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Minimising Risks of Wastage in Modular Construction

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ABSTRACT

Rapid growth of the construction industry has resulted an increase amount of waste generation. Modular construction on Industrialised Building System (IBS) has emerged as a significant innovation in the construction industry, offering numerous benefits such as reduced construction time, improved quality control, and enhanced sustainability. Despite these advantages, the industry still faces challenges related to material wastage, which not only impacts the environment but also contributes to cost overruns. Minimising the risk of wastage in modular construction requires a strategic approach encompassing efficient design, meticulous planning, and the adoption of advanced technologies. This study aims to comprehensively evaluate and compare strategies to minimise wastage in modular construction by achieving the following objectives: identifying types of wastage, examining factors that contribute to wastage, and proposing methods to reduce wastage effectively. This research aims to identify synergies and opportunities for integration among these approaches to optimise material usage, reduce waste, and improve overall efficiency in modular construction in Malaysia. Preliminary interviews were carried out with 5 participants in Klang Valley, focusing on Petaling district to gather data for this pilot study. In addition, a thorough literature review was also performed to identify the common waste in modular construction. The findings highlight the types of waste, influencing factors and mitigation plans to minimise the risk of wastage in modular construction. Adopting AI, BIM and IoT in modular construction projects in Malaysia offers significant potential to minimise waste by enhancing design precision, enabling real-time process monitoring, and predicting inefficiencies before they occur. Thus, the implications and potential impact of this research on the construction industry lie in identifying issues related to wastage in IBS

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and encouraging construction management to address waste concerns, particularly those arising from component defects in building projects.

INTRODUCTION

In Malaysia, Modular Construction is also known as IBS (Industrialised Building System). It refers to a construction method where building components are manufactured in a controlled environment, then transported, positioned, and assembled at the construction site (Kamar et al., 2011). The evolution of modular construction in Malaysia has been significant, reflecting the country's efforts to modernise its construction industry. The concept of modular construction has evolved over decades, with significant advancements in technology and processes. Early modular construction efforts focused on residential buildings, but the method has since expanded to include commercial and industrial structures. Modular construction has gained significant attention across various industries for its efficiency, cost-effectiveness, and sustainability. The first significant project using IBS was the Tunku Abdul Rahman flats in Kuala Lumpur, completed in 1964 (Thanoon et al., 2003). In the 1990s, the government started formulating policies to promote the use of IBS. The Construction Industry Development Board (CIDB) was established in 1994 to regulate and promote the construction industry, including IBS. Several pilot projects were initiated to demonstrate the feasibility and advantages of IBS, focusing on public housing and infrastructure projects. Besides that, to promote the adoption of IBS, the Malaysian government introduced various policies and incentives. In 1998, the Construction Industry Development Board (CIDB) Malaysia was established to regulate and develop the construction industry, including the promotion of IBS (CIDB, 2003). The Malaysian government also launched the IBS Roadmap 2003-2010 to enhance the adoption of IBS through strategic planning and implementation. The 2000s saw significant technological advancements in IBS. Prefabrication technology improved, leading to better quality and efficiency in construction. The use of Building Information Modeling (BIM) became prevalent, enhancing the design and construction process. The IBS Roadmap 2011-2015 further emphasised the need for research and development to keep up with global standards (Kamar et al., 2009). While it is widely considered a sustainable building method, it nonetheless generates a certain amount of waste. Today, IBS is an integral part of Malaysia's construction industry. The Construction Industry Transformation Programme (CITP) 2016-2020 set ambitious targets for the adoption of IBS to improve productivity and sustainability. The focus is now on smart construction, integrating advanced technologies such as automation and robotics (CIDB, 2016). There is a growing emphasis on sustainability in construction. IBS is seen as a sustainable building method due to its ability to reduce waste, improve energy efficiency, and enhance construction site safety. The integration of digital technologies such as BIM, the Internet of Things (IoT) and automation is expected to drive the future of IBS in Malaysia. These technologies enable better project management, real-time monitoring, and enhanced precision in construction.

