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IDENTIFYING POTENTIAL HOUSEHOLD WASTE AS SECONDARY RAW MATERIALS IN THE CONSTRUCTION INDUSTRY: A CASE STUDY OF SRI LANKA

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Abstract. The construction sector contributes significantly to waste generation and resource depletion. Identifying potential household waste for reuse and recycling as secondary raw materials has emerged as a key technique for addressing these environmental concerns. This study uses the Colombo municipality in Sri Lanka to identify and evaluate household waste products having the potential to be reused as secondary raw materials in the construction sector. The study employs a mixed method for data collection and analysis. First, a questionnaire survey of industry experts was conducted to identify and assess the requirements for household waste that may be utilized in the construction sector, followed by a complete literature analysis to determine the reuse applications of potential household waste. The findings of this study will be useful in identifying and evaluating household waste items that may be recycled as secondary raw materials in the construction sector. It would also help to establish sustainable waste management techniques and circular economy practices in Sri Lanka. The study's findings can help policymakers, waste management authorities, and stakeholders in the construction industry to implement effective waste management practices and promote the use of recycled materials in construction projects, reducing environmental impact and conserving natural resources.

Keywords: *Construction industry, household waste, secondary raw materials, Sri Lanka.*

INTRODUCTION

A promising concept that includes potential solutions to the challenges that global society is facing nowadays is the circular economy. Even though the main goal of the circular economy is to lead to a more sustainable economy, contributing to the recycling and reuse of products (Zvirgzdins et al., 2020), it also contains potential solutions related to energy (Zvirgzdins & Linkevics, 2020), transport (Zvirgzdins et al., 2020), construction and real estate sectors (Zvirgzdins et al.,

2019). Current research focuses on identifying potential household waste as secondary raw materials in the construction industry of Sri Lanka.

The Democratic Socialist Republic of Sri Lanka (previously known as Ceylon) is an island located in the Indian Ocean and separated from the southeast coast of India. The country has a population density of approximately 22 million, which has risen over the years. Sri Lanka experienced a gross national product (GNP) of $ 88.58 billion in 2021, with an increment rate of 4.13 % from the previous year (Macrotrends, 2022).

Sri Lanka decentralized its government structure in 1987 with the establishment of provincial councils responsible for carrying out tasks specified by the ministries of the central government and their departments and agencies. The country now has nine provincial councils. These provincial councils include municipal councils (24 MCs), urban councils (41 UCs), and divisional councils, or *pradeshiya sabhas* (*pradheshiya sabha* – a legislative body formed by Sri Lanka's Parliament through its act and other related legal enactments to administer cities, towns, and villages within a given district) (276 DCs). The UCs and DCs are governed by the municipal council of the respective district. Out of nine districts and 24 municipalities, the Colombo Municipal Council (CMC), located in the Colombo District of the Western Province (WP), is one of the most critical government entities since it governs one of the most populated districts in the island. Colombo is very well known as a highly residential zone, and the area is now facing severe land scarcity and environmental threats due to its overpopulation. One of the significant concerns about environmental threats is the generation of municipal solid waste (MSW), especially from household waste. A tragedy occurred with the collapse of the Meethotamulla waste dump due to improper waste management practices followed by the government authorities, and the people residing in Meethotamulla are still facing the consequences of the collapse of the waste dump. Sri Lanka mostly follows the composting of solid wastes and the 3R principles of the circular economy (CE). However, these strategies have failed to satisfy community needs or mitigate environmental threats (Wanaguru et al., 2022).

Furthermore, the Sri Lankan construction industry has experienced a massive downturn due to the impact of the COVID-19 pandemic and the recent economic crisis. It is seen that the industry has failed to come up with alternatives to maintain the material supply chain since it is highly dependent on imported materials. Most high-rated construction companies now tend to leave the island by abandoning new and ongoing projects. This tremendously impacts Sri Lanka's GDP, as the construction sector is considered the second largest contributor to the nation's gross domestic product (GDP) (Mendis et al., 2019).

Studies have been conducted addressing sustainable, logical, and strategic solutions for MSW generation and construction and demolition (C&D) waste generation. Studies have provided evidence of proper solutions to overcome this issue in the Colombo Municipal Area. However, a clear research gap exists on utilising MSW in the construction industry. Hence, rather than dumping MSW waste into landfills or reusing or recycling them on a small scale, it is wise to find

a solution to use the waste in the construction industry, which could keep the materials in a closed loop while reducing the imports of materials.

Therefore, this paper aims to find potential MSW to recycle or reuse as secondary raw materials in the construction industry. The study area has been confined to the Colombo Municipal Area, considering the severity of the case and the ease of conducting the research. The study intends to analyse potential household wastes from all the MSW generated in the Colombo Municipal Area. This study could also be relevant to other local authorities in Sri Lanka and developing countries.

1. LITERATURE REVIEW

1.1. Current Status of MSW Generation in Sri Lanka

Municipal solid waste (MSW) has not only been a threat to the Sri Lankan community but has also been of significant concern around the globe because of high urbanization, population growth, industrial expansion, and many more factors. It is evident that developing countries have to strategically overcome waste generation since the expansion of communities is much more severe than in developed countries (Dharmasiri, 2020). According to the data published by the World Bank, the annual waste generated globally was estimated at 2.01 billion tonnes, and the average MSW generated by a person was recorded at 0.74 kilograms. Further, analysts have predicted this could be increased to nearly 3 billion tonnes by 2050 (The World Bank, 2022).

Data revealed that South Asia has recorded 334 million tonnes of MSW per year, and this is predicted to be 466 million tonnes by 2030 and nearly double by 2050 (The World Bank, 2022). Researchers have found significant reasons for the vast amount of waste generation around the globe. Bandara (2011) stated that people's income level has a high impact on increases in MSW and that it is directly proportional to a person's income. Also, it is argued that increasing amounts of MSW could be a result of population growth and rising living standards. This is evident when analysing the data on MSW generated in Sri Lanka. As consumption patterns have changed, the amount of MSW created in Sri Lanka has risen. Data analysis found that the average quantity of MSW per capita per day in the Colombo Municipal Council was 0.85 kg, compared to 0.75 kg in other municipal councils, 0.60 kg in urban councils, and 0.40 kg in *pradeshiya sabha*s. The primary sources of MSW are households and commercial establishments, while secondary sources are industries and hospitals. The major portion of the MSW stream in Sri Lanka is dominated by organic waste generated from households, markets, and slaughterhouses (Liyanage et al., 2015). An assessment of waste amounts and composition surveys (WACS) by the University of Peradeniya in 2014 indicated that kitchen waste accounts for about 75 % of total waste. The survey further revealed household waste quantities: 7.8 % of wastes were paper and cardboard; 6.1 % were soft and hard plastics; 1 % – textiles; 1.7 % – glass; 0.9 % – metal; and 2.7 % – miscellaneous waste. According to the Central Environment Authority (CEA), a person generates an average of 0.64 kg daily. This could be much higher

in urban municipalities. However, it was noted that many *pradheshiya sabhas* do not collect and manage waste properly. Furthermore, a study conducted by the University of Morotuwa in collaboration with the National Solid Waste Management Support Center (NSWMSC) in 2013 indicated that the whole island generates approximately 3,500 tonnes per day. This is much worse in the present day. Hikkaduwa et al. (2015) stated that all local governments gather 3773.2 tonnes of solid garbage daily. The Western Province collects around 60 % (1663 tonnes) of total waste.

The Colombo municipality is the most urbanized in Sri Lanka, it is seen that waste generation is a considerable issue as the region is getting urbanized day by day and there is a tendency for the region to be overpopulated.

According to data issued by the Waste Management Department of Colombo Municipal Council, several types of household waste have been taken into recycling in 2022, accounting for 1991.77 tonnes. The types of waste included plastic, polythene, paper, cardboard, glass, metal, iron, tin, coconut shells, aluminum, pet bottles, pieces of glass, PVC, and ceramics. According to Fig. 1, it is identified that the household waste materials cardboard, polythene, paper, coconut shells, and glass are the most collected household waste materials throughout the year.

