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Experts' Perceptions of the Management and Minimisation of Waste in the Australian Construction Industry

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Abstract: Effective waste management has become a crucial factor in Australia because, from 1996 to 2015, the population increased by 28%, while Australia's annual waste increased by 170%. In the period 2018–2019, Australia generated 27 Mt of construction demolition waste (44% of all waste). Although 76% of this waste is recycled, there has been a 61% increase in the rate of waste since 2006–2007. Therefore, minimising waste and prioritising waste management are necessary to build a circular economy. This study aims to identify the current waste minimisation perceptions in the Australian construction industry. A semi-structured interview was conducted with 50 industry experts focusing on four sectors (design/planning, building information modelling (BIM), material logistics, and prefabrication). The data were analysed qualitatively and quantitatively (Severity index). The result disclosed that the designers are the first contributor to waste minimisation, followed by the material suppliers/manufacturers. It is revealed that subjective attitude and the personal reluctance to exercise waste mitigation strategies are crucial. The outcome also indicated that BIM has the potential to minimise waste significantly. Overall, 15 key points were highlighted to consider for waste minimisation, and a conceptual framework was proposed. Therefore, identifying waste management's current practices and the responsibility of industry personnel will help minimise waste and bring sustainable development.

Keywords: construction waste; waste minimisation; waste management; prefabrication; BIM

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1. Introduction

The construction industry is undoubtedly an important economic sector, contributing to the GDP (Gross Domestic Product) of both developed and developing country economies. However, this sector has an enormous environmental impact as it consumes substantial natural resources and energy, releases pollutants and greenhouse gases, and generates massive waste [1–3]. Each year, the construction industry contributes to the most significant waste stream, nearly 30% to 40% of total solid waste generated globally [4]. The increased global urbanisation trend also corresponds to the increasing construction waste generated. According to the statistics from the World Bank, the world's major cities contributed 2.01 billion metric tonnes of solid waste in 2016, with a forecast of a 70% increase of 3.40 billion metric tonnes to landfills by 2050 [5]. Australia has experienced a construction boom for the last two decades, with over half a million homes built across the country according to the Housing Industry Association, which is a AUD 2.8 billion investment annually [6]. While the ongoing considerable construction growth in housing may be a boon for Australia's economy, the wave has downsides for the environment. According to the 2018 National Waste Policy report [7], 27 Mt of waste is produced by the construction and demolition industries in Australia. That is nearly a half of all waste produced in the country. The amount of waste produced by the construction and demolition industries increased by 61% from 2006 to 2017 [7]. Nationally, 76% of construction waste is eventually recycled [7]. Furthermore, some states of Australia achieved better waste management; for instance, in the 2018–2019 financial year, Victoria and South Australia achieved 87%

and 91.4% construction demolition waste recycling, respectively [8,9]. However, 6.7 million tonnes of waste still end up in landfills yearly [7]. In this regard, construction waste management and waste generation reduction are significant needs. This can be achieved in many ways, including practicing waste minimisation design concepts, redirecting waste to be reused or recycled (with the help of on-site waste segregation), maximising the potential of prefabrication, using new tools and technology to monitor waste generation and applying a landfill levy [10]. To tackle construction waste issues, many have proposed and adopted the concept of reducing, reusing, and recycling generated waste. Several studies have been found to reduce, reuse, and recycle construction waste in various applications to achieve a circular economy—for example, modification of construction waste through the nano-silica soaking method, the fibre reinforcement method, and carbonation [11–15]. However, to minimise wastage, the first step is to understand the root causes of waste generation and how they can be reduced and minimised in the planning stage of construction [16].

1.1. Pre-Construction or Design Stage

The literature shows that design decisions impact the highest percentages of construction waste generated of a construction project [17–20], and approximately one-third of construction waste directly results from design decisions [21]. However, the construction industry's most common waste management practices mainly focus on issues relating to physical construction waste and recycling guides, where waste is already generated [22]. Many factors and reasons at the pre-construction and design stage result in construction waste. One reason is the lack of waste management plans and practices in the design process. This is due to a lack of interest from clients, knowledge and attitude towards waste minimisation and available training [23]. 'Designing out' waste is a viable approach that can significantly minimise the amount of waste generated during the construction process [24]. It emphasises the 'reduce' aspect of the waste hierarchy (reduce, reuse, recycle) by fully taking into account the details of the project that will impact the production of waste right from the beginning and allowing the designer to explore ways to minimise it [25]. As the construction industry continues to expand, it is worth proactively considering the long-term benefits of using waste minimisation design as a sustainable method to manage waste at its source [26]. According to Esa et al. [21], architects and designers greatly influence reducing waste on any construction phase level if they intentionally design out waste. Many works in the literature suggest that the leading cause of construction waste generation is design changes during the construction process [17–20]. The primary sources of these changes are due to last-minute client requirements, design complexity, criteria changes, design deficiencies, lack of design information, unforeseen ground and site conditions, designer's lack of experience in evaluating construction methods and the sequence of construction operation [27–29]. Lack of knowledge about construction techniques at the design stage and poor material management practices also contribute to significant construction waste [30]. Further, other studies show that approximately one-third of the waste generated during construction can be traced back to poor design and the designers' lack of economic consciousness when choosing materials [31]. This can be attributed to the architect's reluctance to deviate from conventional design methodologies, the limited amount of relevant standards for re-purposed materials, and the lack of knowledge in applying sustainable practices in their design [32,33]. Based on the literature, the key challenges for waste minimisation during the design and pre-construction stage that Australian construction industries face were explored in this study.

1.2. Prefabrication

Prefabrication is considered an effective method in the construction industry [34,35]. It involves producing housing or housing components using factory mechanisation processes [36,37]. These manufactured components are commonly used in construction for areas such as façades, staircases, steel structural frames, external cladding, washrooms and drywall systems [38]. There are numerous benefits to using prefabrication over conventional construction methods. Waste minimisation is the most crucial benefit, and it is predicted that waste generation can be reduced by up to 100% [38]. Concrete waste is reduced by 2% (in weight) using prefabrication over on-site construction [39]. Jaillon et al. [40] reported that using prefabricated components could minimise approximately 84.7% of construction waste. Approximately 87% of waste generation in timber formworks can be avoided using prefabricated components [41]. The prefabricated construction method can also reduce labour costs and overall construction costs [42]. On-site construction time is also reduced as prefabricated parts are ready to be installed [39]. However, the construction industry's prefabrication method is still not encouraged enough, and application in the private sector is even more challenging due to their unique designs [39]. The deterrents for stakeholders concern a lack of guidance and experience in the prefabrication process. Currently, the unknowns of prefabrication are due to their not being a large enough sample size and sufficient data to analyse. There is a need for a more established market with greater competition to grow this industry successfully [34]. Cost is always the most crucial aspect to stakeholders, and cost-saving must be evident when using prefabrication to make it successful [39]. The initial cost of prefabrication is high. Companies hesitate to invest unless there is a stable demand or are aware of the potential economic benefits later in the construction process [43]. In Australia, in the approximately AUD 150 billion construction industry, prefabrication only contributes 3–5% [44,45]. Some interview questions were designed on this topic to reveal the constraints of using prefabricated elements in the Australian construction industry.