LITERATURE REVIEW

Wastage Produced in Modular Construction

The wastage produced by Industrialised Building Systems (IBS) in Malaysia from 2010 to 2024 has shown fluctuations, primarily driven by the construction industry's adoption of IBS technologies and the challenges associated with its implementation. The main types of waste produced in IBS include construction debris, damaged prefabricated components, packaging waste, and excess materials due to transportation damage or mismatches in site conditions. The adoption of IBS was relatively slow, and wastage was a significant concern. Contractors reported issues such as damaged precast components due to improper handling during transportation and installation, which led to material wastage. In addition, insufficient planning and coordination between design and manufacturing contributed to excess waste during assembly stages (Kadir et al., 2006). A lack of trained workers exacerbated these issues, leading to higher than expected material waste despite the intended efficiency of IBS (CIDB, 2003). Between 2015 and 2024, the government increased efforts to encourage the use of IBS through incentives and regulations, but waste management remained a critical challenge. Although companies like PETRA Modular have achieved up to 90% waste reduction through off-site construction, the overall construction sector has continued to experience issues with material overproduction, unused prefabricated parts, and inefficiencies in handling and transportation (PETRA Modular, 2022). This has been partially attributed to poor perception and inadequate training among smaller contractors, which often results in the preference for traditional methods that generate more waste (Rahman & Omar, 2006). As of December 2021, the Construction Industry Development Board (CIDB) has reported a total of 799 development projects. Out of all the development projects reported, a total of 138,548.09 tons have been disposed of at 22 landfill sites under the supervision of SWCorp, which receive construction waste (SWCorp, 2022). The Mayor of Penang Island City Council (MBPP) has disclosed that MBPP is burdened with 235 tonnes of construction waste each day, representing roughly 20% of the total waste output (Lo, 2021). Approximately half of the raw materials we extract are utilised in the global built environment. Illegally disposing of construction debris, including wood and brick remnants, at the Tenaga Nasional Berhad reserve area near Sungai Putat (The Star, 2022). Besides that, the improper disposal of construction waste presents significant risks to both human health and the environment. Furthermore, the prevailing culture of discarding waste remains dominant, with recycling or reusing construction materials being infrequently practiced in Malaysia (Ithnin, 2023). In Klang Valley, the use of Industrialised Building Systems (IBS) in construction has been promoted for its potential to reduce construction waste, but several challenges related to wastage still persist. One key issue is the perception of IBS among stakeholders, as many private contractors still prefer conventional methods. This reluctance is often due to concerns about higher initial costs and the complexities of training workers to handle IBS components. Consequently, the adoption rate remains low, which affects the overall efficiency of waste management in construction projects.

In addition, a broader acceptance of modular building has been delayed by the common association of modular homes with mobile homes and manufactured homes, which often carry a negative reputation due to historical stereotypes, low-quality materials, design flaws, and financial issues (Mobilehomes, 2023). Furthermore, a poorly manufactured product may evade the existing systems designed to prevent defects. The two primary issues typically involve the use of low-quality materials and inadequate workmanship during the assembly of components to create the final product (Justia, 2023). Civil engineering endeavours frequently pose difficulties because conventional materials are susceptible to environmental wear and tear, and certain construction components have limitations in terms of weight (StartUs Insights, 2024). Another issue is the logistical challenge of transporting prefabricated modules, which can result in damage and waste during transit and handling if not properly managed (Loizou et al., 2021; McKinsey, 2024). There are various opinions, including views that modular homes are temporary shelters that will collapse within a decade or two, that the technology is unviable, and that a modular home will be destroyed by the first termite that infests it (Ng, 2024). Besides that, another risk pertains to lifting modules at a construction site. If the crane's position is not carefully planned and correctly installed, there is a possibility that a module could be dropped and damaged (Ng, 2024). "The sports hall, the only part that wasn't 3D modular, appears to be constructed with a gauge steel frame, but it also exhibits structural defects," he remarked. "This suggests that the modular company may be undertaking work in areas where they lack significant experience." (Hakimian, 2023). Initial reports mistakenly identified the insulation material as rock wool, which is non-combustible. However, it was later discovered that the buildings were actually clad with Alucobond aluminium composite panels. Current investigations are concentrating on a thermoplastic substance, probably a resin utilised in bonding the aluminium cladding, which might serve as an accelerant in the event of a fire (Puchades, 2024). Additionally, the high initial investment costs for modular construction, including the need for specialised facilities and technology, can discourage widespread adoption, leading to underutilisation of materials and resources (Garusinghe et al., 2023).