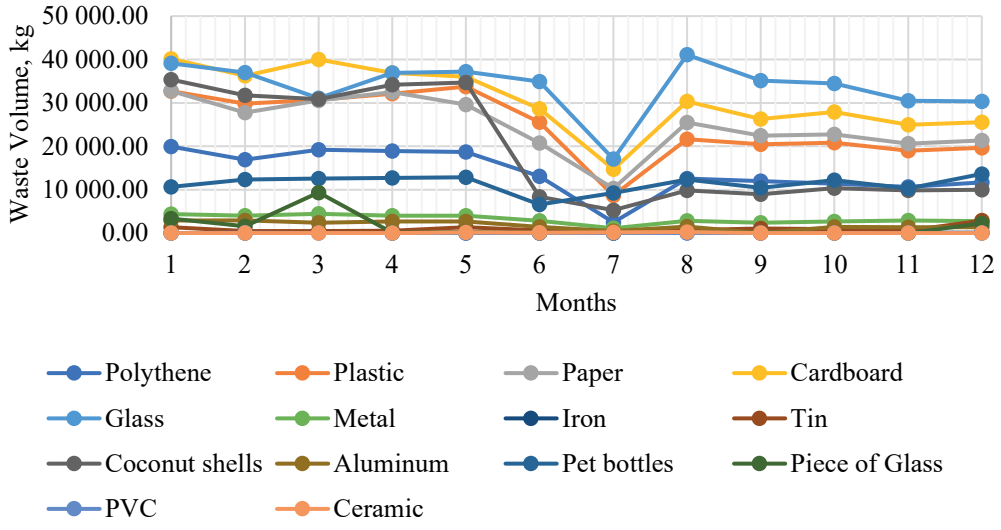

Fig. 1. Collection of recycled waste in Colombo municipality in 2022 (Colombo Municipal Council, 2022).

Furthermore, considerable amounts of mixed wastes (known as wastes that are a mixture of radioactive, biological, and chemical wastes) were transferred into a waste-to-energy plant located in Kerawalapitiya, Colombo, for recycling purposes. The presented line graph (Fig. 2) depicts the variation in the volume of mixed waste delivered to a waste-to-energy plant in the Colombo Municipality between 2021 and 2022. The quantity of mixed waste fluctuated in both years, and it is interesting

to note that the amounts of mixed waste given to the recycling centre decreased dramatically in February 2021. The general trendline, however, suggests that quantities transferred to the plant increased in 2022 compared to 2021. The volume of waste is measured in tonnes.

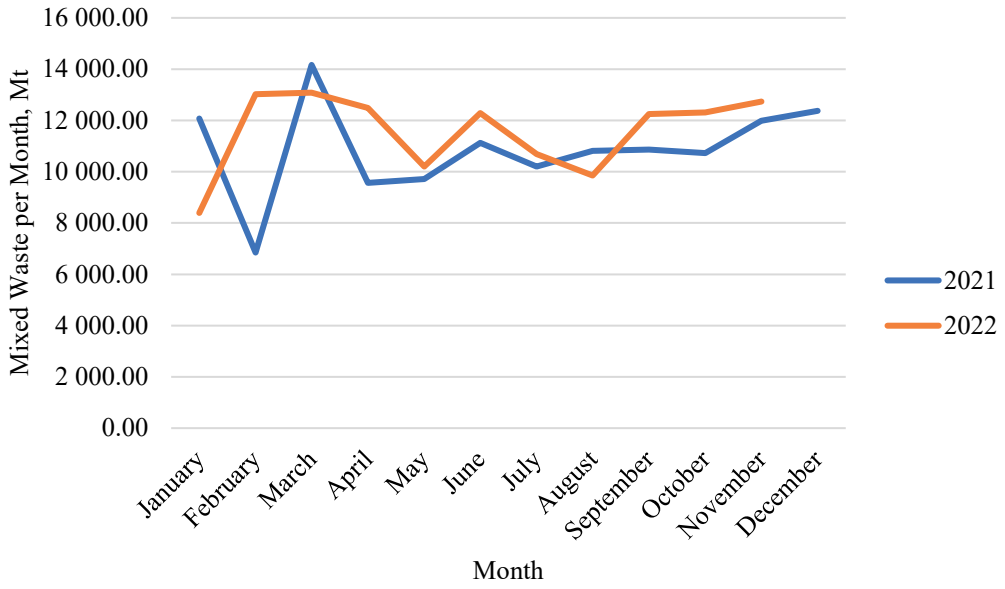

Fig. 2. Mixed waste transferred to waste to energy plant variation in 2021 and 2022 (Colombo Municipal Council, 2022).

Figures 1 and 2 underline that a proper logical and systematic solution must be found to mitigate the MSW generation of the Colombo MC.

1.2. Waste Management Practices in Colombo Municipal Area

In Sri Lanka, government entities including municipalities, urban councils, and the small-scale government administrative units known as *pradheshiya sabha* are mainly responsible for the proper management of MSW. The Colombo Municipal Council (CMC) is one of the largest entities that critically handles and manages waste, as it governs the most highly urbanized region in the island.

CMC has initiated its waste management program in partnership with the private sector. According to the research of Abeykoon and Denagama (2021), the wastes are currently classified as biodegradables, recyclables, and non-recyclables. The government has given full responsibility to the community for segregating these wastes into the abovementioned categories. Compactor trucks and open trucks are utilised to collect non-recyclable trash, while biodegradable waste is only collected using compactor trucks. Recyclable waste is collected by a truck that contains divided compartments. Furthermore, studies reveal that biodegradables are composted and fed to animals. Non-recyclables are transferred to the Kerawalapitiya waste-to-energy facility. Recycling waste collectors come to collect

recyclables from recycling centres and eco kiosks throughout Colombo city. Most composting and 3R principles (reduce, reuse, and recycle) are adopted to manage MSW. The community within the Colombo Municipality is highly aware of managing waste, and a study indicates that the community is mostly aware and practices open waste burning (99 % and 85 %, respectively) (Mendis & Thayaparan, 2021). According to another study, the best waste management technique selected by individuals in the Colombo municipal area is reuse, as 70.8 % of respondents affirmed this practice, while 23.9 % preferred recycling as the best management strategy (Nelumthika et al., 2018). Recycling of materials is now carried out in CMC through an irregular market system. Items are retrieved at several locations throughout the trash stream, including at the household level, during collection and transportation by local authority personnel, and at the final disposal site by garbage pickers and municipal workers. The collected components are sold to collecting companies, cleaned and sold to local industrialists for recycling, or are sent overseas. In addition, around 5 % of the garbage collected is treated in various homes and central composting systems (Liyanage et al., 2015).

Most research, however, indicates that almost all waste management techniques in Sri Lanka are inefficient and poor, particularly at the CMC, which is the most susceptible organisation confronting MSW generation, and must take preventative measures to reduce the potential threats produced by solid wastes. One way of doing this could be finding alternative solutions to use these MSW as secondary materials within the construction sector.

1.3. Reuse/Recycle Applications of MSW in Sri Lanka

Various governmental and non-governmental organizations in Sri Lanka, such as the Ministry of the Environment and the Central Environment Authority (CEA), focus on the concept of integrated waste management. The focal point of integrated solid waste management is waste reduction, resource recovery, reuse and recycling, biological treatment, incineration, and landfilling.

Paper, glass, and metal resource recycling have been practiced informally in Sri Lanka. Small traders and scavengers collect these items and sell them for recycling. Paper is recycled regardless of size. Paper mills use wastepaper in the production process, and handmade paper has become a trendy cottage industry. Glass recycling is the most successful recycling process in the country due to the safe market for recovered used glass. Ceylon Glass Company uses approximately 40 % recycled glass (cullet) in the glass manufacturing. Opportunities exist in both cases, but the main limitation is the lack of community support in collecting and bringing them to the centres. Areas where small door-to-door collectors of recyclable materials work well (Colombo suburbs) have some success in recycling glass, metal, and paper (Fernando, 2019).

