DEVELOPING A CONCEPTUAL FRAMEWORK FOR 'DESIGNING OUT WASTE' IN CONSTRUCTION CIRCULAR ECONOMY: A SYSTEMATIC LITERATURE REVIEW

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Construction is consuming large amounts of natural resources while producing high quantities of waste as the industry is following a reactive approach to waste management. A more effective approach is to 'design out waste (DoW)' by promoting waste reduction early in the project. However, the literature lacks a framework to support a systemic adoption of the DoW concept. This paper presents the preliminary results of a systematic literature review of 55 highly relevant journal articles to develop an integrated framework of DoW strategies and identify associated barriers. The framework includes nineteen strategies grouped under five principles. A socio-technical approach was adopted to categorise barriers into six barrier factors. The findings reveal that the 'Design for off-site construction' principle is the most effective for waste reduction, while there are many barriers associated with the 'Design for reuse and recovery' principle. The most prominent barriers are related to 'Industry structure' and 'People, knowledge and awareness' and the priority mitigating actions include adopting BIM tools, training, financial incentives, and policy support.

Keywords: construction; circular economy; design out waste

INTRODUCTION

The solid waste from construction activities constitutes about 40% of the total waste produced (Ajayi *et al.,* 2017). Over the past ten years, there has been a significant increase in the production of Construction and Demolition Waste (CDW), reflecting the exceptional economic expansion in developing countries (Pisarro, 2016). While waste management, intended to drive up the value chain of CDW, is important, it is a reactive approach and does not solve the problem of how to reduce the volume of materials entering the waste stream. Waste management should go in tandem with waste reduction, but the former has been the focus of the construction industry with the latter only starting to receive attention. This paper focuses on the latter.

Among the different stages of construction, the design stage is a crucial step in achieving waste reduction at the source since it is the stage when material usage can be controlled (Llatas and Osmani, 2016). There are suggestions that 33% of all on-

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site waste is due to a failure to implement waste reduction measures during the design stages (Abadi *et al.,* 2023). Possible sources of materials becoming waste include incorrect procurement in ordering and take-off errors for construction waste generation (Mohammed *et al.,* 2021), improper material handling activities (Mohammed *et al.,* 2021), inefficient design documents (Ajayi *et al.,* 2017), and inadequate design consideration for the construction demolition (Osmani *et al.,* 2008).

The construction industry is increasing adopting a proactive approach to the Circular Economy (CE) to eliminate waste, reduce energy consumption and carbon emissions in material production, and enhance resource efficiency (Waheed *et al.,* 2024). This strategy, termed 'Designing Out Waste (DoW)', aims to minimise waste, optimise resource use, and strengthen the synergy among the environment, economy, and society (WRAP, 2009). It advocates for designing long-lasting products with sustainable materials (Jahan *et al.,* 2022). By focusing on waste minimisation at the source, DoW seeks to reduce waste production and facilitate the reuse, recycling and recovery of materials throughout the building lifecycle.

The DoW approach advocates the proactive minimisation of potential construction and demolition waste (CDW) at source level through efficient use of materials from at every stage of the building lifecycle (Laovisutthichai *et al.,* 2022). The UK government-funded Waste and Resources Action Programme (WRAP, 2009) identified five principles of the DoW concept, focused on design for efficient procurement, materials optimisation, off-site construction, reuse and recycling, and deconstruction. However, turning the principles into actions is difficult and there lacks an integrated framework of strategies to facilitate the effective implementation of the DoW approach in construction. Moreover, barriers to the effective implementations of these strategies and potential priority mitigation actions need to be understood

This paper conducts a systematic review of DoW and proposes a conceptual framework based on the WRAP principles of DoW. The framework aims to identify detailed strategies that are actionable and effectively guide researchers or practitioners in implementing DoW within the construction sector. The framework of strategies was developed further to recognise barriers and the corresponding mitigating actions to overcome the barrier factors. The research questions based on the proposed research are:

RQ1. What are strategies that can facilitate the DoW approach?

RQ2. What are the barriers to the implementation of the identified DoW strategies?

RQ3. What are mitigating actions to overcome these barriers?

The 'Design Out Waste' Principles

The five DoW principles as encouraged by WRAP are:

(i) design for waste efficient procurement,

(ii) design for materials optimisation,

(iii) design for off-site construction,

(iv) design for reuse and recycling, and

(v) design for deconstruction and flexibility.