Ensuring proper storage facilities that protect against environmental factors is crucial to maintain the integrity of the materials (Peiris et al., 2021). Secure and robust connections between modules are crucial for the structural integrity of the building. Issues such as improper jointing, inadequate sealing, and misalignment of connecting elements can compromise the overall stability and weather-tightness of the structure (Richardson, 2016). Modules are often manufactured off-site and transported to the construction site. During this process, they are susceptible to damage. Proper handling techniques and robust packaging are essential to prevent damage during transit (Lawson et al., 2012). Material wastage occurs when construction materials are improperly used, damaged, or discarded. Despite the IBS approach aiming to reduce such waste by prefabricating components off-site, mishandling during transportation, installation errors, and poor planning can still result in material waste. An example, during the installation phase, precast concrete elements may not fit perfectly, leading to trimming or discarding excess materials. Many modular construction sites are located in urban areas with limited space for waste segregation and storage, leading to potential inefficiencies in waste management practices (Yuan & Shen, 2011). Prefabricated IBS components are often large and may require significant staging areas on-site. If not properly managed, the assembly of these modules can result in leftover space that is difficult to repurpose.

In context of manufacturing defects, poor quality control during the manufacturing process can lead to defects in the prefabricated modules. Inadequate inspection and testing can result in the use of substandard materials, which may not meet the required specifications and standards (Hasan et al., 2019). Many workers in the modular construction industry may have experience in traditional construction methods but lack the specific skills required for modular techniques. This mismatch can lead to mistakes that cause material wastage (Hong et al., 2018). Efficient logistics management, including route planning and proper scheduling, can mitigate these risks (Gibb & Isack, 2003). Standardising building components can lead to more efficient use of materials. Standardisation involves creating uniform components that can be mass-produced, reducing variability and waste (Goodier & Gibb, 2007). Next, poor integration of IBS components into the initial architectural designs often leads to inefficiencies. This includes discrepancies between the modular design and the actual site conditions, requiring rework or modifications, which results in material wastage. A lack of synchronisation between design, prefabrication, and installation increases wastage significantly (Kamar et al., 2009). The adoption of IBS requires precise and detailed planning, as components are prefabricated off-site. Any inaccuracies or incomplete information in the design can lead to mistakes in production, leading to discarded or unusable materials (Yunus & Yang, 2011). The failure to adhere to standardised IBS components across projects results in inefficiencies and increased wastage during the planning phase. This is because non-standardised designs often necessitate custom-built components that may not fit perfectly with existing systems, leading to excess material or scrap (CIDB, 2003). Planning failures in logistics, such as improper transport or inadequate on-site storage of prefabricated components, can cause damage to materials, further increasing wastage (Zawawi, 2009).

In Malaysia, initiatives to standardise components have shown promise in reducing waste in modular construction projects (CIDB, 2015). In recent years, efforts to reduce IBS wastage have included better training programs, stricter regulations on handling and transportation of IBS components, and technological innovations that improve waste minimisation at both the design and production stages. However, challenges still remain in scaling these improvements across the broader construction industry in Malaysia (Yunus, 2011). Hence, the current framework for waste management in modular construction is still developing. Although modular construction has the potential to significantly reduce waste compared to traditional methods, achieving these reductions consistently requires meticulous planning and execution, as well as robust waste management practices at both the production and construction sites (Loizou et al., 2021). Thus,

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the objectives of this research are to identify the types of wastage produce in Modular Construction, to investigate the factors that contribute to the wastage produce in Modular Construction and to propose mitigation plan to reduce wastage pertaining to Modular Construction.