Aerobic and anaerobic digestion are proven technologies practiced in the country for a while. Aerobic digestion of solid waste is more popular in the country due to its ease of operation (Forster-Carneiro et al., 2008). Among certain technical approaches in composting, a passively aerated open windrow system (large-scale method of composting organic waste) is feasible for Sri Lanka, because, apart from

the occasional heap rotation, it requires little active participation and can be used anywhere available. Typically, this is used for farms and municipalities. Therefore, converting some of MSW's organic waste into compost is an environmentally friendly method and an attractive economic alternative for agricultural countries like Sri Lanka. Currently, the government pays great attention to organic farming, and there is a high demand for compost and organic products in both local and export markets. The Sedawatte composting plant was designed to treat the organic waste generated by the municipality of Colombo, but it is difficult to control the amount of waste entering the system. The Ministry of Environment (through the "Pilisaru" project), CEA, Sevanatha, Arthacharya, and Practical Action are some of the pioneering agencies that have tried to promote domestic composting programs in the country (Dandeniya & Caucci, 2020).

The country has all the resources, materials, and expertise required for anaerobic digestion. According to Bandara (2011), several institutions can design and train people to use the types of digesters used for anaerobic digestion. Sevanatha, Energy Forum, and Practical Action are agencies that have implemented continuous types of digesters in areas such as Dickwella, Negambo, Karapitiya Hospital, Passyala, and Wattala. NERD has received an award and has the patent for its batch-type digester, which is in operation in several areas of the country, including Kiruloponne, Ja-ela, Anuradhapura, Kollonnawa, and the Vajira orphanage in Kotte. Biogas Energy aims to treat biodegradable waste in Sri Lanka's MSW with mature anaerobic digestion technology and achieve good energy production levels to meet the country's energy requirements.

Most municipal solid waste is combustible. Proper incineration is a better solution for MSW residues in Sri Lanka regarding greenhouse gas emissions, water pollution, soil contamination, and socio-economic concerns. However, due to the high capitalisation of imported incinerators, incineration is currently only used for clinical waste and is available in some government and private hospitals in the country.

The success of an integrated solid waste management program depends only on the attitudes and motivation of the community. No single management technique can be applied unless community members are willing to sort out waste material. It is unfortunate since, given the type of waste generated in Sri Lanka, a major portion can be easily treated at the household or municipal level if the people are willing.

2. RESEARCH METHODOLOGY

The methods of research are explained in this chapter. The study area, data collection, and data analysis are all included in this chapter. Out of the three methodologies – qualitative, quantitative, and mixed – the mixed method was used to conduct the research. A questionnaire survey was distributed to obtain the opinions of construction professionals and other industrialists in this particular subject area on whether the Sri Lankan government accurately follows the necessary practice of MSW management. Furthermore, a Likert scale was used in which respondents were asked to rate the degree of awareness and knowledge of

household waste in construction applications and the degree of potential benefits of incorporating household waste in construction. Each of the above questions was asked to be rated on a scale ranging from 1 to 5 (1 – strongly disagree; 2 – disagree; 3 – neutral; 4 – agree; 5 – strongly agree). To obtain the sources for the sample of literature review (LR), the flow diagram (see Fig. 3) was followed. To obtain the required literature, the Scopus database was used.

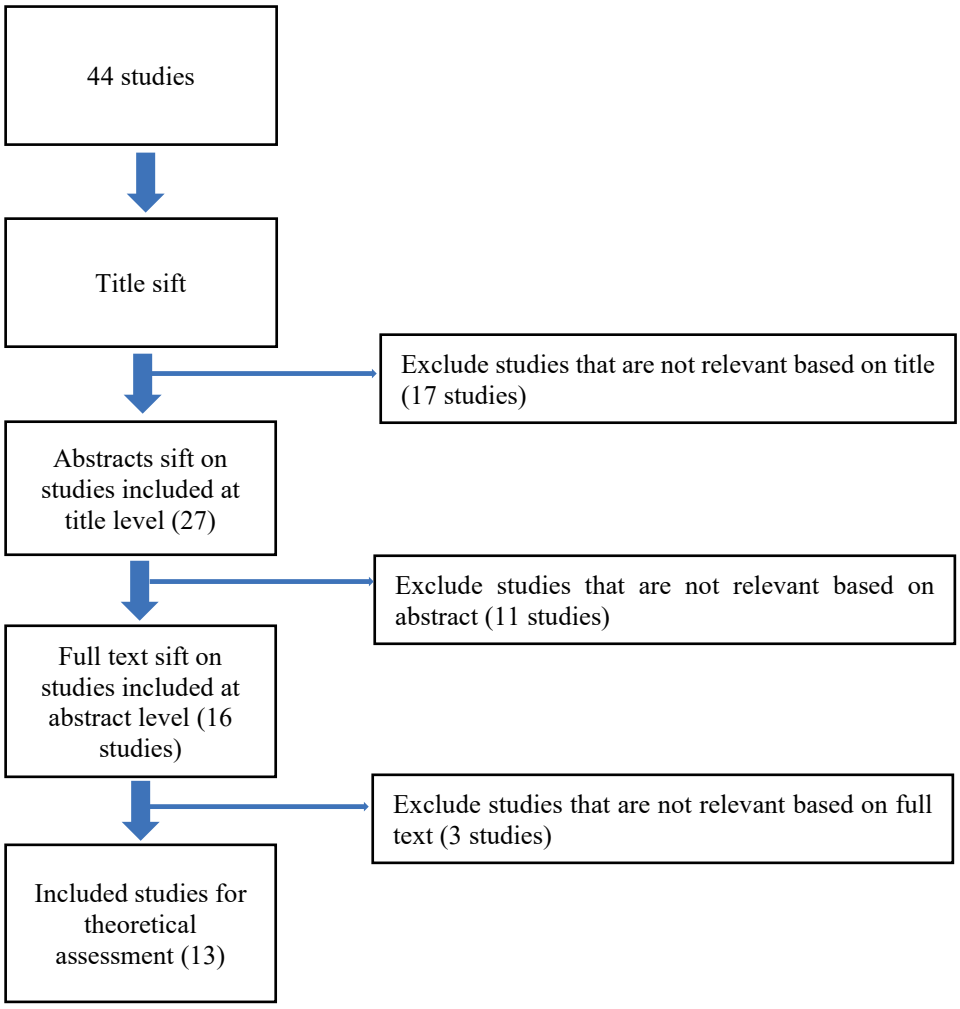

Fig. 3. The process of selecting papers for literature review (adapted from (Booth et al., 2012)).

The flowchart in Fig. 3 describes the methodical procedure used to collect the requisite literature research for the study focusing on household waste and secondary materials in the construction sector. The Scopus database was used, and keyword combinations included "domestic waste", "construction industry", "applications", and "secondary material." Initially, 113 results were obtained, and those articles were again filtered to obtain the most recent articles published within the last 5 years. Then 44 documents were obtained. After that 17 articles were

excluded considering the title of the article. Out of the remaining 27 articles, 11 were excluded considering the abstract, and finally, 3 articles were excluded referring to the full text. The goal was to identify relevant papers supporting the research, and 13 sources were chosen to conduct the study.

2.1. Study Area

According to the census details of the Registrar General of Sri Lanka, Sri Lanka has a population of 22.18 million. As mentioned in Table 1, the Colombo District had a population of approximately 1.8 million in 2012.

Table 1. The population of Colombo District (Department of Census & Statistics, 2012)

Council	Total
Colombo District	**1 806 035**
Colombo MC	561 314
Dehiwala-Mt. Laviniya MC	184 468
Moratuwa MC	168 280
Sri Jayawardanapura. Kotte MC	107 925
Kaduwela MC	252 041
Kolonnawa UC	60 044
Seethawakapura UC	30 308
Maharagama UC	196 423
Kesbewa UC	185 122
Boralasgamuwa UC	60 110

However, the total population of Colombo District counted in 2012 has increased due to high urbanisation and social expansion, and now the Colombo District has the highest population of 2 478 000 (2022) which has the potential to the generation of huge household waste (Department of Census & Statics, 2012).