1.3. Material Procurement and Logistics

Management of a construction project is highly challenging because it is a complex task that requires time, cost, safety, and quality issues. Material logistics are the plans to ensure the efficient flow of materials from suppliers or manufacturers to construction sites [46]. The contractors usually do these plans to manage their work efficiently [46]. Appropriate material logistics and planning can reduce construction waste significantly by resolving problems associated with project scheduling, construction work, material inventory, time management, transportation, and material handling cost [47]. Previous results in the literature highlighted that low waste commitment from material suppliers, purchase management and delivery of the accurate bill of quantity plays a significant role in construction waste mitigation [47]. In Australia, procurement ordering and take-off errors are considered among the top five reasons for construction waste generation [48]. Therefore, material procurement and logistics are significant sectors to explore for construction waste minimisation highlighted in this study.

1.4. Building Information Modelling (BIM)

Over the past two decades, extensive research has been conducted on the effectiveness of construction waste management (CWM) tools and methods, such as implementing BIM in construction projects. Throughout the years, BIM practice has matured due to its ability to reduce cost and time and improve material logistics as well as productivity [49]. In general, BIM is a modelling technology that produces, communicates, and analyses building models [50]. BIM can improve and enhance communication and collaboration. Thus, increasing efficiency reduces errors, resulting in the reduction in resources, energy, materials and waste [51,52], which is why BIM has the potential to aid waste minimisation and prevention at the pre-construction stage. BIM-based validation is a process that can be used to reduce design errors, change orders, and rework in the planning, design, pre-construction, and construction stages because it can detect clashes through design review virtually at the design stage [53–55]. Research conducted by Won et al. [56] claimed that implementing BIM-based design validation can reduce 4.3–15.2% of construction waste generation. However, despite the benefits of BIM in improving building process performance, the implementation of BIM-aided tools and methods in CWM is still insufficient because there is a lack of BIM-compatible CWM tools in the industry [57,58]. In Australia, the government has emphasised the application of BIM in construction propjets since 2011. However, most construction industry is applying BIM in its basic form instead of the more complex and integrated form [59,60].

1.5. Circular Economy (CE)

CE is an economic model that aims to minimise raw material input, waste generation, emission, and energy by promoting the circularity of the material through 3R principles (reduction, reuse, and recycling) [61–63]. It is a regenerative system in which resource input, waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops [61,62,64]. This process can be achieved through waste minimisation in the design stage, prevention, reduction, maintenance, repair, reuse, and recycling [61,62]. The main principles of a circular economy are avoiding waste generation, improving resource recovery, increasing the use of recycled materials, better managing material flow for the benefit of the environment, economy, and society, and supporting innovations. For sustainable development, balanced integration of economic performance, social inclusiveness, and environmental resilience is crucial to the benefit of current and future generations [65,66]. As the construction industry is responsible for enormous waste generation, implementing CE for construction demolition waste is beneficial because most waste is reusable or recyclable.

Therefore, a gap exists in identifying the prime obstructions to waste minimisation in the Australian construction industry in the context of workplace waste management practices, material logistics, BIM application, and prefabrication. This study aims to identify the opinion of construction industry experts on waste minimisation perceptions focusing on the four crucial steps of workplace waste management practices. These are minimising waste during project design and planning using BIM, waste minimisation during material procurement and logistics, and last but not least, waste minimisation through prefabrication or modular construction. The outcome of this study will be helpful for waste minimisation, improving current waste management practices, and developing a circular economy to bring sustainable development. A semi-structured interview was conducted with industry experts to achieve the research aim. Their opinions are analysed to identify the crucial contributors to waste generation in the Australian construction industry.

2. Research Methodology

This research aims to identify the current waste minimisation practices and the experts' perceptions of managing and minimising waste in the Australian Construction industry. A semi-structured interview focused on four major categories of workplace waste management practices: project design and planning; application of building information modelling (BIM); material procurement and logistics; and prefabrication or modular construction.

The process of developing the interview questions was as follows (Appendix A):

a. According to the literature review, architects and project planners significantly impact the minimisation of construction waste due to how they convey their knowledge, consciousness, and behaviour towards applying sustainable materials and design principles in their projects. Hence, a section of the interview questions targeted construction designers and planners to assess their involvement in Australia's current waste management practices.
b. The utilisation of BIM can improve the performance of a project; thus, the participants were asked whether they incorporate BIM to assist with material estimation and procurement processes. The BIM section of the interview aimed to understand how the Australian construction industry implements BIM in their project and how they utilise it in waste management and reduction. The participants were asked whether there were any current estimation tools or programs at their workplace.
c. The material procurement and logistics section of the interview covers issues regarding estimation tools and programs in use in the Australian engineering workplace. Use of sustainable and environmentally friendly materials for projects during ma-

terials procurement, availability of sustainable/recycled products in the Australian engineering and construction industry, the utilisation of BIM to assist material estimation and procurement process, and stages during material procurement and logistics that produce the most waste.

d. Interviewees were asked about applying the prefabrication method in waste minimisation, and a set of interview questions were prepared based on prefabrication or modular construction.

According to the above literature review, 20 questions for every four categories were prepared. Researchers and experts from the construction industry reviewed the interview questions to validate the content and gather qualitative and quantitative data. Equation (1) was applied to get the content validity (CVR) ratio.

$$\mathrm{CVR} = \frac{\mathrm{Ne} - \mathrm{N}/2}{\mathrm{N}/2} \tag{1}$$

where

N_e = Number of essential questions suggested by experts.
N = Number of experts from the construction industry (in this case, 12). According to the suggestion by Lawshe [67], the questions with a higher CVR than 0.49 were selected for the semi-structured interview. A similar method was used in the previous study by Navratnam et al. [44].

Table 1 illustrates the interview questions prepared for each category in this study. The qualitative data analysis was performed when the statistical procedure was inappropriate while interpreting and analysing the data. Q5 to Q22 were analysed through qualitative analysis and graphically represented, while Q22 and Q23 were analysed with a Likert scale from 1 to 5 [68]. The participants were asked to rank the most responsible sector for generating construction waste and the sector with the most impact in minimising construction waste. The ranking was from 5 (most important) to 1 (least important) (quantitative analysis, Severity index) [69].

Table 1. The interview questions for each category.