The first principle ensures resource-efficient procurement methods, simplified material specifications, reduced waste, and optimised procurement routes (Bilal *et al.,* 2015). The second principle focuses on the efficient material use during design (Othman and Elsawaf, 2021). The third principle involves volumetric and modular construction, off-site pre-cut and prefabricated building elements, and off-site prefabrication of structural elements (WRAP, 2009). The fourth principle relates to using recycled materials, reusing sites and buildings, and incorporating recycled components and demolition materials throughout the project lifecycle (Pisarro, 2016; Othman and Elsawaf, 2021). The fifth principle encourages maintenance, refurbishment, and effective material recovery throughout the building life cycle with focus on the end-of-life stage (Othman and Elsawaf, 2021). The framework proposed later in this paper will classify DoW strategies under the five WRAP principles. A systematic literature review is conducted in this study to identify design strategies relevant to the five WRAP principles, and a framework is proposed to the facilitate the implementation of the DoW approach.

The Socio-Technical System

The socio-technical System (STS) is an organisational theory that aims to achieve system success through cooperative optimisation by considering both social and technical subsystems. STS uses knowledge to guide the design of technology-enabled communities and systems. It includes six subsystems related to structure, people, goals, procedure, technology, and culture (Davis *et al.,* 2014; J. Hester, 2013).

First, 'industry structure' includes workflow, authority, and communication systems. Second, 'people, knowledge, and awareness' are actors with their experiences and awareness encompassing organisation members and primary constituents who either execute or influence the work. Third, 'goals and incentives' delineate the purpose of the work system and its support to the organisation. Fourth, 'procedure' is a method or instruction that is used to complete each aspect of the task or objectives. Fifth, 'technology' is a tool employed within the labour system. Sixth, 'culture' of an organisation is the set of values, expectations, and practices that influence and direct the behaviour of its members. Based on the definitions, the barriers of the DoW strategies will be categorised into six barrier factors using a socio-technical framework according to their occurrence. These include: 'Industry Structure', 'People, Knowledge, and Awareness', 'Goals and Incentives', 'Procedure', 'Technology' and 'Culture'.

METHOD

To answer the above research questions, the first step is to conduct a systematic literature review (SLR) of the relevant construction. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) procedure, 55 peer-reviewed journal articles were identified, including a title search focusing on 'Design Out Waste' and waste reduction strategies in construction, and an inductive approach to explore interactions between the identified DoW strategies, associated barriers, and relevant mitigating actions. Figure 1 summarises the data collection process used in this study.

As shown in the PRISMA flowchart in Figure 1, there were three main stages: data identification, screening, and inclusion. The data identification started in March 2024, and covered the databases in 'Google Scholar', 'Scopus' and 'Web of Science'. This resulted in 1,142 records comprising journal articles, conference papers, doctoral dissertations, books and a small number of others. In the screening stage, 302 duplicate records, 10 records marked as ineligible by the automation tools, and 360 non-journal articles were removed. Moreover, the authors browsed through the abstracts of the remaining articles, which resulted in the removal of 218 unretrievable full text articles and 197 irrelevant articles. The final research sample includes 55 peer-reviewed journal articles relevant to the research topic (54% building sector, 46% construction in general).

A bibliometric analysis, including chronological and geographical distributions, was performed on the final SLR sample to trace the intellectual structure and growth patterns of this field of research. A framework for implementing the DoW approach was developed by classifying waste elimination/reduction strategies identified in the research sample under the five WRAP principles. Barriers associated with these strategies were identified and categorised into six barrier factors (i.e. categories) using a socio-technical framework; these include: 'Industry Structure', 'People, Knowledge and Awareness', 'Goals and Incentives', 'Procedure', 'Technology' and 'Culture'. The effectiveness of the identified strategies to the DoW in construction, and the magnitude of the identified barriers were established based on the frequency of their occurrence in the SLR sample. Moreover, a Sankey diagram was used to map the associations between the identified strategies and barriers as perceived in the research sample. Finally, a list of mitigating actions was proposed with focus on the principle associated with the largest number of barriers, the barrier impacting on the largest number of strategies, and the most prominent barrier factors in the research sample.