METHODOLOGY

For this research, a qualitative method was used. Both primary and secondary data were employed where the primary data was obtained through in-depth interviews and the secondary data was used in the process of gathering information for the literature review. The purposive sampling was targeted participants to the Contractors registered with the Construction Industry Development Board (CIDB). A pilot study typically involves a small number of participants to test the feasibility of the research design and data collection tools. The population size for the common range for purposive sampling is 5 participants, was used to compute the sample size for this research A sample size of 5 is often considered acceptable in qualitative research because the focus is on depth rather than breadth, and the goal is not to achieve generalisability but to gather insights and improve the study design (Lim & Tan, 2022). In qualitative research, a pilot study is typically conducted to test the feasibility of the research design, methodology, and tools. The number of participants in a pilot study varies, but in qualitative research, smaller sample sizes are common. A pilot study for a qualitative study on modular construction in Malaysia may include anywhere from 5 to 15 participants, depending on the scope and complexity of the study (Ahmad & Rahman, 2020). The goal is not to achieve statistical generalisation but rather to refine data collection techniques and ensure clarity in the research process. The term thematic review using ATLAS.ti as the tool introduced by (Zairul, 2020; Zairul, 2021) was applied as this research method applies thematic procedure in literature reviews. When analysing the interview transcripts, ATLAS.ti was used to code the data, facilitating the identification of themes related to sustainability and cost-efficiency in modular construction (Rahim & Kamaruddin, 2021). According to Clarke & Braun (2013) defined thematic analysis as a process of identifying the pattern construct themes over through reading on the subject. The next step is to identifying the pattern form a category to understand the trend of wastage produce in modular construction.

In this qualitative research on minimising wastage in modular construction using ATLAS.ti, the process typically involves several key steps. First, researchers collect data through interviews, observations, and document reviews related to waste management in modular construction. These data are then imported into ATLAS.ti for analysis. The next step is coding, the researchers systematically label segments of text related to wastage minimisation strategies, categorising the data into themes such as types of wastage, factors of wastage, and mitigation plans. Through the software's advanced tools, like network views and co-occurrence analysis, researchers identify patterns and relationships between different waste minimisation practices. ATLAS.ti also allows for the visualisation of findings, helping researchers map out the causes of wastage and the effectiveness of various solutions. Finally, the insights gained from this analysis are used to develop recommendations for reducing waste in modular construction projects, based on the data-driven evidence gathered through the qualitative research process.

RESULTS AND DISCUSSION

The interview was conduct via online platform and physical meeting with the selected contractors. Selection bias occurs when the participants selected for the pilot study are not representative of the broader population of interest. Include a diverse range of participants, such as large, medium, and small companies, as well as government bodies and consultants involved in the modular construction industry (Creswell J. W., 2014). For this pilot study, participants included project managers, architects, engineers, and regulatory bodies

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such as CIDB, reflecting the diverse stakeholders involved in modular construction (Ahmad & Rahman, 2020). These stakeholder groups are crucial for gaining a comprehensive understanding of the key factors affecting modular construction in Malaysia. A well-rounded pilot study can offer valuable insights from different perspectives, leading to a more refined and successful full-scale study. The obtained data was analysed and tabulated using Thematic analysis using ATLAS.ti Version 24. ATLAS.ti is a qualitative data analysis software used for coding and analysing qualitative data, such as interviews, surveys, and other textual or multimedia data.

For this study, a pilot study was conducted to serve as the preliminary phase of the overall research protocol, involving a smaller-scale investigation designed to aid in the planning and refinement of the main study. It precedes the primary trial to assess the study's feasibility and validity. In-depth interviews using purposive sampling targeting IBS experts were conducted to gain information on how IBS adoption could minimise wastage in modular construction. The findings of this preliminary pilot study have highlighted significant information pertaining to the types of waste, influencing factors and mitigation plans on reducing wastage in modular construction.

Types of Wastage

Data from the interview's highlights that the types and quantities of waste generated during modular construction are influenced by multiple factors, including design efficiency, material selection, and construction practices. Design inefficiencies, such as poor planning or miscalculations, can result in excess material usage or offcuts, while the choice of materials plays a crucial role in determining waste levels. For example, selecting materials with shorter lifespans or those prone to damage during transportation can lead to greater waste. Construction practices, particularly those involving assembly and handling of modules can also influence the amount of waste produced, as improper techniques or lack of precision can lead to material loss.