As per the Colombo city profile, the total number of residential properties in the Colombo municipal area is 106 068. Therefore, the analysis of potential household waste focused on the Colombo Municipal Council area (see Fig. 4), Colombo district, Sri Lanka, as the case study area.

Understanding the local context is critical for effective waste-to-resource initiatives and the map (Fig. 4) provides a visual reference for the study's scope and area of examination. It also emphasizes the significance of localized research in tackling the global problem of environmentally friendly construction and waste reduction practices.

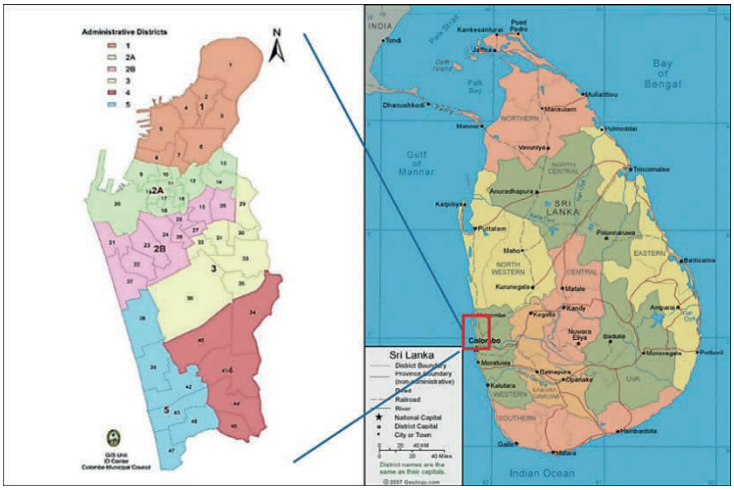

Fig. 4. Map of Sri Lanka and Colombo municipal area (Wickremasinghe & Kaluthanthri, 2021).

2.2. Data Analysis

The data was gathered through questionnaire surveys to identify and choose eligible household waste for recycling and use as secondary materials in the construction industry based on the perception of construction professionals in Sri Lanka. The data analysis was carried out using two distinct methodologies. To begin, all quantitative data acquired via an open-ended questionnaire were analysed using MS Excel software, and the findings were created in tables and visually to carry out the discussion portion of this chapter via the final result. Then, a thorough literature review was conducted by referring to books, journals, and other publications in order to find prospective uses for selected household wastes that may be employed in the construction industry.

3. RESULTS

3.1. Occupational Profile of the Respondents

This section presents the comprehensive analysis of data gathered from the diverse community of respondents who participated in the questionnaire survey representing various professional backgrounds in the construction field. Table 2 presents the respondents' occupational data distribution, demonstrating the sample's diversity and representation.

Table 2. Respondents' occupational profile (developed by authors)

Occupation	No. of respondents
Engineer	30
Project Manager	8
Architect	5
Quantity surveyor	5
Consultant	4
Site supervisor	4
Academia	4
Quality analyst	1
Total	**61**

This diversified representation across numerous professional occupations highlights the dataset's diversity and improves the credibility and applicability of the subsequent analysis.

According to Fig. 5, the respondents' industrial experience demonstrates a dynamic spectrum of construction-related tenure, providing a diversified viewpoint on the issue. A substantial majority of respondents, 39.3 %, said they had 1 to 5 years of construction industry experience. This group provides perspectives of individuals who are new to the field yet have already gained practical knowledge of the Sri Lankan construction industry.

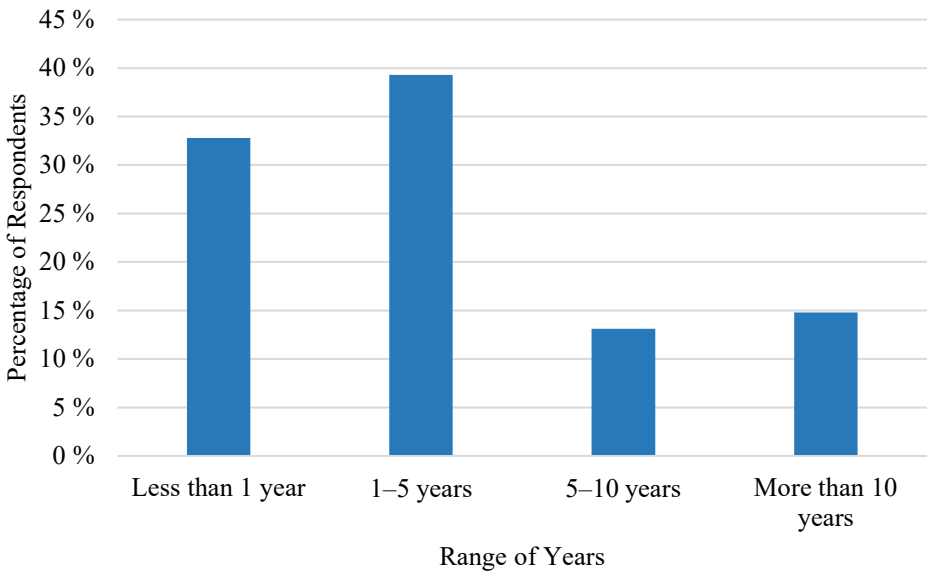

Fig. 5. Experience of respondents in the construction industry (developed by authors).

Furthermore, 32.8 % of respondents stated having less than one year of experience, indicating a group of people new to the industry. Their unique perspectives offer vital insights into the problems and possibilities encountered by individuals who have newly entered the construction industry. In contrast, 14.8 % of participants had considerable industry expertise, with more than ten years of experience. This experienced group provides an immense amount of information acquired from their years of participation in construction activities, perhaps providing light on long-term patterns and changes in the construction industry. Finally, 13.1 % of respondents had 5 to 10 years of experience, which added another layer of insight to the study. This set of individuals provides a unique combination of views acquired from their collective years in the construction industry.

Understanding respondents' experience profiles is critical when assessing what viewpoints and knowledge people offer to the construction industry. It contextualises the survey results and comments, allowing for a more thorough understanding of industry trends and challenges.

3.2. Sustainability of the Sri Lankan Construction Industry

The perspectives of the survey participants on the sustainability of the Sri Lankan construction industry, particularly on waste management procedures, give significant insights into the professional community's present views.

According to the survey results, 57.4 % of respondents consider the industry's sustainability regarding waste management procedures to be slightly sustainable. This conclusion implies that these experts are cautiously optimistic, noting that while there may be some beneficial waste management initiatives, there is room for improvement regarding stronger and more comprehensive environmentally friendly approaches. Furthermore, 24.6 % of participants believe waste management procedures implemented are at a moderate level. This viewpoint offers a more balanced evaluation, demonstrating that significant steps are being achieved towards environmentally friendly waste management procedures but with areas for additional growth and refinement.

Surprisingly, 18 % of respondents expressed a more negative viewpoint, claiming that the sector is not sustainable regarding waste management approaches. This emphasizes the urgent need to address current practices and correspond them with sustainable methods, such as appropriate waste disposal, proper waste segregation, and recycling. Furthermore, no participant believes that the industry is highly sustainable regarding waste management. Figure 6 illustrates respondents' views on the sustainability of the Sri Lankan construction industry.

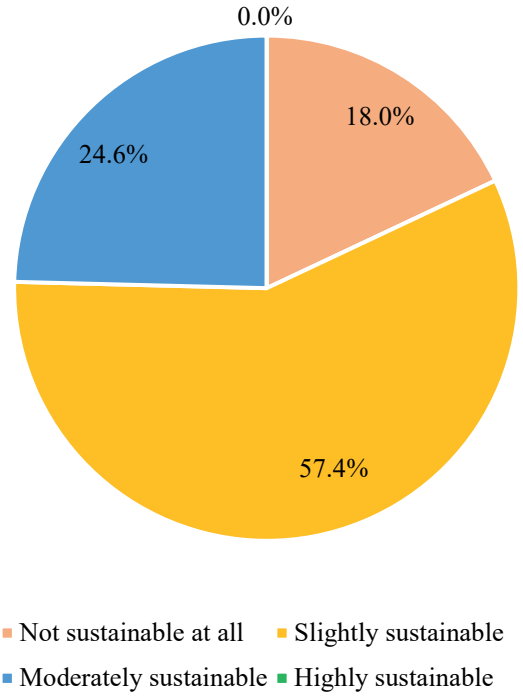

Fig. 6. Perspectives of respondents on the sustainability of Sri Lanka's construction industry (developed by authors).