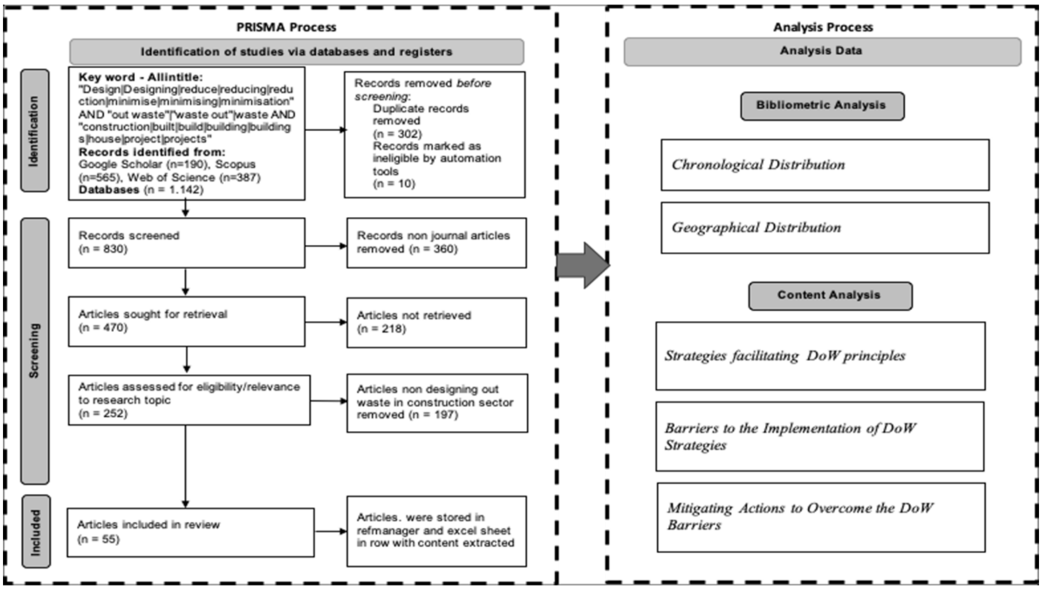

Figure 1: A Systematic Literature Review Procedure

FINDINGS

The chronological distribution of articles in the research sample, Figure 2, shows that studies related to the DoW approach have increased significantly in the past decade. Reducing construction waste is a topical issue in many countries (Esa *et al.,* 2017). Figure 3 shows the geographical distribution of countries where studies in the SLR sample were conducted. There are 5 regions, 12 countries, and 47 occurrences that can be identified from 55 journal articles. The distribution reveals that the region with the highest production of articles in 'Design Out Waste' (DoW) was Asia, and China was the most productive country that published articles discussing this issue. China had witnessed a large increase in construction activities and waste production because of its increasing urbanisation. The Chinese government is pushing research related to prefabricated construction because it produces less trash than traditional cast-in-situ construction (Hao *et al.,* 2021). Asia was a region with the largest population in the world that will need to develop more housing and residential buildings for the next future.

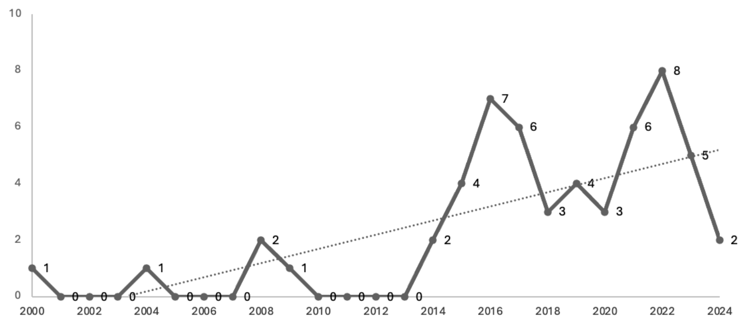

Figure 2: The chronological distribution of the research sample

Regions	Countries	Number	Percentage	Rank
Asia (55.32%)	China	13	27.66%	1
	Malaysia	5	10.64%	3
	Egypt	4	8.51%	4
	South Korea	2	4.26%	6
	Turkey	1	2.13%	7
	Singapore	1	2.13%	7
Europe (34.04%)	The UK	12	25.53%	2
	Spain	3	6.38%	5
	Slovak	1	2.13%	7
Oceania (6.38%)	Australia	3	6.38%	5
Africa (2.13%)	Republic of Mauritius	1	2.13%	7
Latin America & Caribbean (2.13%)	Costa-Rica	1	2.13%	7
		47	100.00%	

Figure 3: The geographical distributions of the research sample

Contents Analysis

This section provides an analysis of the contents of the SLR to provide insight into the three research questions.