Additionally, improper storage conditions emerge as a significant factor in material damage and subsequent waste generation. When modules are stored without adequate protection from environmental elements, such as moisture, extreme temperature fluctuations, or physical impacts, they are susceptible to degradation. Exposure to moisture, for instance, can lead to mold growth, warping, or weakening of structural components, while temperature fluctuations can cause materials to expand or contract, compromising their durability. Physical impacts, such as rough handling or insufficient protection during storage, may result in surface damage or structural impairments. These issues not only degrade the quality of materials but also increase the likelihood of waste, as damaged modules may need to be repaired or replaced. Consequently, the implementation of proper storage protocols is essential in preserving material integrity and reducing waste during the modular construction process. This pilot study helps to knowledge the research objectives in types of wastage produce in modular construction in Malaysia.

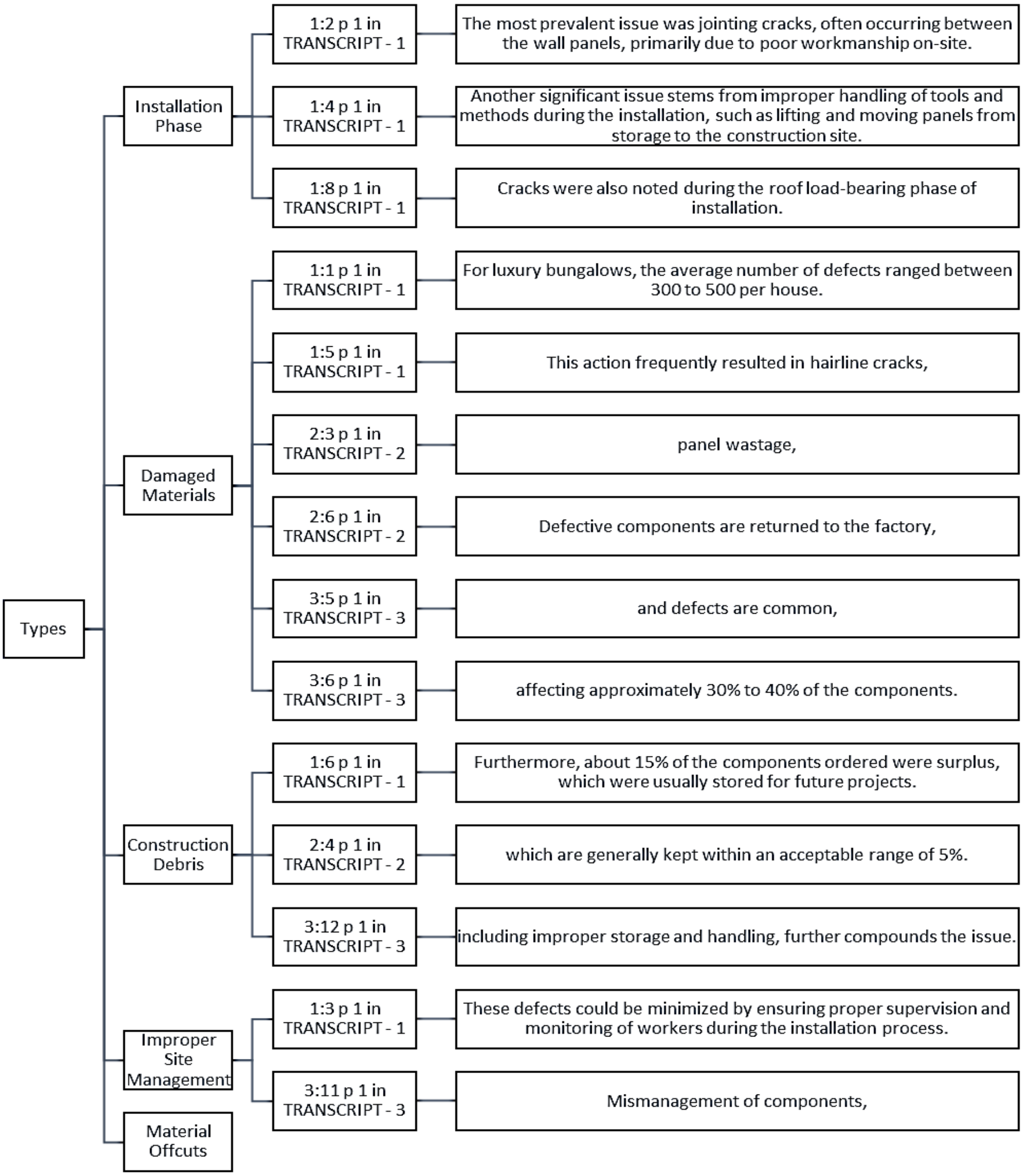

Fig. 1. Overall Network to Answer Research Question 1

Source: Authors (2024)

Factors that Contribute to Wastage

In Malaysia, the adoption of modular construction has been promoted as a means to reduce wastage. However, despite its potential benefits, several factors still contribute to wastage in this construction method. The use of high-quality wall panels in construction results in smooth surfaces with minimal errors, offering time savings and durability. However, challenges due to defects caused by design and planning, manufacturing process, workers lack required skills and training, transportation, supply chain and logistics, workmanship, as well as site management need to be addressed.

The most crucial factors in producing wastage is modular construction in Malaysia is, design and planning wastage often caused by defects due to the complex nature of offsite production, where standardised designs and sizes sometimes limit flexibility during construction phase. For instance, during the installation phase, precast concrete