, such as respiratory illness, birth defects, cancer, etc. (Aboginije et al. 2020).

26.3.3 Impact on Economy

The built environment is the core of every economy, providing the infrastructure needed to improve growth, but the way it consumes natural resources makes it responsible for some of the most serious changes in the local and global environment (Dania et al. 2008). Globally, the building industry is known as an economic investment, and its association with economic development is well asserted as many developing and developed nations have learned the significance of it at a socio-economic level necessary for employment and sustainable development of a country. It is vibrant for the progress of a nation since it provides necessary infrastructures and materials for activities like commerce, services, and utilities (Hasmori et al. 2020).

Building material waste is a major economic concern since the raw materials involved in the building elements are not further recycled, which is not economically and environmentally feasible (Marrero et al. 2017). Proper recycling of building material waste can also boost up the economy by creating a variety of jobs in the field of recycling and salvaging of building material waste which also helps in the business sense by creating a powerful social image, improving production efficiency and their profits, and hence improving product quality and overall environmental performance (Jain 2012; Oyenuga and Bhamidimarri 2015).

26.4 Traditional Disposal Strategies for Building Material Waste

The traditional method for waste management has often been the dumping of waste construction materials in landfills, but this would not be feasible in the years to come (Ginga et al. 2020). Maximum building material waste is transported for disposal to landfills that consume vast land resources and posing safety issues because of the excessive accumulation. In the metropolitan lifestyle, the growth in construction and urbanization technology has led to a significant quantity of constructive wastes. The maximum part of constructive wastes represents waste by reconstruction after demolition. Improper disposal of such solid wastes generates unsanitary and soil barren conditions or turns to environmental pollution (Luangcharoenrat et al. 2019). It is essential to reduce the dumping of building material waste at landfills (Berge et al. 2018).

26.5 Sustainable Technologies for the Disposal of Building Material Waste

Sustainable construction is an integrative and holistic building process that seeks to restore harmony between the natural and the built environment. Appropriate construction waste management, reduction, reuse, and recycling methods are important for each nation (Lei et al. 2019). Five key groups consist of the building waste management hierarchy (El-Haggar 2007);

1. Reduce,
2. Reuse,
3. Recycle,
4. Recover, and
5. Disposal

United Kingdom, North America, Europe, and various parts of Asia accepted the 3R Principle, which is to reduce, reuse, and re-process waste (Shen et al. 2002; Sakai et al. 2011; Allwood et al. 2011; Hasmori et al. 2020). Coventry and Guthrie (1998) stated remarkable reasons to prefer all such traditional approaches like minimizing the risk of environmental pollution and uncertainty to human health. This report was also found economically in support as can reduce project costs, expanded business support (Shen et al. 2002; Dania et al. 2007).

26.5.1 Reduce, Reuse, Recycle, Recover (4R) Strategy

In 4R approaches, waste reduction is the primary method related to reducing building material waste production at its local stage. The reduction could be accomplished by diminishing or withdrawing unspecified activities at running projects, or by preserving current buildings instead of constructing new ones. Though, it can also be managed by improving the dimension of modern construction or can build new construction with substantiality to prolong life. The reduction in building trash is recognized as the most effective and efficient method but several factors including design changes, poor material handling, lack of capability among the laborers, weather, etc. arise the building material wastes. Besides, the reduction of building material wastes not only manages the generation of waste but also helps to reduce the running cost of disposal and recycling. Reduction in building material waste saves the landfilling premises and lowers the environmental negative impacts (Kralj and Markic 2008; Osmani et al. 2008). Reduce, Reuse, Recycle are the strategies