Strategies facilitating DoW principles

Table 1 shows a total of 19 strategies (S1-S19) classified under the five DoW principles suggested in the WRAP report, and their frequencies occurrence in the SLR samples. The findings reviled that the 'Design for off-site construction (29.89%)' principle was the most effective principle to design out waste in construction, while the 'Prefabrication manufacturing (11.96%)' was perceived in the research sample as the most effective DoW strategy.

Table 1: A framework of Strategies for the DoW implementation in construction

DoW Principles	Code	Strategies	References	Frequency	Rank
Design for off-site construction. Freq: 55 (29.89%)	S1	prefabrication manufacturing	(Wang et al., 2014; Othman and Elsawaf, 2021; Laovisutthichai et al., 2022)	22 (11.96%)	1
	S2	designing for modern method of construction	(Osmani et al., 2008; Laovisutthichai et al., 2022)	14 (7.61%)	3
	S3	pre-assembled elements	(Wang et al., 2014; Othman and Elsawaf, 2021)	10 (5.43%)	6
	S4	modular design principles	(Waheed et al., 2024; Wang et al., 2014)	9 (4.89%)	7
Design for reuse and recovery. Freq: 43 (23.37%)	S5	reuse existing sites and materials	(Mohammed et al., 2021; Othman and Elsawaf, 2021; Jahan et al., 2022)	19 (10.33%)	2
	S6	recycling component and demolition materials	(Osmani et al., 2008; Othman and Elsawaf, 2021)	14 (7.61%)	3
	S7	segregate or sorting waste	(Hao et al., 2019; Mohammed et al., 2021)	6 (3.26%)	9
	S8	recovery component and demolition materials	(Mohammed et al., 2021; Waheed et al., 2024)	4 (2.17%)	11
Design for material optimisation. Freq: 35 (19.02%)	S9	material logistics management	(Esa et al., 2017; Jahan et al., 2022)	14 (7.61%)	3
	S10	designing for standard materials size	(Osmani et al., 2008;Othman and Elsawaf, 2021)	12 (6.52%)	4
	S11	optimised layout	(Ajayi et al., 2017; Mohammed et al., 2021)	5 (2.72%)	10
	S12	selecting a local material	(Othman and Elsawaf, 2021; Waheed et al., 2024)	4 (2.17%)	11
Design for waste-efficient procurement. Freq: 32 (17.39%)	S13	accuracy and comprehensiveness of design documents	(Laovisutthichai et al., 2022; Osmani et al., 2008)	12 (6.52%)	4
	S14	contract management	(Ajayi et al., 2017; Esa et al., 2017)	8 (4.35%)	8
	S15	considering material lifetime and durability	(Llatas and Osmani, 2016; Waheed et al., 2024)	8 (4.35%)	8
	S16	feasibility study of waste estimation	(Baldwin et al., 2009; Ajayi et al., 2017)	4 (2.17%)	11
Design for deconstruction and flexibility. Freq: 19 (10.33%)	S17	use a flexible design	(Bilal et al., 2015; Ajayi et al., 2017)	11 (5.98%)	5
	S18	designing for deconstruction	(Osmani et al., 2008; Bilal et al., 2015)06/06/2024 17:48:00	4 (2.17%)	11
	S19	considering maintenance and refurbishment	(Waheed et al., 2024; Othman and Elsawaf, 2021)	4 (2.17%)	11
				184 (100.00%)	

These findings align with literature that the prefabrication of building elements off-site and precast design can effectively reduce approximately 84.7% of construction waste (Jahan *et al.,* 2022; Hassan and Alashwal, 2024). Extensive off-site construction decreases waste management costs and mitigates global environmental and social impacts (Hao *et al.,* 2021; Li *et al.,* 2015). Additionally, prefabricated reduces labour and overall construction costs (Jahan *et al.,* 2022; Wang *et al.,* 2014).