elements may not align or fit as intended, often due to slight discrepancies in design or manufacturing tolerances. This misalignment can necessitate trimming or cutting portions of the material to achieve the desired fit, resulting in the generation of waste. In some cases, if the discrepancy is too significant, entire elements may need to be discarded and replaced, further increasing material waste. Such issues underscore the importance of precision in the design, manufacturing, and installation processes to minimise excess material and reduce the overall waste generated in construction projects.

Moreover, the manufacturing process itself can contribute to significant waste. Improper curing of concrete panels, for example, can result in dehydration, causing cracks and compromising the structural integrity of the panels. These defects render the panels unusable or require additional resources to repair, leading to further material wastage. Inadequate quality control during manufacturing, such as incorrect curing times or improper environmental conditions, exacerbates these issues, as damaged or defective components must be discarded or reworked. Addressing these manufacturing inefficiencies is critical to minimising waste and ensuring that materials are utilised effectively in construction. Besides that, defects can also occur during transportation and logistics management. For example, long journeys to transport components as well as exceeding components quantity per trip to reduce transportation cost can lead to components defects. Other than that, poor site management with improper storage can also contribute to wastage in modular construction. The wastage of products in modular construction in Malaysia which significantly influenced by factors related to worker skill and training can be addressed through comprehensive training programs, certification, on-the-job training, quality control measures, and continuous professional development. This can mitigate material wastage and improve overall construction efficiency. This pilot study helps to knowledge the research objectives in factors contributed to the wastage produce in modular construction in Malaysia.