The discussion on respondents' perspectives of stakeholders in waste management in Sri Lanka adhering to the municipal solid waste legislation framework gives useful insights into ensuring the compliance of practices with the regulatory framework.

According to Fig. 7, a substantial percentage of respondents, 52.5 %, stated that waste management stakeholders "sometimes" adhere to the municipal solid waste legislation framework. This indicates a mixed degree of compliance, in which certain attempts are made to align with the regulations, but adherence may not be constant in some cases. Surprisingly, 34.4 % of participants stated that stakeholders "rarely" follow the statutory framework. According to this viewpoint, there is a significant gap between regulations and actual waste management approaches. This conclusion emphasizes the necessity of removing impediments that prevent the framework from being implemented consistently and effectively. A smaller proportion of respondents (8.2 %) stated that stakeholders "often" adhere to the municipal solid waste legislation framework. This positive approach implies that there are occasions where stakeholders display a proactive commitment to complying with regulatory obligations, indicating possible areas for improvement and efficient procedures that can be expanded further. Notably, 4.9 % of respondents stated that stakeholders "never" adhere to the framework. This point of view indicates a disturbing lack of adherence to existing laws and emphasizes the

importance of resolving gaps in comprehension, enforcement, and accountability. No participants stated that the appropriate authorities "always" adhere to the waste management legislation framework.

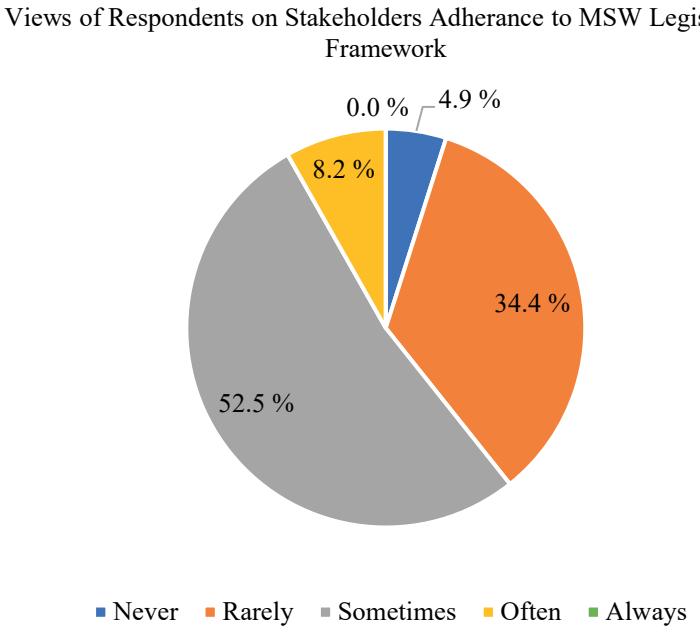

Fig. 7. Stakeholders' participation in MSW legislative framework (developed by authors).

Understanding the degree of participation of various stakeholders is critical for developing efficient waste management procedures and regulations. It emphasizes the collaborative efforts necessary to establish long-term solutions to MSW concerns and the necessity of participatory decision-making procedures within the legal framework. There is room for improvement in encouraging key stakeholders in the sector to be active participants in the industry's long-term sustainable development.

3.3. Awareness and Knowledge of Household Wastes in the Construction Industry

The construction industry is critical to developing cutting-edge infrastructure and urban development. Within this industry, there has been an increasing emphasis on sustainability and environmental responsibility in recent years. Raising awareness and improving comprehension of the proper handling of waste from homes, and investing in the possibility to use them during construction activities is a vital component of this sustainability initiative. To properly execute the introduction of municipal solid waste into the construction industry as a secondary material, the perception and willingness to accept among the industry professionals

play a significant role. The bar chart illustrated in Fig. 8 shows the awareness and knowledge of respondents on using domestic waste in the construction industry.

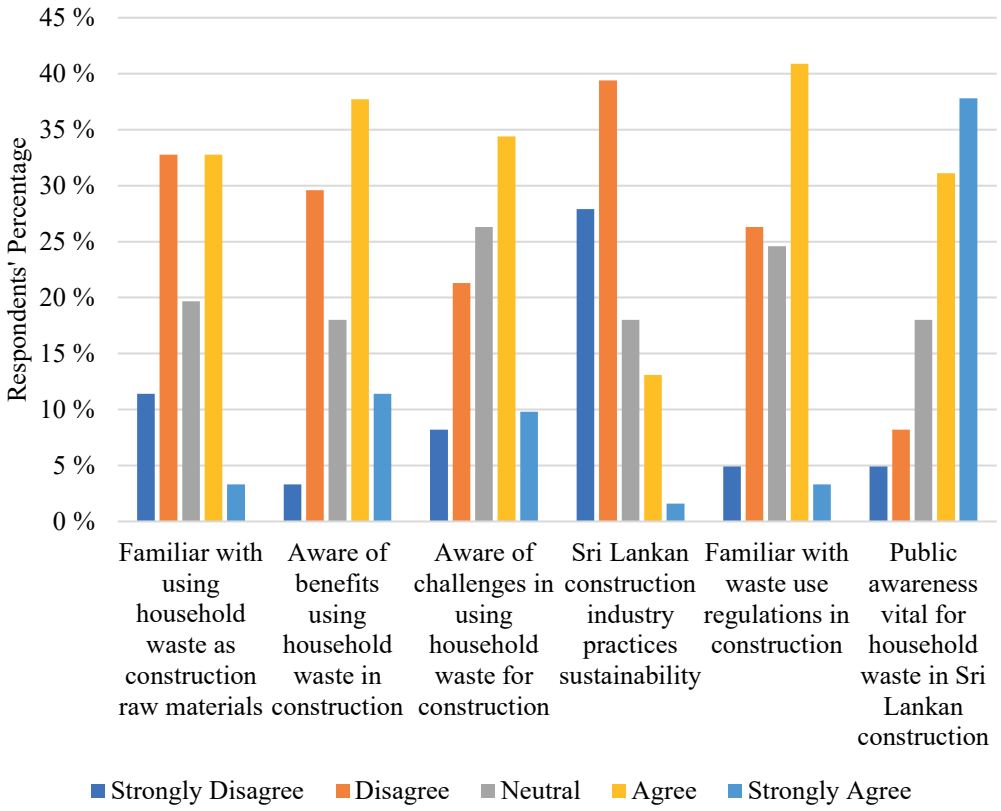

Fig. 8. Respondents' awareness and knowledge of domestic waste in construction (developed by authors).

As shown in Fig. 8, an equal percentage of respondents (32.8 %) agree and disagree with the concept of using household waste as secondary raw materials in construction activities. This indicates that there is a need for awareness and knowledge sharing among industry stakeholders on the possible applications of MSW in construction operations. Furthermore, only 3.3 % strongly agree that they are fully aware of the MSW applications in the construction industry. However, it is worth noticing that 37.7 % agree on the potential benefits of incorporating MSW in the construction industry, and 29.6 % indicated that they were unaware of the potential advantages. Furthermore, 18 % were doubtful whether this could benefit the industry. While 34.4 % of the population stated that they were aware of the barriers that hinder the introduction of MSW into construction, 21.3 % stressed that they were unaware, and 8.2 % had no idea about the possible challenges.