Therefore, strategies in ' Design for off-site construction' should be priority in the DoW implementation. The 'Design for reuse and recovery (23.37%)' principle came second, 'Design for material optimisation (19.02%)' came third, and 'Design for waste-efficient procurement (17.39%)' came forth. The 'Design for deconstruction and flexibility' came last with only 10.33% suggesting more research will be needed to develop strategies relevant to this principle. This framework of strategies can assist researchers and practitioners in determining DoW's implementation priorities in the early stages in construction based on DoW principles.

Barriers to the Implementation of DoW Strategies

Barriers to the implementation of the DoW strategies were identified in the research sample; 21 barriers in total (B1-B21). These were classified into six barrier factors, i.e. categories, using a socio-technical framework, Table 2. Moreover, the importance of the identified barriers was established based on the frequency of their occurrence in the SLR sample. Findings revealed that the most prominent barrier factor was 'Industry Structure (24.39%)', with the 'lack of commitment of project stakeholders' being the main barrier listed under this category. This barrier was the most prevalent (13,41%) compared to other barriers.

Table 2: Barriers to the DoW implementation classified using a socio-technical framework

Barrier Factors	Code	Barriers	References	Frequency	Rank
Industry Structure Freq: 20 (24.39%)	B1	lack of commitment of project stakeholders	(Ajayi et al., 2017; Jahan et al., 2022; Hassan and Alashwal, 2024)	11 (13.41%)	1
	B2	lack of commitment of the policymaker	(Jahan et al., 2022; Osmani et al., 2008)	6 (7.32%)	3
	B3	ineffective communication throughout the building lifecycle	(Osmani et al., 2008)	2 (2.44%)	7
	B4	inadequacy of the education system	(Abarca-Guerrero et al., 2017)	1 (1.22%)	8
People, knowledge, and awareness Freq: 17 (20.73%)	B5	lack of knowledge to design out waste	(Jahan et al., 2022; Mohammed et al., 2021)	7 (8.54%)	2
	B6	lack of experiences and skills in construction practices	(Laovisutthichai et al., 2022; Yu et al., 2021)	6 (7.32%)	3
	B7	lack of training	(Osmani et al., 2008; Jahan et al., 2022)	4 (4.88%)	5
Goals and incentives Freq: 15 (18.29%)	B8	low incentive for waste operation	(Yu et al., 2021; Mohammed et al., 2021)	5 (6.10%)	4
	B9	high initial cost for waste management	(Abarca-Guerrero et al., 2017; Jahan et al., 2022)	4 (4.88%)	5
	B10	lack of a well-developed waste recycling market	(Abarca-Guerrero et al., 2017; Yu et al., 2021)	3 (3.66%)	6
	B11	design change	(Mohammed et al., 2021; Hassan and Alashwal, 2024)	2 (2.44%)	7
	B12	low cost for construction waste disposal	(Mohammed et al., 2021)	1 (1.22%)	8
Procedure Freq: 11 (13.41%)	B13	lack of guidance/standard for reducing construction waste	(Mohammed et al., 2021; Jahan et al., 2022)	4 (4.88%)	5
	B14	lack of imposing the design out waste in the contract	(Hassan and Alashwal, 2024; Jahan et al., 2022)	4 (4.88%)	5
	B15	lack of supervision/monitoring system	(Mohammed et al., 2021; Yu et al., 2021)	3 (3.66%)	6
Technology Freq: 10 (12,20%)	B16	lack of technology tools usage	(Bilal et al., 2015; Llatas and Osmani, 2016)	5 (6.10%)	4
	B17	lack of design and documentation using technology	(Hassan and Alashwal, 2024; Mohammed et al., 2021)	3 (3.66%)	6
	B18	lack of methods and design tools	(Jahan et al., 2022; Llatas and Osmani, 2016)	2 (2.44%)	7
Culture Freq: 9 (10,98%)	B19	non-collaborative culture	(Hassan and Alashwal, 2024; Ajayi et al., 2017)	4 (4.88%)	5
	B20	waste accepted as inevitable	(Osmani et al., 2008; Abarca-Guerrero et al., 2017)	3 (3.66%)	6
	B21	difficulties in changing work practices of workforce	(Ajayi et al., 2017; Abarca-Guerrero et al., 2017)	2 (2.44%)	7
				82 (100.00%)	