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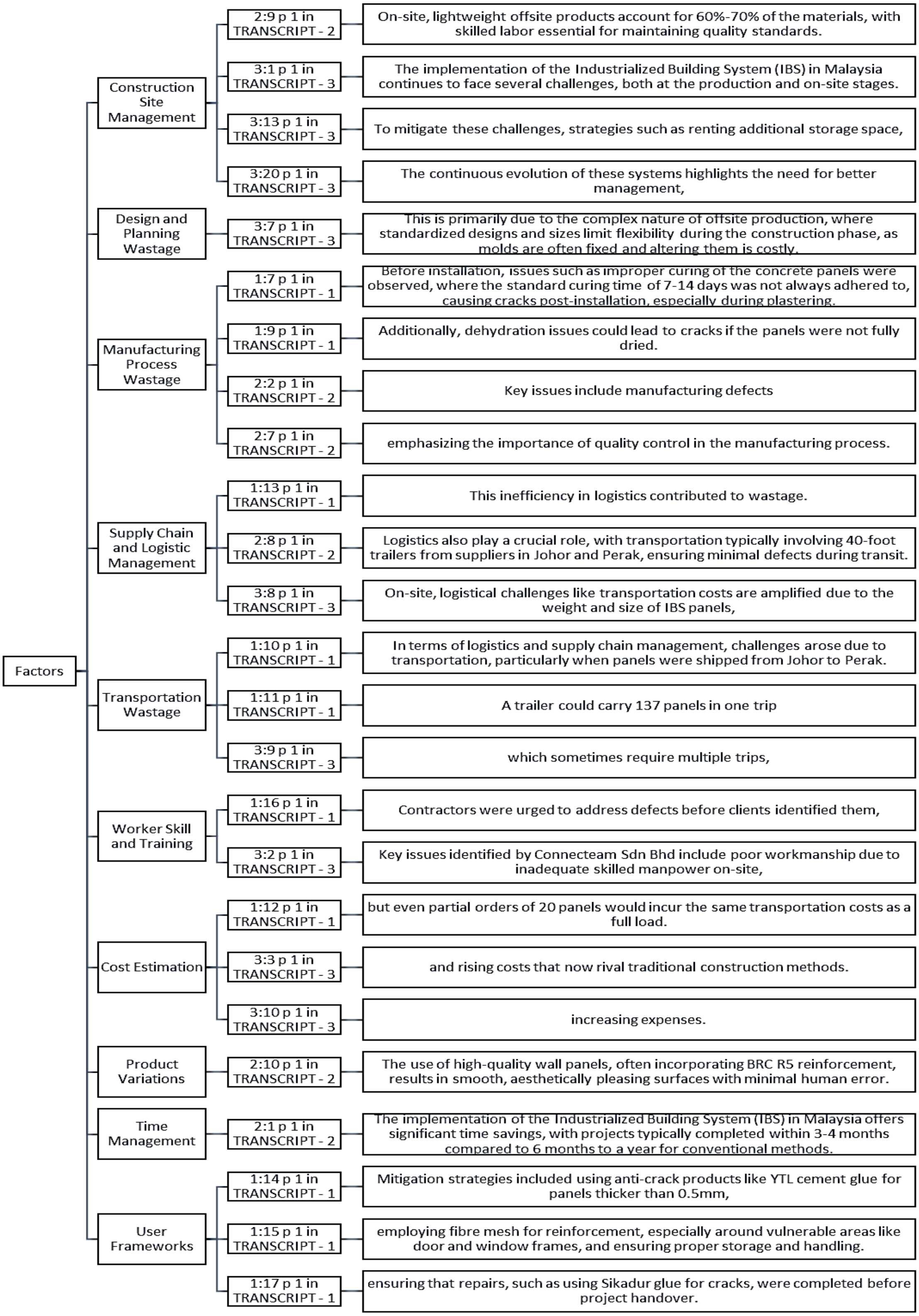

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Fig. 2. Overall Network to Answer Research Question 2

Source: Authors (2024)

Strategies to Reduce Wastage

Fig. 3. Overall Network to Answer Research Question 3

Source: Authors (2024)

Wastage in modular construction due to defects of components can be mitigated through precise design optimisation and components standardisation, improved supply chain management, Artificial Intelligence (AI) and smart technologies adoption, training and awareness programs, as well as waste recycling and reuse practice. For instance, optimising AI tools and smart technology such as Information Modeling (BIM) can enhance precise planning and execution in construction projects and thus reducing defects which lead to wastage. Furthermore, government policies and regulations could facilitate encouraging the use of IBS for better efficiency and wastage reduction. In Malaysia, there's a push for the adoption of Industrialised Building Systems (IBS) to improve efficiency wastage reduction. The government mandates the use of IBS for certain projects and aims to standardise its usage across the industry. Apart from that, initiatives such as reusing and recycling materials, creating IBS-specific industrial zones, and workforce training are being implemented to promote sustainable practices and maximise the benefits of modular construction.