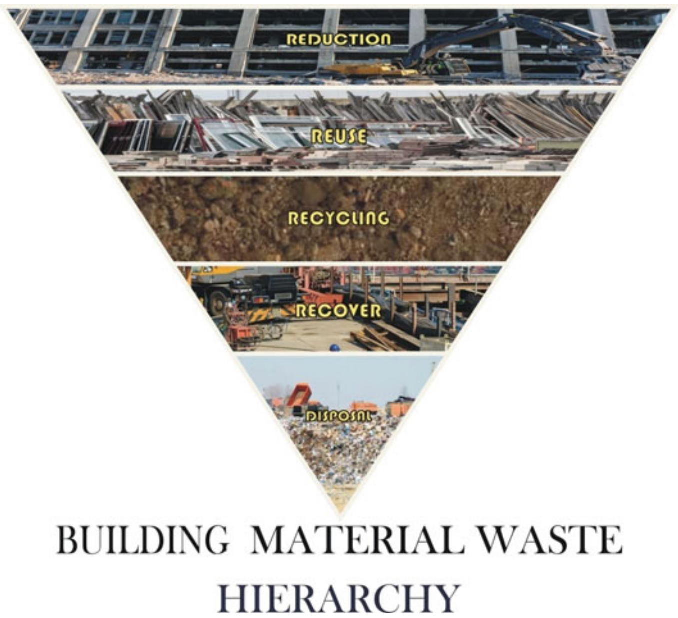

Fig. 26.2 4Rs rule of building material waste management hierarchy

to reduce the consequences of building material waste production (Yu et al. 2021) (Fig. 26.2).

The reuse and recycling of building waste eliminate the demand for raw materials and resources, reducing environmental pollution, aesthetic impacts, and disruption to natural habitats accordingly (Craighill and Powell 1997). Reusing building material waste is also the right sustainable approach for environmental management. The reuse approach is a good alternative if they satisfy some criteria like dimensions and quality, to manage and delaying final disposal or recycling of building material waste production. It is a simple repairing, refurbishing, or effortless recovery of used appliances from a building material waste manufacturer. Hence, reusable waste can be marketed at their production site or by auction. Even, a lot of raw building material debris including gravel and aggregate products, Concrete, Clean wood, Plastics, Insulation materials, iron materials, etc. can be used as a resource.

In Recycle strategy, all used, re-used, or unused matters are considered as waste and processed into valuable new products. Building materials enterprises (BMEs) and waste recycling enterprises (WREs) are two primary players in the recycling of building waste, and their waste recycling decisions influence the development of the waste recycling industry (He and Yuan 2020). Before recycling, these building wastes are screened on-site or off-site and will be transported to the processing center and re-manufactured into new or same products. Waste screening is based on laboratory research or scientific approach and durability evaluation. For example, concrete and gravel can be recycled into aggregated concrete products; Wood can be into furniture;

Metals like steel, copper, etc. can be separately recycled into new valuable products. Bricks and cement chips, sand, stone breaks, etc. can be refurbished as tiles. Hence, a large quantity of building material waste is left after typical management and is dumped in the landfills. It is referred to as waste disposals (Dania et al. 2008). Waste glass from the building sector is one of the major problems for effective waste treatment and reduction. The recycled glass has been developed to be used in structural buildings (Adekomaya and Majozi 2021). Bakchan and Faust (2019) estimated the production of construction waste (CW) from institutional building ventures and also quantified the benefits of CW recycling as saving trees, water, energy, and greenhouse gas pollution in the atmosphere.

26.6 Building Material Waste Management: Global Best Practices and Plan

The disposal and management of building waste have become crucial challenges all over the world (Chen et al. 2021). Building material waste includes large volumes of dangerous materials that adversely impact public health and the environment (Nadeem et al. 2021). The strategy of building material waste management is minimizing waste at its root source (Ferguson et al. 1995). The building material waste management is ongoing in U.K, France, Denmark, Germany, U.S.A, Japan, etc. In these developed countries, around 94% of architects, engineers, consultants, and owners are interested in green buildings or sustainable buildings. In China, the Chinese government is founded the "Polluter Pays Principle" under environmental law to promote sustainable building and integrated construction waste management (Chen et al. 2017a, b).

Many nations decrease construction material waste by implementing new laws and creating attentiveness. Singapore, Japan, and European nations are at the front for handling and reusing construction waste. In Japan, 20 subdivisions of 'building material by-products' are systematically administered rendering to categories. The core principle in managing building material waste in Japan is to reduce and recover the produced waste at the building site. Singapore emphasizes developing principles for green buildings to mitigate the production of building material waste from the source (Lei et al. 2019). Though, recycling of building material waste was initiated during World War-II in Germany and was to tackle disposing of the large quantity of demolished waste. At present, studies throughout the world have demonstrated possibilities for the reuse or recycling of building material waste. In India, Central Building Research Institute (CBRI), Roorkee, and Central Road Research Institute (CRRI), New Delhi are in focus to work on recycling of aggregates (Ponnada and Kameswari 2015).