This was closely followed by the 'People, knowledge, and awareness (20.73%)' and 'Goals and incentives (18.29%)' barrier factors reflecting the importance of policies and industry guidance to raise awareness and create incentive for strategy adoption. Despite of their collective importance, the remaining three barrier factors, including 'Procedures (13.41%)', 'Technology (12.20%)' and 'Culture (10.98%)', received less attention in the research sample. On the other hand, the 'Lack of commitment of project stakeholders (13.41%)' was the most frequently mentioned barrier in the research sample. These findings align with literature that one significant barrier to reducing construction waste is the lack of stakeholders' commitment and support for a waste management plan (Abarca-Guerrero *et al.,* 2017). It is essential for all stakeholders to commit to ensuring compliance with the waste management plan (Esa *et al.,* 2017).

The associations between the DoW principles/strategies and the identified factors/barriers were also mapped, Table 3 and Figure 4. The thickness of the flows in the Sankey diagram in Figure 4 reflects the effectiveness of DoW strategies and the magnitude of associated barriers based on their frequencies in the research sample, which are presented as (occurrence, percentage) corresponding to the 'Frequency' column in Table 1 and 2. The findings revealed that strategies under the 'Design for reuse and recovery' principle were associated with the largest number of barriers, 12 barriers, reflecting on current concerns in the literature about difficulties associated with material reuse. Strategies under the 'Design for off-site construction' and 'Design for material optimisation' were associated with 10 barriers respectively. Lastly, the 'Design for waste-efficient procurement' and 'Design for deconstruction and flexibility' have 7 barriers for each. On the other hand, and despite its moderate importance in percentage terms, the 'Lack of experiences and skills in construction practices (7.32% - B6) and 'Lack of technology tools usage (6.10% - B16)' barriers had impacts on most DoW strategies, reflecting its criticality to DoW.

Table 3: Associations between the DoW strategies and identified barriers

Principles of Design Out Waste	**Barriers based on Socio-Technical System**					
	Industry Structure (B1-B4)	*People, knowledge, and awareness* (B5-B7)	*Goals and incentives* (B8-B12)	*Procedure* (B13-B15)	*Technology* (B16-B18)	*Culture* (B19-B21)
Design for off-site construction (S1-S4)	**S1-B2** (Li et al., 2015) **S2-B1** (Yu et al., 2021) **S3-B1** (Osmani et al., 2008)	**S1-B7** (Osmani et al., 2008) **S2-B6** (Osmani et al., 2008) **S3-B6** (Yu et al., 2021) **S4-B6** (Yu et al., 2021)	**S1-B9** (Abarca-Guerrero et al., 2017)	**S1-B13** (Jahan et al., 2022)	**S1-B16** (Jahan et al., 2022) **S4-B18** (Llatas and Osmani, 2016) **S2-B16** (Bilal et al., 2015)	**S1-B20** (Osmani et al., 2008) **S1-B21** (Jahan et al., 2022)
Design for reuse and recovery (S5-S8)	**S5-B4** (Abarca-Guerrero et al., 2017) **S6-B4** (Abarca-Guerrero et al., 2017)	**S5-B5** (Mohammed et al., 2021) **S5-B6** (Yu et al., 2021) **S6-B6** (Yu et al., 2021) **S8-B5** (Mohammed et al., 2021)	**S5-B8** (Abarca-Guerrero et al., 2017) **S5-B12** (Mohammed et al., 2021) **S6-B8** (Abarca-Guerrero et al., 2017) **S6-B10** (Mohammed et al., 2021) **S6-B12** (Mohammed et al., 2021) **S7-B9** (Jahan et al., 2022) **S8-B9** (Li et al., 2015) **S8-B12** (Mohammed et al., 2021)	**S5-B13** (Yu et al., 2021) **S5-B15** (Mohammed et al., 2021) **S6-B13** (Yu et al., 2021) **S6-B15** (Mohammed et al., 2021) **S8-B15** (Mohammed et al., 2021)	**S5-B16** (Jahan et al., 2022) **S6-B16** (Jahan et al., 2022)	**S5-B21** (Yu et al., 2021) **S6-B21** (Yu et al., 2021) **S7-B19** (Esa et al., 2017)
Design for material optimisation (S9-S12)	**S12-B1** (Esa et al., 2017)	**S9-B5** (Mohammed et al., 2021) **S10-B7** (Osmani et al., 2008) **S12-B6** (Osmani et al., 2008)	**S9-B12** (Mohammed et al., 2021)	**S9-B15** (Mohammed et al., 2021) **S10-B13** (Mohammed et al., 2021) **S11-B15** (Mohammed et al., 2021)	**S9-B16** (Jahan et al., 2022) **S10-B17** (Jahan et al., 2022)	**S10-B20** (Osmani et al., 2008)
Design for waste-efficient procurement (S13-S16)	**S14-B2** (Yu et al., 2021) **S15-B1** (Osmani et al., 2008)	**S15-B6** (Yu et al., 2021) **S16-B7** (Osmani et al., 2008)	**S13-B11** (Yu et al., 2021)	**S14-B14** (Jahan et al., 2022) **S16-B14** (Jahan et al., 2022)	**S13-B16** (Jahan et al., 2022)	**S13-B20** (Mohammed et al., 2021) **S16-B20** (Osmani et al., 2008)
Design for deconstruction and flexibility (S17-S19)	**S17-B1** (Bilal et al., 2015) **S18-B3** (Osmani et al., 2008) **S19-B1** (Othman and Elsawaf, 2021)	**S18-B7** (Osmani et al., 2008)	**S17-B11** (Hassan and Alashwal, 2024)	**S18-B13** (Mohammed et al., 2021)	**S18-B16** (Jahan et al., 2022)	**S18-B20** (Osmani et al., 2008) **S19-B21** (Abarca-Guerrero et al., 2017)