Besides that, Artificial Intelligence (AI) and smart technologies, such as Building Information Modeling (BIM) and the Internet of Things (IoT), are increasingly being adopted in modular construction, enhancing efficiency, precision, and sustainability. Modular construction including systems like the Industrialised Building System (IBS) in Malaysia, benefits from these technologies by improving processes like design, manufacturing, and on-site assembly. BIM enables highly detailed 3D models that facilitate the precise planning of modular components before construction begins. By providing accurate design models, BIM reduces errors, rework, and over-ordering of materials (Smith & Thomas, 2021). In example, when integrating BIM in modular construction, project managers can use data from previous projects to predict material requirements more accurately, avoiding overproduction or underutilisation. Furthermore, AI algorithms can analyse large datasets from previous modular construction projects to optimise the design of new buildings. AI can predict potential delays, cost overruns, or material shortages by analysing project data in real-time. This helps project managers make proactive decisions to mitigate risks, ensuring that modular construction projects stay on track (Rahman & Ismail, 2021). AI can use machine learning algorithms to predict where material waste is most likely to occur, allowing for proactive measures. It can also optimise the cutting of materials, reducing excess waste during production or fabrication of modular units (Lee & Lim, 2022). In addition, IoT-enabled sensors can detect inefficiencies during the transportation and assembly of modular components. For instance, if certain materials are at risk of damage during storage or transit, IoT sensors can alert project managers, preventing unnecessary waste (Zhang & Liu, 2020). By monitoring the condition of materials in real-time, IoT can prevent wastage due to environmental factors such as moisture and temperature fluctuations that may affect material integrity.

By integrating AI, BIM, and IoT, the entire modular construction process can be automated and optimised. BIM serves as the digital foundation, while AI helps in decision-making, and IoT provides real-time feedback from sensors. This integration enhances coordination from the design phase to on-site assembly, leading to smarter, faster, and more sustainable construction processes. A modular construction project can employ BIM to design modular units with minimal waste, while IoT sensors monitor the condition and usage of materials, and AI algorithms predict potential waste points during manufacturing and assembly. Together, these technologies can help create an optimised, waste-efficient workflow (Khan & Abdullah, 2023). This pilot study helps to knowledge the research objectives in mitigation plans to reduce wastage in modular construction in Malaysia.

CONCLUSION

Defects in IBS components can occur due to factors such design and planning, manufacturing process, workers lack required skills and training, transportation difficulties, supply chain and logistics inefficiencies, workmanship, as well as poor site management. The findings also revealed recurring challenges such as jointing cracks, improper tool handling and techniques, excess components, inadequate curing of concrete panels ultimately contributing to waste generation in modular construction. Mitigation strategies include precise design optimisation and components standardisation, using anti-crack products, reinforcement methods, proper storage and handling, improved supply chain management, Artificial Intelligence (AI) and smart technologies adoption, training and awareness programs, as well as waste recycling and reuse practice. Wastage in modular construction due to defects of components can be addressed through precise design optimisation and components standardisation, improved supply chain management, Artificial Intelligence (AI) and smart technologies adoption, training and awareness programs, government policies and regulations to facilitate effective IBS implementation, as well as waste recycling and reuse practice. Adopting AI, BIM, and IoT in modular construction projects in Malaysia offers significant potential to minimise waste by improving the precision of design, monitoring real-time processes, and predicting inefficiencies before they happen. These technologies are especially valuable in modular construction, where prefabrication and assembly require precise coordination and resource optimisation. Besides that, assessment should also be carried out to guarantee the quality of products and components which serve as a guide to monitor and evaluate product quality and obtain certification that meets the standard. This can also minimise the waste production in modular construction in IBS construction projects. For future studies, this research suggests for testing the impact of AI or BIM on wastage reduction and conducting larger-scale studies to validate the findings.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

All authors contributed to the study conception and design. Data collection and analysis were performed by Siti Nurmarlina Kamaruddin. Dr Farrah Zuhaira Ismail conceptualised the overall research framework and supervised the research progress. The first draft of this article was written by Siti Nurmarlina Kamaruddin and Dr Farrah Zuhaira Ismail. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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