Categories	Questions (Appendix A)
Project Design and Planning	Q4, Q8, Q9, Q10, Q11, Q12
Building Information Modelling (BIM)	Q5, Q6, Q7, Q13, Q16, Q18, Q22
Material Procurement and Logistics	Q11, Q14, Q16, Q17
Prefabrication or Modular Construction	Q19, Q20, Q21, Q22

The Severity index (SI) was calculated using the following Equation (2).

$$\mathrm{SI} = \Sigma \frac{\mathrm{w}}{\mathrm{A} \times \mathrm{N}} \tag{2}$$

where

w = Weighting factor (in this case, 5 = most important to 1 = least important),
A = Highest weight (in this case, 5), and
N = Total sample size.

Overall, this study's findings present a conceptual framework based on critical focus points.

3. Results and Discussion

In an attempt to achieve a broad understanding of the current status of the construction industry in waste management, the interview was focused on gathering information from a wide array of industry roles. BIM managers, site engineers, project planners, architects and project estimators of the construction industry were the respondents for this study.

The interview was conducted from 7 June 2021 to 28 November 2021. The interviewees are selected randomly from social media such as LinkedIn and Facebook from the Australian construction industry. They are invited to participate in the interview. In total, 50 interviews were conducted, and 10 participants from each category were selected for the interview. The literature shows that when people answer a question similarly, small sample size is sufficient for the analysis [70]. Again, it is expected that a homogeneous population with a smaller sample size can serve the research purpose [71]. In this study, the sample size was fifty—ten BIM managers (20%), ten site engineers (20%), ten project planners (20%), ten architects (20%) and ten project estimators (20%) were invited to join the interview (Figure 1). Therefore, the sample size was homogeneous and provided uniform responses from the interviewee in the context of construction waste minimisation perceptions. Thus, this sample size was deemed acceptable in this study. The geographic location of the interviewees was Melbourne, Victoria, Australia. Figure 1 represents the professional role of the participants in the industry.

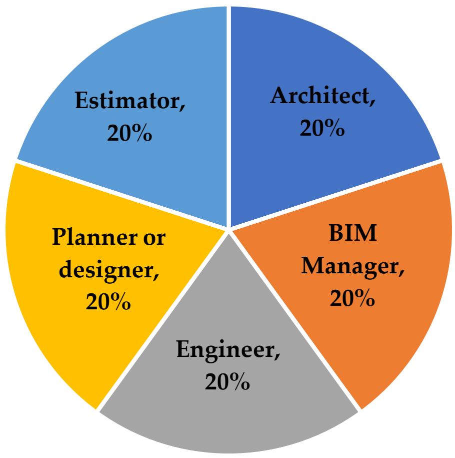


Figure 1. Interview participants' roles in the construction industry.

Table 2 represents the participants' experience in the construction industry. Approximately 36% of the participants have more than 15 years of experience in the construction industry, and approximately 50% have more than 11+ years of experience. Again, their responses were considered homogeneous as there are professionals with high experience in the construction industry. The interview found that 78% of the participants were directly or indirectly involved with project planning, estimating and material handling. These participants have work experience in the construction industry in Melbourne and the other states of Australia. Thus, through their opinion, an overall scenario of waste minimisation perception of Australia is achieved in this study.

Table 2. Interview participants' experience in the construction industry.

Year of Experiences	No of Participants	Percentages (%)
0–5 years	11	22
6–10 years	14	28
11–15 years	7	14
15–20 years	10	20
20 years and above	8	16
Total	**50**	**100%**

3.1. Perception of Waste Minimisation in the Design Stage

The roles of architects, engineers and project planners have a significant impact on the minimisation of construction waste. The way they convey their knowledge, consciousness, and behaviour towards sustainable materials and design principles in their projects is a crucial contributing factor to waste minimisation [31,32]. The participants' qualifications, knowledge, and willingness to implement circular economy opportunities by using recycled and sustainable materials are explored in this study. Out of the 50 participants, 80% were either fully or somewhat involved in a design and planning/management role in their current positions. Thus, to determine the exposure and knowledge of the participants in waste-conscious design principles, the series of questions were prefaced with whether they had received any formal training/education on sustainable design. Approximately 70% of the participants confirmed that they had undertaken some form of training, either as a course in their university education or through workshops that their respective companies organised. With this information, it can be concluded that acquiring knowledge from formal institutions will subsequently result in a more conscientious approach to sustainable construction design. However, the interview results show that despite attaining qualifications, only 30% (15 participants) took waste minimisation as a significant consideration in their project's design and planning stage (Figure 2a). This highlights the issue where a designer's subjective attitude and personal reluctance to exercise waste-mitigating methodologies is still the crucial factor that defines the impact they will have on the wastage produced by the construction industry [31,32,72].

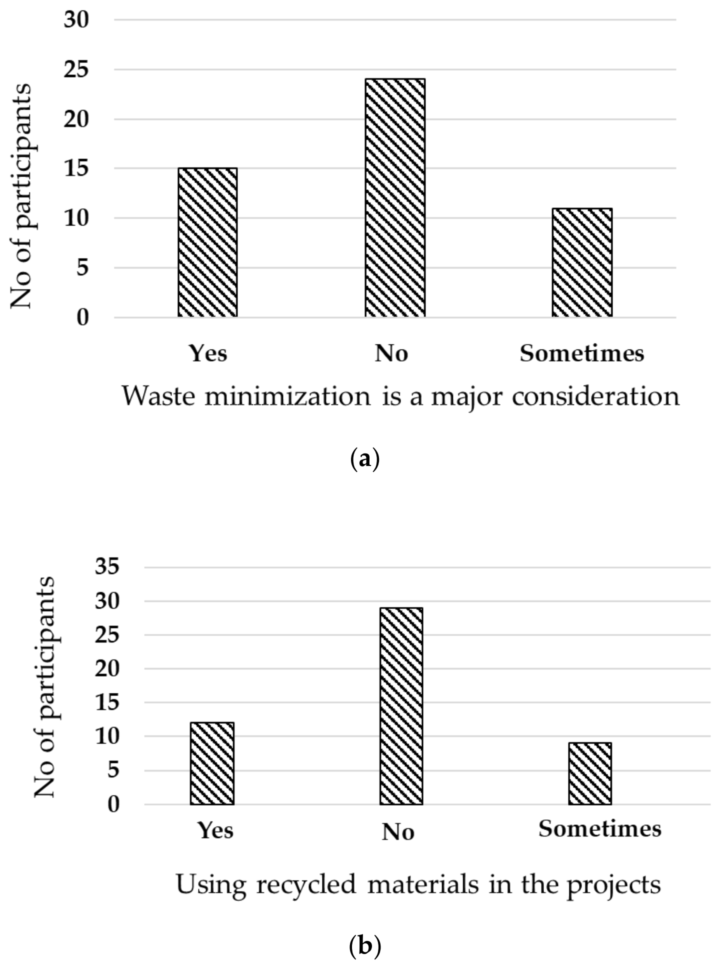


Figure 2. Participants' perception's: (**a**) waste minimisation and (**b**) uses of recycled materials.