Furthermore, the majority of respondents (39.4 %) disagree with the statement that the Sri Lankan construction industry follows international and local sustainable guidelines. This was supported by another 27.9 % of the population strongly disagreeing with the above statement. This indicates that immediate actions are

needed within the industry to transform towards an environmentally healthy sector. It is worth noticing that 40.9 % of participants stressed that they know the existing regulations and guidelines for using MSW in construction activities. Though industry professionals are unaware of the possible advantages and challenges of incorporating MSW in the construction industry, they have knowledge of sustainable guidelines and legislative frameworks, which is a positive indicator. Yet, 26.3 % stated that they are lacking in knowledge about the existing regulations and guidelines. In order to implement this operation, the majority of respondents (37.8%) strongly agree that public awareness and education programs are important for the promotion of the use of household waste in the construction industry of Sri Lanka.

The use of MSW in the construction industry may provide several major advantages, contributing to both environmental sustainability and economic efficiency. 45.9 % of respondents believe that utilising household waste in construction is a prime solution for natural resource depletion, and 32.8 % of respondents supported the statement by stressing it could be moderately beneficial. While 44.3 % of respondents argued that using MSW as a secondary material could reduce landfill usage and other associated environmental threats, 29.5 % believe it is highly beneficial for the industry. It is worth noticing that half of the population stressed that using MSW waste in construction can lead to cost savings compared to traditional construction materials, and utilising municipal solid waste as construction materials can encourage better waste management practices as moderately advantageous to the industry. For every nation, one of the mandatory targets given by the United Nations (UN) is to achieve the sustainable development goals (SDG) stipulated by the organisation. 42.6 % of survey participants stated that introducing household waste into construction activities could help Sri Lanka achieve sustainable development goals 11, 12 and 13. Only less than 10 % of industry professionals believe that none of the above statements are beneficial. This could be due to the lack of awareness and knowledge on the applications of MSW in construction and the regulations and policies connected to it. Figure 9 illustrates respondents' views on the benefits that could be achieved by using MSW in construction operations as a secondary resource.

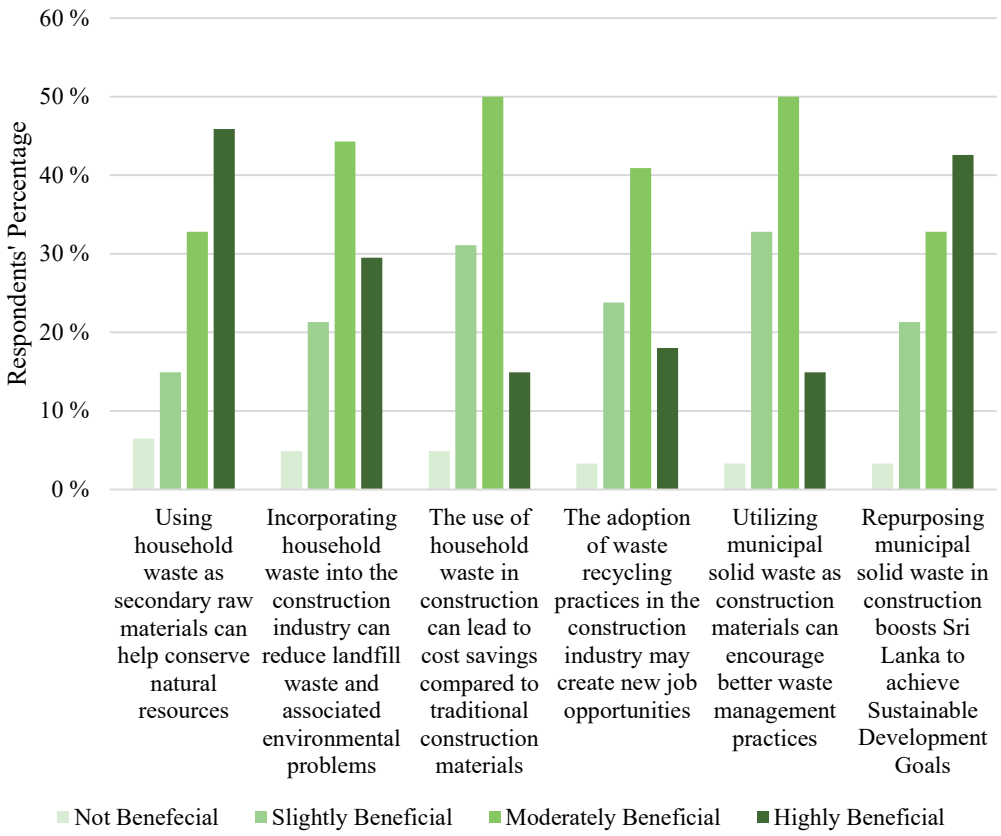

Fig. 9. Perception of respondents on the benefits that could be achieved by using MSW in construction (developed by authors).

3.4. Applications of MSW in the Construction Industry

Household waste, often known as domestic waste, is a type of MSW that consists mostly of disposable items produced by households. Every year, the world creates 2.01 billion tonnes of MSW, with at least 33 % not being managed in an ecologically sustainable manner (Wong et al., 2022). MSW is mostly derived from residential waste, with 80 % of recyclable waste ending in landfills (Razali et al., 2020). As a result, the survey recorded industry specialists' perspectives on the potential MSW that may be recycled and reused in the construction industry.

Most construction professionals (86.9 %) who participated in the survey stressed that disposed wood could be used as an alternative material in construction activities. Furthermore, waste metal is also regarded as a secondary resource to the construction industry by 80.3 % of respondents. Cardboard also gained interest from 78.7 % of respondents. An equal proportion (77.1 %) stated that paper and plastic are also applicable to reuse as secondary materials in construction activities. 55.7 % believed that waste glass has some sort of potential to be repurposed in several construction activities. Almost half of the survey participants (52.5 %) argued that electronic (e-waste) and organic waste could be an ideal resource to be reused in construction while 47.5 % believed it is not. The majority of the

respondents (50.8 %) stated that textile waste has no potential to be reused in the Sri Lankan construction industry. Table 3 shows respondents' opinions on the materials that might be used as secondary resources in the construction sector.

Table 3. Applicability of several MSWs (developed by authors)

Household waste	Not Applicable	Applicable
Plastic	22.9 %	77.1 %
Metal	19.7 %	80.3 %
Glass	44.3 %	55.7 %
Paper	22.9 %	77.1 %
Cardboard	21.3 %	78.7 %
Textile waste	50.8 %	49.2 %
Electronic (e-waste)	47.5 %	52.5 %
Organic waste	47.5 %	52.5 %
Wood	13.1 %	86.9 %

Figure 10 depicts respondents' perspectives on types of waste that could potentially be applied as secondary material in the construction industry of Sri Lanka.

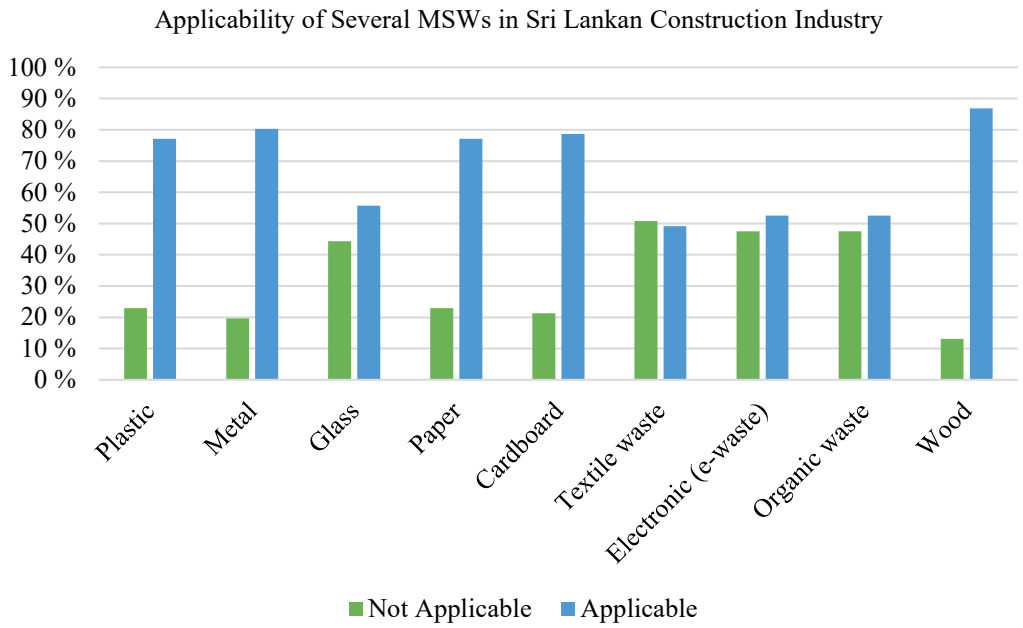

Fig. 10. Respondents' perception of the applicability of several domestic waste types (developed by authors).