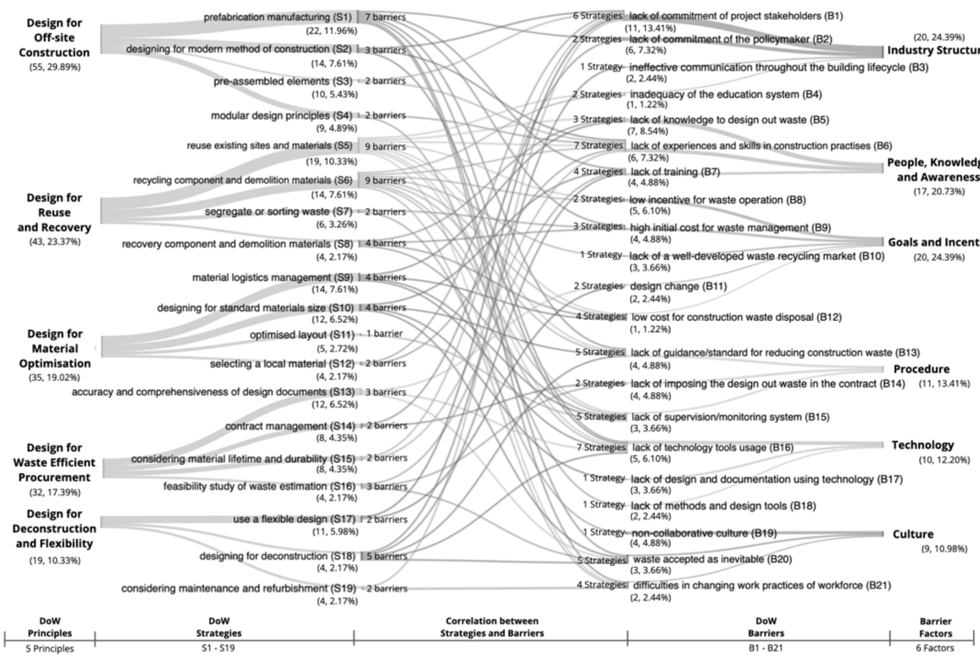

Figure 4: A Sankey diagram of DoW principles/strategies and associated barriers

Mitigating Actions to Overcome the DoW Barriers

Priority mitigating actions focus on: (i) the DoW principle associated with the largest number of barriers, (ii) the barrier that has impacts on the largest number of strategies, and (iii) the most prominent barrier factors in the research sample. Firstly, Table 3 showed the 'Design for reuse and recovery' principle was associated with the largest number of barriers, 12 in total. Based on Figure 4, The 'reuse existing sites and materials' and 'recycling component and demolition materials' strategies had the greatest number of barriers. From the ' Goals and incentives' perspectives, overcoming barriers would require a strategic use of CE policies to provide financial incentives for relevant DoW strategies (B8), offset the initial costs of waste reduction (B9), and prevent construction waste disposal (B12), which in turn will help develop the waste management market (B10). Form the 'Procedure' perspectives, guidance and standards at the industry level should promote CDW reduction rather that recycling (B13), and supervision systems should be established to monitor compliance (B15). These actions align with views in the literature that cost saving must be evident to project stakeholders to adopt DoW strategies (Jahan *et al.,* 2022) and providing financial incentives and CE policies are the most effective strategies to promote waste reduction in design practices (Osmani *et al.,* 2008).

Secondly, despite its moderate importance in percentage terms in Table 2, the 'B6: Lack of experiences and skills in construction practices (7.32%) and 'B16: Lack of technology tools usage (6.10%)' barriers had impacts on most DoW strategies, reflecting its criticality to the DoW (Figure 4). The lack of agreement on technology tool usage (Hassan and Alashwal, 2024) and the unavailability of technological capabilities across the project team (Abadi *et al.,* 2023) were the predominant challenges to implementing the DoW in construction. Even though Building Information Modelling (BIM) implementation in design practices can reduce construction waste generation by 4.3-15.2%, implementing this technology needs to be supported by providing guidance and standards in the construction sector. It is crucial to provide sufficient training related to CDW management and how to use BIM to improve the CE in construction. Providing training and education will improve attitudes toward waste minimisation (Jahan *et al.,* 2022). Moreover, incentives must be implemented after adequately training stakeholders (Liu *et al.,* 2015).