Another aspect of the design stage that could support the circular economy is allocating recycled materials to replace the standard, mass-manufactured construction elements, typically concrete, steel, and timber [73]. The participants were queried about their experience using recycled materials in their projects, and the results positively indicate that 42% (21 participants) of the participants have been exposed to sustainable products (Figure 2b). According to their responses, the typical positive impacts of using such materials are that recycled products can be a great selling point to some clients who are more environmentally conscious (due to the reduced carbon footprint and embodied energy of the structure). In addition, recycled materials can often prove more cost-effective in the long run due to the minimal maintenance required throughout their life cycle. However, a consensus was evident wherein the downside of integrating upcycled elements is that it tends to be more costly than its standard counterpart.

There are also concerns over the reliability and consistency of the materials as a structural element, as well as the overall unfamiliarity of contractors and designers on how to work with the product. This enforces the initial findings from the literature review. The reluctance of designers and planners to deviate from conventional methods of project conceptualisation can be sourced from the lack of knowledge and guidance in using recycled materials in construction projects [31].

3.2. Perceptions of Waste Minimisation in Material Procurement and Logistics

The respondents were asked about their involvement with material procurement and logistics, and it was found that out of the 50 respondents, 80% are involved in them. The respondents were asked whether there were any current estimation tools or programs at their workplace. The result shows more than 70% of the respondents do not or sometimes use estimation tools or programs in their workplace, while only 30% always use a form of estimation tool and programs in their workplace (Table 3). The participant identified Mitek 20/20 and Micro Excel file with cut optimising macro as the estimation tools/programs and methods used at their workplace. The result also shows that more than 70% of the participant does not use these tools or programs to quantify wastage from purchasing errors and material handling. The result indicates that most respondents do not utilise any form of estimation tools or programs in the workplace. Therefore, this is a prime reason that prevents them from receiving the benefits that come with the utilisation of estimation tools and programs, such as quantifying wastage from purchasing errors and material handling, which can lead to more waste generation throughout the project.

Table 3. Interview responses on material procurement and logistics.

Interview Questions	Opinions	Responses
Level of involvement in material procurement and logistics	Always	80%
	Sometimes	20%
Usage of tools or programs to quantify wastage from purchasing errors or material handling	Always	27.27%
	Sometimes	72.73%
Option of sustainable/recycled products from the suppliers or manufactures	Yes	64%
	No	36%
The large market for sustainable materials in the Australian Industry	Yes	80%
	No	20%
Utilisation of BIM to assist material estimation and procurement process	Yes	20%
	No	80%

The participants were asked whether any supplier/manufacturer provided options for sustainable/recycled products and how difficult it is to source sustainable/recycled materials in the Australian industry. The results indicated that approximately 64% of the participants' supplier/manufacturers provide options for sustainable/recycled products, which show that these products are available in the Australian construction industry (Table 3). Even the majority (approximately 80%) of the participants agree that a bigger market for sustainable materials in the Australian industry should exist. This indicates that the reluctance to use sustainable and recycled materials is the main barrier to implementing sustainable and recycled materials in construction projects. The project planners are not motivated to use these recycled materials due to the lack of standardisation available for these materials. That is why the project planners cannot rely on the quality of the recycled materials. The availability of recycled materials and the client's willingness to use these materials are some significant issues to consider.

The participants were asked whether they incorporate BIM to assist with material estimation and procurement processes. The result shows that only 20% of the participants use BIM to help in material estimation and procurement (Table 3). This is because, in most construction companies, BIM is not available in their line of work. Even the industry is not encouraging or providing sufficient training to utilise BIM for maximum outcomes in waste reduction. BIM-based project harmonisation and management among stakeholders is not practised much in the industry. The participants were asked what percentage of their projects specify sustainable and environmentally friendly materials as their preference instead of its standard equivalent. Only 25% of the participant stated that their project defines sustainable and environmentally friendly materials as their preference instead of its standard equivalent (Figure 3a). Over 60% of the participant find it neither easy nor difficult to source sustainable/recycled materials in the Australian industry (Figure 3b). Comparing the problematic and accessible side of the graph shows that more participants find it difficult to source sustainable and recycled materials in the Australian industry. This indicates that the availability and sourcing of sustainable and recycled materials must improve.