Building material waste, if not adequately handled, has harmed the environment. Efficient disposal of building material waste is also of key significance for sustainable development. The stakeholders in the building industry need to regulate and handle the production of construction waste. There are several efforts have been made to recycle and process building material waste for use in the manufacturing of different construction materials (Wahi et al. 2016). For the application of suitable management techniques, construction waste composition analysis is always important (Wu et al. 2019b). Ding et al. (2016b) developed a system dynamics (SD) based environmental efficiency simulation for the reduction and control of building material waste during the construction process in Shenzhen, China. The findings of the simulation demonstrate that source reduction is an efficient measure of waste reduction that can minimize 27.05% of overall waste generation. Implementation of construction waste reduction may decrease 53.77% of landfills. Ding et al. (2018) built a two-stage device dynamics (SD) model for environmental benefit assessment of construction waste reduction using Vensim tools. This model included the subsystem for building waste reduction management, the waste generation, and recycling subsystem, and the subsystem for environmental profit evaluation. The findings of the simulation highlight that reduction management will minimize waste generation by 40.63%.

Building information modeling (BIM) design validation is an important way of reducing the amount of construction waste. BIM may be practiced as a less costly, simulated, and technological framework to encourage designers to analyze numerous design alternatives, or contractors to assess various construction schemes (Lu et al. 2017). The construction waste is produced largely due to incorrect design and unforeseen changes in the design and construction processes (Won et al. 2016). Shi and Xu 2021 developed a Building Information Modeling (BIM) CDW information framework using Revit software to reduce the CDW based on the 3R principle, which overcomes the barriers to the implementation of BIM and illustrates the information directly applicable to CDW.

Construction Waste Reduction (CWR) refers to reducing the quantity of hazardous waste produced during construction projects and facilitating the sustainability of the construction industry. This research seeks to enhance the awareness of the essential steps to be engaged in the application of CWR in construction by building stakeholders (Liu et al. 2020). In the course of the construction phase, the construction sector has become extra involved in pushing towards the introduction of a creative approach for minimizing waste and environmental impacts (EIs). Life Cycle Assessment (LCA) is an internationally recognized approach for the environmental impact assessment or concern of buildings (Khasreen et al. 2009; Jalaei et al. 2019).

The utilization of Recycled Concrete Aggregate (RCA) in cement concrete as a partial or complete substitute for Natural Aggregate (NA) was proposed by Shaban et al. (2021) to handle the tremendous amount of building material waste. Recycled Aggregates (RA) resultant from construction material waste may be used along with Natural Aggregates (NA). Ali et al. (2021) observed increased concrete strength after assessment of the cumulative effect of Recycled Aggregates Concrete (RAC) and Styrene-Butadiene Rubber (SBR) Latex on concrete workability. Ultimately, recycling waste concrete for fine aggregate processing would conserve landfill spaces and protect natural sand and thereby reduce the carbon footprint of buildings (Soni and Shukla 2021). There is an emerging movement in the global building sector to follow a "zero-waste" objective at the site level, but little is understood about it (Lu et al.

2021). Bilal et al. (2016) proposed Big Data architecture for building waste analytics, which can store and process vast quantities of data scalably and efficiently using a commodity server cluster. Bakshan et al. (2017) used a Bayesian Network study to identify causal behavioral determinants for enhancing construction waste management (CWM) practices. Chi et al. (2020) analyzed the success of LEED (Leadership in Energy and Environmental Design) approved projects in the United States and China for the minimization of construction waste. Minimization of building waste is an important environmental priority of green building ranking systems.

26.7 Conclusion

After increased urbanization and construction activities, the issue of building material waste has become more severe over the last two decades. There are myriad approaches in which building material waste and pollution can have economic, environmental, and social impacts. The treatment of building waste worldwide has been committed to growing research efforts. Priority must be given to improving waste management methods for the decrease of building waste. The reuse of building material waste can prevent the production of building waste. The methods should be developed concerning reduce, reuse, recycling, and adequate disposal of building waste, thereby delivering environmental and economic benefits through the execution of waste management. Today, sustainable development includes the smart implementation of environmentally-friendly green resources and creative concepts.

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