Lastly, based on Table 2, the 'Industry Structure (24.39%)', 'People and awareness (20.73%)', and 'Goals and incentives (18.29%)' were the most occurring barrier factors in the research sample, requiring careful addressment. Mitigating barriers in these categories requires a clear understanding of the roles and responsibilities of all team members (Ajayi *et al.,* 2017), effective communication and coordination of design information using BIM tools (Hassan and Alashwal, 2024), embedding sustainability and waste reduction in education at the university level (Abarca-Guerrero *et al.,* 2017), providing training on waste reduction to industry practitioners (Jahan *et al.,* 2022), ensuring fewer design changes during construction (Ajayi *et al.,* 2017), providing financial rewards for waste reduction (Osmani *et al.,* 2008), raising waste landfilling charges (Hao *et al.,* 2021), and providing access to alternative materials supply chains (Yu *et al.,* 2021).

CONCLUSIONS

There have been calls in the literature for adopting a more proactive approach to waste management in construction focused on waste reduction. However, both the literature and practice have lacked an integrated framework of strategies to support waste reduction in construction. The 'Design-out Waste (DoW)' approach proposed in this paper is an umbrella concept including design strategies focused on waste prevention from the early stages of a construction project. A systematic literature review including 55 journal articles was conducted, and a framework for the systemic implementation of the 'Design out Waste' approach in construction was proposed. The framework included nineteen strategies grouped into five key principles. The findings reviled the 'Design for off-site construction' and 'Design for reuse and recovery' strategies had more potentials for reducing waste in construction. Barries hindering the successful implementation of DoW strategies were also identified and classified into six barrier factors (i.e. categories) using a socio-technical framework. The 'Design for reuse and recovery' strategies were associated with more barriers, while the 'Industry structure' and 'People, knowledge and awareness' were the most prominent barrier factors in the research sample. Moreover, the associations between strategies in the proposed framework and identified barriers were mapped using a Sankey diagram. Subsequently, a list of priority mitigating actions was proposed to overcome the most prominent barriers. These include adopting standard BIM tools across the whole project team, providing training, offering financial incentives, and policy support.

The limitations of this study are twofold. Firstly, the proposed conceptual framework was based on the analysis of a secondary data in peer-reviewed journal articles with no support from empirical evidence drawn from industry settings. Secondly, the effectiveness of strategies in the framework and the magnitude of associated barriers were established based on their frequencies in the SLR sample, which may not reflect on reality. Future research will seek to validate the proposed framework using feedback from industry practitioners and develop a maturity model to support the embedment of DoW strategies in design practices.

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