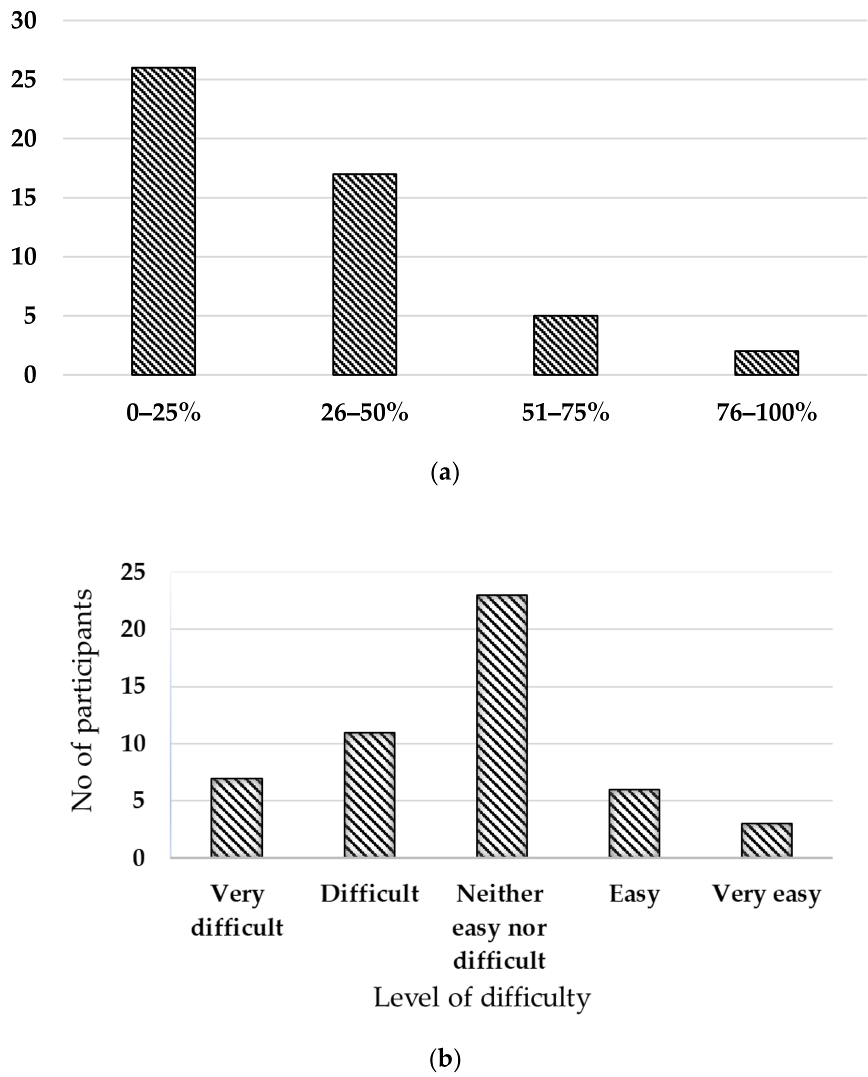


Figure 3. The uses of sustainable materials and constraints of sources: (**a**) using sustainable materials and (**b**) the difficulty of sourcing sustainable/recycled materials.

The participants were asked what material procurement/handling stage generates the most wasted or damaged goods. Approximately half of the participants indicated that estimation/quantity surveying creates the most wasted or damaged goods (Figure 4). Only approximately 20% of the participant picked material transport/handling as the reason most wasted or damaged goods were generated. Some participants suggested other reasons, such as direct procurement, over-ordering, and timber offcuts from production to generate wasted or damaged goods.

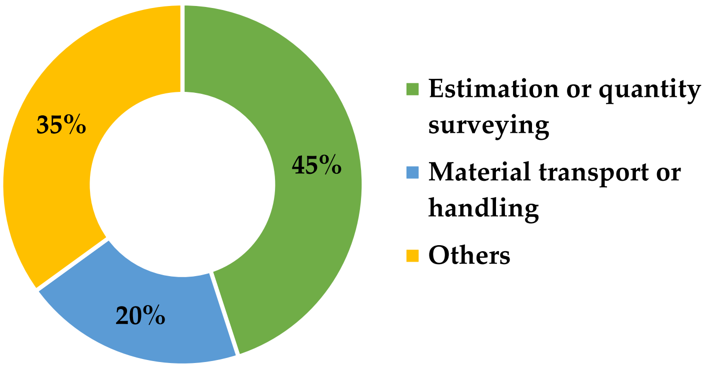


Figure 4. The population wastes production at the material procurement and logistics stages.

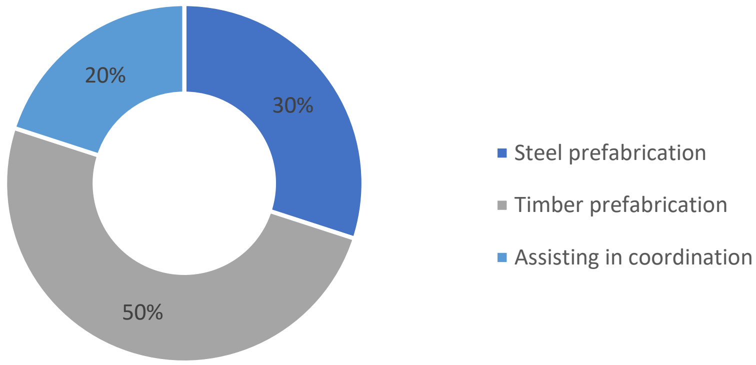
3.3. Perception of Waste Minimisation through Prefabrication and Modular Construction

Among the interview participants, 36% are directly involved with the prefabrication industry. A total of 60% are involved in steel fabrication, 20% are engaged in timber prefabrication, and 20% are not directly involved in the design and manufacturing and are responsible for coordinating (Figure 5a).

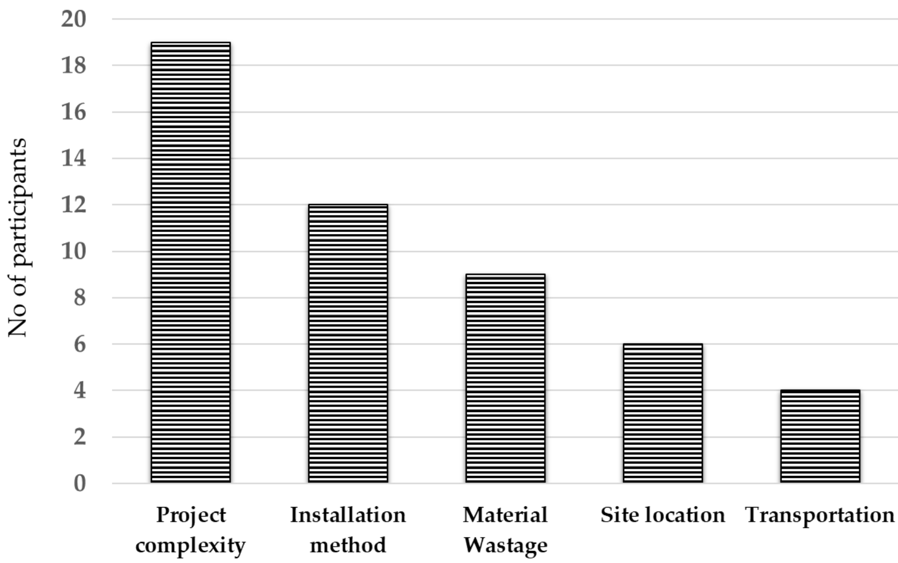
The individuals involved in the manufacturing process were tasked with identifying the primary factors limiting the universal acceptance of prefabricated components in the industry. Based on the results in Figure 5b, most participants (38%) acknowledged project complexity, establishing it as the most significant factor to consider in the Australian construction industry. This complies with previous findings in the literature. Issues, including client requirements and design inflexibility, make prefabricated components undesirable in the private housing sector [41,74–76]. The rigid manufacturing design process also creates other related issues, including the installation difficulty.

Futher, approximately 24% of participants identified this as the next most important aspect to consider. Numerous variables can affect the installation process, including the availability of machinery and appropriate tools, the quality of the prefabricated components and the expertise/skills of labourers. A total of 18% believe that material wastage is a significant consideration in prefabricated components. As mentioned earlier in the research paper, prefabrication can generate less waste than traditional on-site construction methods; the participants have also acknowledged this in their responses.

Site location and transportation were mentioned by 12%, and 8% of participants highlighted either consideration. These factors have implications for the use of prefabricated components. Generally, site managers will organise subcontractors to transport these components on site [77].



(**a**)



(**b**)

Figure 5. The population of the prefabrication industry and the consideration for its application: (**a**) pouplation participants and (**b**) primary consideration.