It is evident that there is a potential for the above-selected domestic wastes to be reused as secondary materials in the Sri Lankan construction industry. Furthermore, these wastes can be divided into two groups: non-hazardous wastes (paper, glass, plastic, etc.) and hazardous wastes (batteries, house cleaners, metal, etc.). Table 4 provides a detailed analysis of how these non-hazardous wastes may be repurposed and the potential achievements that could be gained in the construction industry.

Table 4. Types of non-hazardous wastes and their applications in construction (developed by authors)

Waste category	Application	Achievements	Source
Plastic	Plastic waste, such as polyethylene terephthalate (PET), can be utilized in asphalt modification	Enhance the aging resistance, resilience modulus, and adhesiveness of asphalt binders or mixes, and lower the cost	(Wong et al., 2022)
	Used as an architectural component such as non-load bearing facade components	Reduce the structural weight of the building	(Pons & Abt, 2020)
	Can be used in the production of bricks, tiles, concrete, and roads as a binder, aggregate, fine aggregate, modifier, or substitute for cement and sand	Reduces the use of mined construction materials and the use of landfill	(Lamba et., 2021)
Glass	Use glass waste in the bituminous mixture	The asphalt's stiffness modulus is increased, as is its resistance to permanent deformation.	(Wong et al., 2022)
	Glass powder can be used in cement production	Better compressive and tensile strengths in concrete	(Fahad et al., 2021)
	Can be used as a supplementary building material	Increase mechanical properties	(Neri et al., 2021a)
Paper	Use in concrete production as an additive	Increase the concrete strength	(Solahuddin, 2022)
	Use as a fiber in cement-based building materials	Improve bond strength between fibers and matrix	(Hospodarova et al., 2018)
	Use shredded wastepaper as an additive	Increase the concrete slump and split the tensile strength	(Solahuddin & Yahaya, 2022)
Cardboard	Can be used to construct insulating panels	Enhance acoustic performance, transportability and reduce cost	(Neri et al., 2021a)
Textile waste	Can be used as an alternative material in enhancing indoor thermal insulation	Reduce temperature inside the building and decrease heat flux	(Neri et al., 2021b)
Wood	Used to produce wood-bio-concrete (WBC)	Climate change mitigation and CO_2 emission reduction	(Caldas et al., 2021)
	Produce noise and thermal insulating cement-bonded particleboards	Enhance economic viability in buildings. Improve thermal and acoustic comfort	(Wang et al., 2016)

Table 5 presents an in-depth review of how hazardous wastes can be reused and the potential gains in the construction industry.

Table 5. Types of hazardous wastes and their applications in construction (developed by authors)

Waste category	Application	Achievements	Source
Metal	Enhance acoustic performance	Increase life expectancy and resistance to moisture	(Neri et al., 2021b)
	Use instead of limestone in self-compact concrete production. Can be used as a fluxing agent or aggregate in the road and hydraulic construction	Reduce costs and save energy in construction	(Fahad et al., 2021)
Electronic (e-waste)	As asphalt binder modifiers, e-waste such as acrylonitrile butadiene styrene (ABS) and high impact polystyrene (HIPS) can be employed	Improve the stiffness and elasticity of the modified binder. Improved low and high-temperature performance, and greater creep stiffness	(Wong et al., 2022)
Organic waste	Produce biodiesel to use in construction machinery	Significantly reduces emissions and fuel costs	(Santana et al., 2021)
	Use sewage sludge (SS) in concrete mixtures	Improve the workability and cohesiveness of the fresh concrete mixture. Furthermore, the mineral content of the sludge can operate as an additional supply of cementitious material, thereby increasing the strength and longevity of the concrete	(Vilakazi et al., 2022)
	Use pulverised eggshells as a raw material for cement clinker production	Reduce the harvest of limestone for cement production. Reduce landfill waste	(Her et al., 2022)
	Use waste cooking oil (WCO) in bio-asphalt as a binder replacement	A suitable inclusion of WCO of less than 5 % was found to improve the physical and rheological characteristics of the binder in terms of penetration, softening point, elasticity, and viscosity.	(Wong et al., 2022)

3.5. Barriers and Enablers to Utilize MSW as an Alternative Resource

The study findings outline several barriers to sustainable waste management and using MSW as a secondary material in the construction industry. Lack of understanding and expertise about the circular economy is cited as a major impediment by 88.5 % of respondents. Furthermore, 70.5 % feel that the lack of active participation from relevant authorities, such as government entities and construction firms, impedes progress toward sustainable waste management. Most responders (59 %) cite insufficient waste segregation techniques, highlighting the critical need for improved waste management systems. Inadequate waste segregation not only impedes recycling efforts but also raises disposal expenses. Another 59 % stressed that the construction industry's traditional practices often resist change due to concerns about cost, time, and unfamiliarity with new approaches. According to 57.4 % of the respondents, the lack of specialized research in sustainable waste management and circular economy methods for the construction sector hinders innovation and advancement. Universities and research institutions should work with industry to perform studies on effective waste management systems, resource recovery technologies, and life cycle evaluations of building materials. Furthermore, 44.3 % responded that inadequate recycling facilities are a key obstacle for the sector not to upcycle its products, which can greatly cut imports. Only 39.3 % believe that insufficient infrastructure and innovative technology for waste separation, recycling, and reuse might hinder progress towards sustainable waste management. Figure 11 illustrates the views of construction professionals on the barriers that hinder the use of MSW in construction activities.

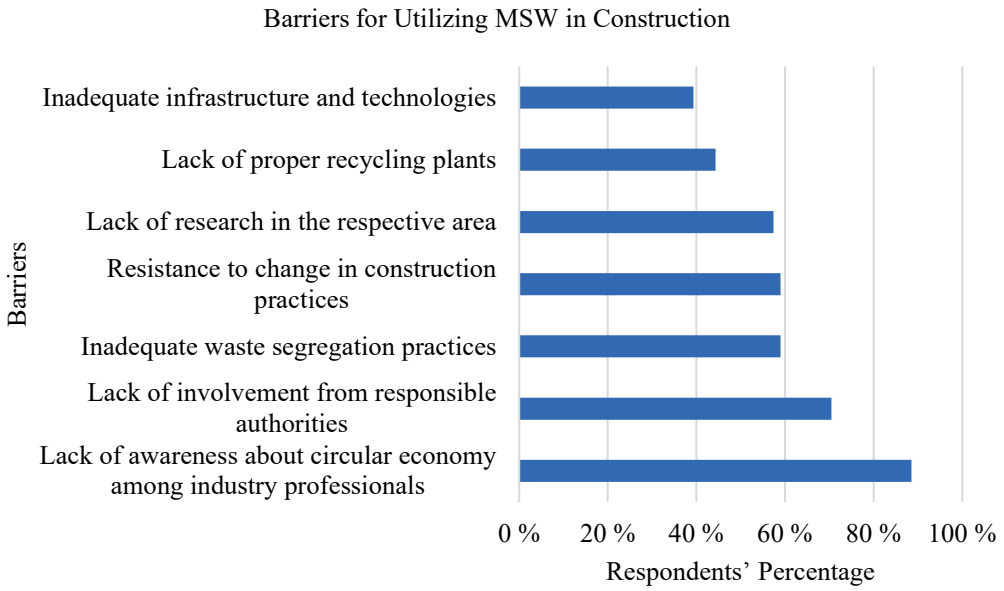

Fig. 11. Barriers for utilizing MSW in construction (developed by authors).