3.4. Participants' Perception of Waste Minimisation Using BIM

It is evident from the literature that the pre-construction and design stage is responsible for a large amount of construction waste generation. In this regard, the utilisation of BIM in construction projects can ultimately reduce waste generation by increasing efficiency and reducing errors [33,78].

The data showed that 40% of the participants utilise BIM/CAD in their projects. The data analysis also shows the types of BIM and CAD programs the participants are exposed to at their workplaces. Figure 6a illustrates the BIM and CAD programs and the number of participants exposed to these programs at their workplaces. It is seen that there are different BIM programs available to the industry. However, based on this result, more organisations are using CAD rather than BIM. There should be more use of BIM programs in the industry to utilise their ability to aid with the reduction in waste generation. In Figure 6b, the pie chart indicates that 50% of the participants personally use BIM/CAD programs to assist them in their work.

All the participants were asked if they believed using CAD/BIM programs in projects significantly reduces construction waste. Half of the participants (50%) use these tools (Figure 6b). The participants were asked how the industry uses CAD/BIM programs to reduce waste generation. A total of 50% of the participants do not use the CAD and BIM programs at their workplace to their maximum capacity to reduce waste generation. This indicates that those exposed to BIM are more aware that BIM has the potential and ability to reduce waste generation. They are aware that waste generation can be reduced and prevented during the construction stage by proper management during the pre-construction stage, which mirrors the literature.

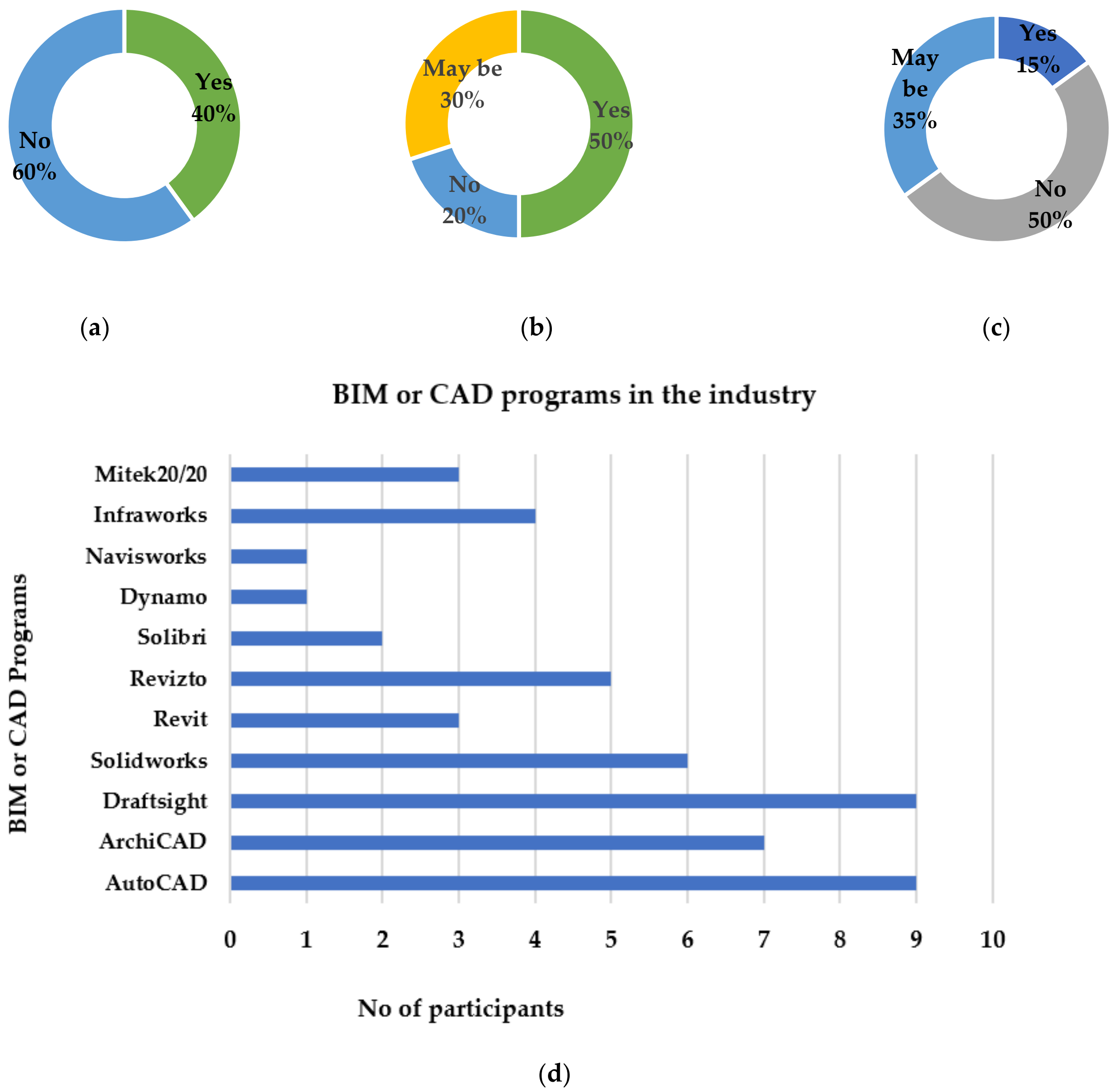


Figure 6. The uses of CAD/BIM: (**a**) assist work personally; (**b**) impact on reducing waste; (**c**) maximised in its capacity to waste reduction; and (**d**) available in the industry.

BIM can optimise the design before manufacturing, allowing the ability to order the exact estimation of materials, thus preventing waste generation during construction. The results and the literature indicate that BIM can help inform decisions for selecting products and analyse data to inform construction types and the carbon repercussions of those decisions.

Data analysis shows that 40% of the participants exposed to BIM believed that applying workplace waste management plans and strategies is essential. Regarding the group with no BIM exposure, 60% of the participants also believed the same. This shows that those with BIM exposure are more aware of the importance of waste management plans and strategies in the workplace than the group that is not exposed to BIM. Therefore, both groups and the construction industry know the importance and value of applying waste management plans in a workplace as it helps monitor and reduces construction waste.

Therefore, most participants know that using CAD and BIM programs in the project can significantly reduce construction waste, regardless of their exposure to BIM. Based on the interview data, not all industries utilise BIM and CAD programs to their max capacity to reduce waste generation. Only 15% of the participants from the group with BIM and no BIM exposures indicate that the BIM and CAD programs at their workplace are utilised to their maximum capacity to reduce waste (Figure 6c).

Since the application of BIM and CAD programs in project visualisation is effective in project planning and coordination, it is helpful in construction waste management during the design phase. However, amongst the participants, 60% indicated that BIM or CAD programs are not typically used in their line of work (Figure 6a). On the other hand, those with BIM experience highlighted the features that, in their opinion, have the most impact on the management and reduction in construction waste. The responses include the ability of BIM programs to generate an accurate bill of materials, enhance material optimisation by identifying the correct use of elements and plan overlaying to identify any issues on site that should be considered before any construction work.

3.5. General Ranking Analysis

All participants were tasked with ranking each profession in the construction industry regarding the following questions:

- Which profession is most responsible for generating construction waste?
- Which profession has the most impact on minimising construction waste?

The ranking was from 5 (most important) to 1 (least important), and an average was calculated for responses separated by the three sectors involved. These are the following results:

The participants' responses to responsibility in construction waste generation are summarised in Table 4. Based on their responses regarding the responsibility level for construction waste generation, it is found that design/project planners are regarded as the most critical sector (SI: 0932), with a consensus across the participants, being ranked either 1st or 2nd. This supports the earlier literature discussed in the research paper, which considers design decisions during the pre-construction stage as generating the highest percentage of waste during construction [78]. The material suppliers/manufacturers sector is regarded as the 2nd most responsible by two participant groups. It is important to note that the individuals involved in prefabrication consider their sector a highly responsible party.

Table 4. Severity index for the responsibility in construction waste generation.

Profession	Participants Involved in Prefabrication	Participants Engaged in Design and Layout	Participants Involved in Material Procurement and Handling
Designers/Project Planners	(0.942) 1st	(0.871) 2nd	(0.932) 1st
Labourers	(0.622) 4th	(0.731) 3rd	(0.601) 4th
Engineers	(0.602) 5th	(0.647) 4th	(0.685) 5th
Site Managers	(0.711) 3rd	(0.912) 1st	(0.740) 3rd
Material Suppliers/Manufacturers	(0.801) 2nd	(0.566) 5th	(0.861) 2nd

Table 5 represents the sectors ranked by participants responsible for construction waste generation. It is seen that material suppliers or manufacturers are the most critical sector for waste minimisation (SI: 0.8–0.7), followed by designers and project planners, who are equally crucial in minimising construction waste. The early stages of designing and planning can have an impactful effect on reducing waste generation.

These participants witnessed first-hand the waste produced during the manufacturing process, hence their decision to rank it as the 2nd most responsible sector (Table 5). Interestingly, participants in the design and layout sector rated material suppliers/manufacturing as the most important (SI: 0.872). They acknowledged the material suppliers/manufacturing, and designer/project planners as the most responsible waste production sectors, outlining the importance of focusing on the pre-construction process. Minimising the waste generated at the initial source is essential; hence mitigation strategies should focus on these sectors. Site managers are the 2nd most responsible for the design and layout participants and are viewed moderately by the other two sectors. This selection may be due to the understanding that these individuals overlook most of the on-site construction process. Hence, they are responsible for an extensive amount of waste generated. labourers and engineers are the two sectors that are generally identified as the least responsible (0.6–0.5) among all participants performing their roles without considering waste.

Table 5. Responsibility in minimising waste generation.

Profession	Participants Involved in Prefabrication	Participants Engaged in Design and Layout	Participants Engaged in Material Procurement and Handling
Designers/Project Planners	(0.792) 1st	(0.592) 5th	(0.762) 1st
Labourers	(0.520) 5th	(0.672) 3rd	(0.622) 3rd
Engineers	(0.601) 4th	(0.620) 4th	(0.578) 4th
Site Managers	(0.622) 3rd	(0.721) 2nd	(0.502) 5th
Material Suppliers/Manufacturers	(0.722) 2nd	(0.872) 1st	(0.729) 2nd

3.6. Conceptual Framework Based on the Findings

This study explores four stages of workplace waste management practices through a semi-structured interview with industry personnel from the Australian construction industry. The current situation of waste management and experts' perceptions on waste minimisation were the focus explored in this study. The experts' opinions and responsibility for waste generation and minimisation are highlighted in Figure 7.

Fifteen key points are identified in these four stages of waste management practice to consider for waste mitigation. Designers, project planners, material suppliers, or manufacturers are responsible for waste generation and minimisation. In the project design and planning stage, the designer's academic qualification and relevant training are essential, along with their willingness to practice waste minimisation strategies. In their training programme, it is also necessary to provide knowledge about using recycled materials in construction projects to develop a circular economy. In the material procurement and logistic stage, estimation or quantity surveying is a significant point to consider for waste mitigation indicated by the interviewees. In that case, BIM can be incorporated to place exact orders and minimise design errors to avoid waste. Most interviewees found difficulty in sourcing recycled and sustainable materials in the Australian industry, which indicated a need exists to establish a potential market for recycled material where materials should be available according to the relevant standard.

It is necessary to obtain environmental accreditation for a construction company and use recycled material to ensure sustainable development. The benefits of an organisation receiving such accreditation go beyond their environmental blueprint and include marketability to prospective clients. Displaying an interest in being environmentally sustainable throughout the prefabrication process will market the organisation as being eco-friendly and potentially attract buyers who share the same beliefs on this subject [34]. The government should consider implementing a certain level of accreditation that must be achieved for an organisation to operate in the prefabrication industry. This will limit the potential for waste generation during this process and raise greater awareness of this issue transitioning into the future [39].

Although prefabrication or modular construction is gaining popularity, project complexity and difficulty installing the precast element component are still crucial factors hindering its acceptability industrywide. Overall, it is necessary to vastly expose BIM in the Australian construction industry to obtain the benefits for waste prevention, reduction, reuse and recycling. Based on the research finding, a conceptual framework is represented in Figure 7. Further research is necessary to identify how BIM can be incorporated to manage construction waste effectively.