The increasing focus on sustainability and efficient use of resources has sparked interest in the construction industry in using MSW materials. As shown in Fig. 12, the study's findings highlighted the critical importance of various strategies and opportunities in encouraging the incorporation of household waste into construction procedures. The strong support (88.5 %) for educational initiatives and training campaigns emphasizes the need to address the knowledge gap regarding the use of household waste in construction. The large majority (78.7 %) supporting government incentives emphasizes the crucial significance of policy interventions in fostering long-term transformation. Governments may play a critical role in encouraging construction firms to employ local waste materials by providing tax breaks, grants, or subsidies for projects that use such materials. Financial incentives are required, according to 65.6 % of respondents. Governments may stimulate research on creative applications of waste from homes in construction by providing grants and financing possibilities. Furthermore, 57.4 % believe that leveraging modern technologies is an important approach. Modern technologies, such as automatic waste sorting systems and AI-driven waste characterization, can improve waste processing efficiency and reliability. The use of MSW-derived products as a prerequisite for green building certification (55.7 %) demonstrates a movement toward acknowledging the environmental benefits of such actions. Incorporating household waste materials into buildings can help to minimize the demand for virgin resources, landfill waste, and carbon emissions.

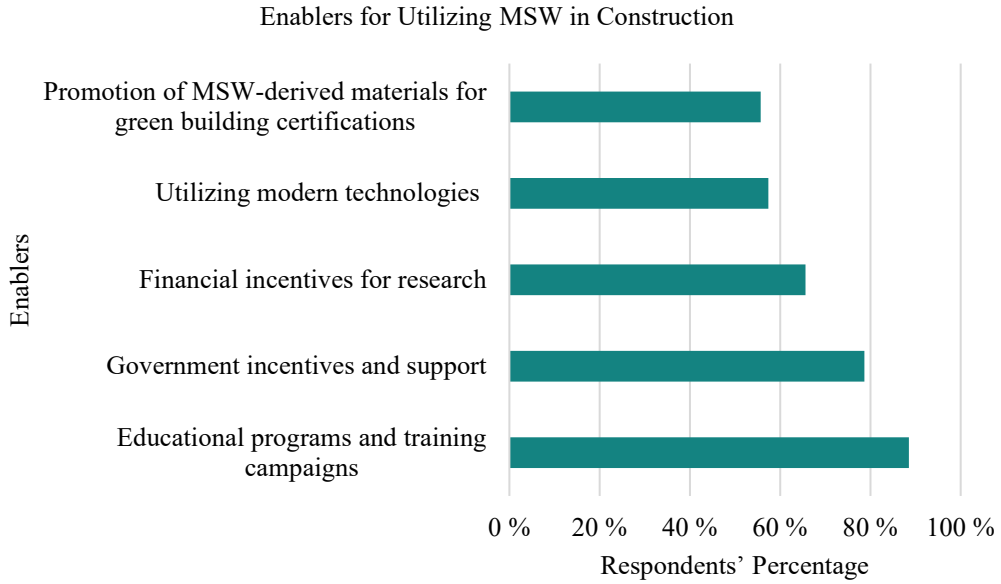

Fig. 12. Enablers for utilising MSW in construction (developed by authors).

Understanding these enablers is critical for stakeholders such as engineers, building owners, contractors, consultants, architects and designers, environmental and waste management specialists, and policymakers as they seek to promote

sustainable waste-to-resource strategies. By tackling these issues, the construction industry of Sri Lanka may realise MSW's full potential as a useful resource in construction, opening the path for more environmentally friendly and economically feasible construction methods.

4. DISCUSSION

The findings presented in this section offer valuable insights into the perspectives of professionals of Sri Lankan construction industry professionals on the sustainability of waste management procedures and the potential use of household waste as secondary materials in construction activities. The wide occupational profile of respondents, as shown in Table 2, demonstrates a comprehensive representation of various responsibilities within the sector, boosting the reliability and usefulness of the following study.

The assessment of the sustainability of the Sri Lankan construction industry, particularly concerning waste management procedures, offers a comprehensive view of the current opinions of participants. The survey results, as depicted in Fig. 6, suggest that a significant portion of respondents (57.4 %) perceive the industry's sustainability in terms of waste management procedures to be slightly sustainable. This cautious optimism underscores the need for further improvements in adopting environmentally friendly approaches. The fact that 18 % of respondents disagree that the sector is not sustainable at all highlights the urgency of addressing current waste management practices. This aligns with previous research emphasizing the importance of transitioning to more sustainable waste management strategies to mitigate environmental impacts (Elshaboury et al., 2022).

Furthermore, the insights into stakeholders' adherence to the municipal solid waste legislation framework, as illustrated in Fig. 7, highlight the complex landscape of regulatory compliance in waste management. The varying degrees of adherence reported by respondents (ranging from "sometimes" to "never") underline the need for consistent enforcement and the removal of obstacles hindering effective implementation. This finding aligns with studies that emphasize the importance of regulatory enforcement to ensure sustainable waste management practices (Kofoworola & Gheewala, 2009).

The discussion on the awareness and knowledge of household waste in the construction industry highlights the potential of incorporating MSW as secondary materials in construction activities. The balanced distribution of responses on the usage of domestic waste in construction suggests that additional knowledge dissemination within the sector is required. Most respondents stated that they were unaware of the possible advantages and problems related to MSW in construction, highlighting the importance of educational activities. This conclusion is consistent with prior research that has emphasized the importance of awareness and education in influencing the adoption of sustainable behaviors (Ritzén & Sandström, 2017).

The potential applications of MSW in the construction industry, as outlined in Tables 4 and 5, suggest that various types of waste materials can be repurposed as secondary resources, contributing to environmental sustainability and economic

efficiency. For instance, the utilization of plastic waste as a binder in construction materials or using organic waste to produce biodiesel for construction machinery exemplifies innovative approaches that align with circular economy principles. These findings resonate with studies that highlight the potential of waste materials to enhance the properties of construction materials (Lamba et al., 2021; Liang et al., 2022).

However, the survey also identifies barriers to utilizing MSW as an alternative resource. The lack of understanding of the circular economy, insufficient waste segregation techniques, and resistance to change within traditional construction practices are among the significant challenges reported by respondents. These barriers emphasize the need for capacity building, regulatory support, and technological advancements to overcome obstacles and drive sustainable waste management practices within the industry (Weerakoon et al., 2023).

Regarding enablers, respondents overwhelmingly support educational initiatives, government incentives, financial incentives, and the use of modern technologies to facilitate the incorporation of household waste into construction activities. This aligns with existing research that underscores the importance of policy interventions, technological advancements, and stakeholder education in promoting sustainable practices (Smith et al., 2020; Madhkali & Sithole, 2023).

Overall, the findings stated in this article illustrate the enormous potential and significant issues surrounding the use of household waste in Sri Lanka's construction industry.

CONCLUSIONS

This study focused on the key issue of utilizing household waste as secondary raw materials in the construction industry of Sri Lanka. The research focused on the significant potential for recycling domestic waste into valuable resources for building applications by conducting an exhaustive review of the literature and gathering the viewpoints of construction experts from diverse backgrounds.

The findings highlight the need for a paradigm change in waste management procedures, focusing on transitioning from traditional disposal methods to environmentally friendly resource management solutions. This approach provides many benefits to the construction sector such as reducing shortages of resources, decreasing environmental impact, and developing a circular economy mindset among industrialists. Furthermore, this study adds to the current body of knowledge by providing empirical insights into the practicality and constraints of using domestic waste-derived materials in construction procedures, particularly in the Sri Lankan setting.

As the globe grapples with the need for sustainable development, this study serves as a light of innovation, inviting stakeholders, politicians, and industry practitioners to pave a path toward a more regenerative and environmentally conscious construction industry.

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