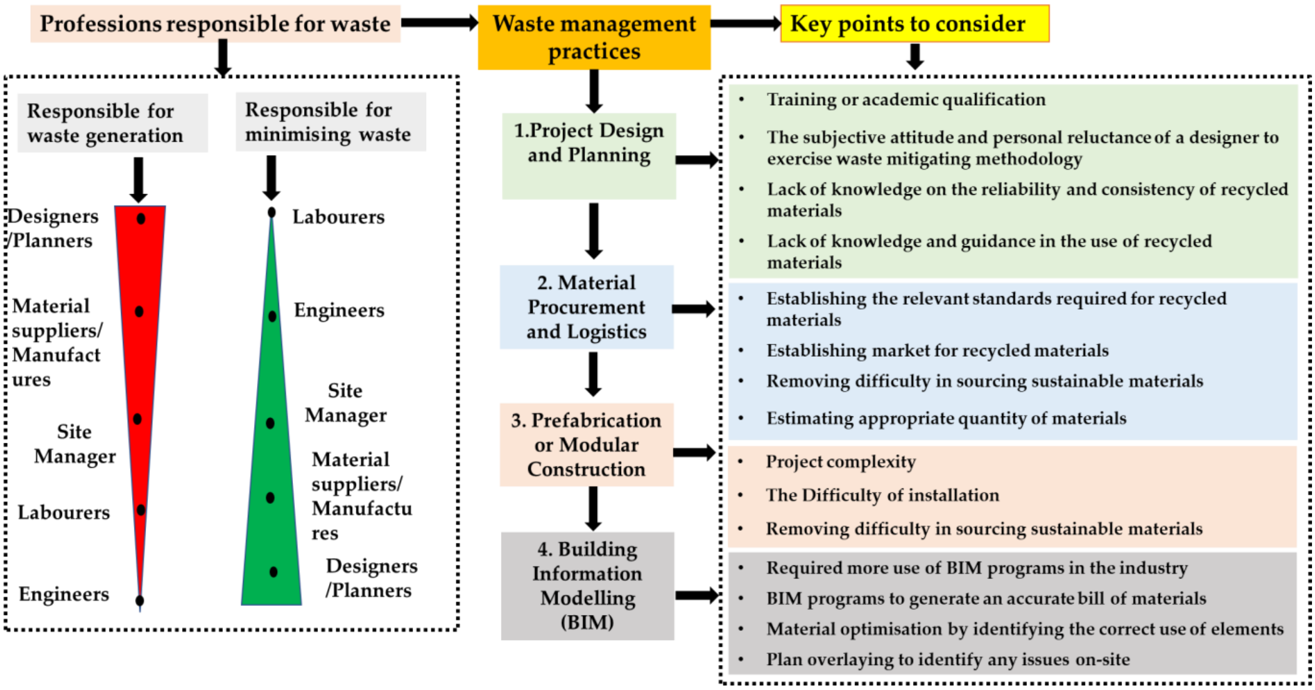


Figure 7. Conceptual framework based on research findings.

4. Conclusions

This study identified the current constraints of waste minimisation in the Australian construction industry, and a conceptual framework is proposed based on the study findings. In using sustainable and environmentally friendly materials, the industry still lacks the knowledge and guidance in using recycled materials in construction projects. The majority of the participants have experience with recycled materials, and there is potential for the construction industry to promote recycled and environmentally friendly materials further to promote sustainable development. Based on the study findings, the following recommendations are made to boost the circular economy.

- All the stakeholders in the construction project need to be cooperative and are reluctant to practice a waste management protocol for environmental, economic, and social benefits.
- A secondary market for recycled materials needs to be established to enhance the application of recycled materials. Selecting the relevant standards required and instituting a market that specialises in supplying re-purposed structural materials certified to use as an equivalent to virgin construction products can promote the application of these recycled materials. In this regard, government support and initiative are mandatory.
- Although prefabrication is considered a practical waste reduction approach, project complexity was acknowledged as an essential factor based on this study's results because it limits the universal acceptance of prefabricated components in the industry. Therefore, adequate design training and encouraging the clients to choose simple design structures can be effective solutions.
- The industry lacks BIM-compatible CWM tools, essential for reducing construction waste generation and improving material logistics. Therefore, to bring sustainable development, every workplace in the construction industry should push to utilise BIM and provide sufficient training to the employees on BIM-based CWM tools.

Limitations and Future Research

The limitations of this study are that it investigates the waste minimisation perception of the construction industry involving limited stakeholders. This study's scope is restricted to Australia (only in Melbourne, Victoria), and a sample size of 50 is used for data analysis. As the research was conducted during the COVID-19 outbreak, only 50 interviews could be completed. Due to COVID-19, only five stakeholders—BIM managers, site engineers, project planners, architects and project estimators—were involved in this study. Thus, it is essential to investigate other stakeholders' perceptions—for example, project contractors, coordinators, clients, project managers, supervisors, sustainability managers, carpenters, and joiners—because more engagement of industry personnel will provide substantial knowledge on waste minimisation.

The limitations can be improved by conducting future research through semi-structured interviews involving other stakeholders and selecting different geographical locations in Australia. The proposed conceptual framework for construction waste minimisation can be applied in future research to identify waste minimisation perceptions in other countries. Further research is recommended to determine how BIM can be utilised at its maximum capacity in every stage of construction and incorporated to manage construction waste effectively. In this regard, BIM-integrated construction waste estimation and minimisation tools can be explored in the design, material procurement, and logistic stages to boost the circular economy through minimising waste generation.

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Appendix A. Interview Questions

1. Has your company obtained any environmental accreditation?
2. Are there any waste management plans/strategies currently in your workplace?
3. How often do you implement these minimising waste practices in your work?
4. In your opinion, is the application of waste management plans/strategies in your workplace essential?
5. Does your company typically use computer-aided design and BIM programs (such as AutoCAD and SolidWorks) to assist in your work?
6. Do you personally use CAD/BIM programs to assist you in your work?
7. To your knowledge, are the CAD/BIM programs used in your workplace maximised in its capacity to reduce waste generation?
8. Generally speaking, does your current job position have any involvement in construction design and planning (management)?
9. Have you received any formal training/education on sustainable design?
10. In your experience in project design and planning, has minimising construction waste been major consideration?

11. Have you had any experience in using recycled materials in your projects/designs?
12. In your experience, what percentage of your clients specify sustainable and environmentally friendly materials to be utilised in their projects?
13. Have you utilised BIM to assist you in your design and planning process?
14. Generally speaking, does your current job position have any involvement in material procurement and logistics?
15. Are there any estimation tools and programs currently in use in your workplace?
16. Have you used these tools or programs to quantify wastage from purchasing errors and material handling?
17. In your experience, what percentage of your projects specify sustainable and environmentally friendly materials as their preference instead of its standard equivalent?
18. Have you utilised BIM to assist you in your material estimation and procurement process?
19. Generally speaking, does your current job position have any involvement in the manufacturing of prefabricated and/or modular components?
20. What construction element does your company typically manufacture prefabricated components in?
21. Is your company involved in designing the prefabricated components?
22. Is BIM an essential tool in your product design and manufacturing process?
23. Please rank the personnel responsible for construction waste generation (ranking was from 1 (most important) to 5 (least important))

Options:

Profession	Participants Involved in Prefabrication	Participants Involved in Design and Layout	Participants Involved in Material Procurement and Handling
Designers/Project Planners			
Labourers			
Engineers			
Site Managers			
Material Suppliers/Manufacturers			

24. Please rank the personnel responsible for minimising waste generation (ranking was from 1 (most important) to 5 (least important))

Options:

Profession	Participants Involved in Prefabrication	Participants Involved in DesignandLayout	Participants Involved in Material ProcurementandHandling
Designers/Project Planners			
Labourers			
Engineers			
Site Managers			
Material Suppliers/Manufacturers			

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