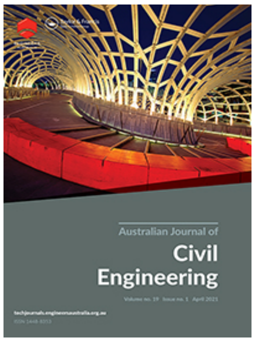

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ARTICLE

Front-end construction waste minimization strategies

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ABSTRACT

With construction waste accounting for 40% of all waste produced in Australia, this paper evaluates front-end strategies to minimize physical site waste on Australian projects. Front-end strategies are those practices at the initial phase of the material logistics chain that will reduce or totally remove site waste, rather than simply treat the residual waste product.

Following a global literature review, a qualitative methods approach using a pragmatic research framework was developed. The respondent sample for this research was from across the spectrum of Australian building and construction industry, varying from industry company directors to general superintendents.

The paper observes that the historically rapid increase in construction waste will be exacerbated by the very real increasing risk of waste due to recovery from disaster damage (bush fire, flood and storm surge coupled with climate change). Increasingly intelligent front-end strategies that minimize waste have therefore become a high priority for action.

It is concluded that the most effective way to reduce construction waste in Australia is via regulatory change, requiring policies and procedures that focus on front-end strategies. This paper explores some opportunities for action in the areas of management, design and procurement in line with the themes identified in the surveys

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Construction; Front End; Waste Minimisation Strategy

1. Introduction

The worldwide construction industry consumes the highest amount of raw materials (Yates 2013). Zero Waste Scotland (2017) estimates that, on average, approximately 13% of physical construction materials are wasted on project sites. A study by the World Economic Forum (WEF) suggests that 75% of construction waste, worldwide, is discarded (World Economic Forum 2016).

Non-renewable raw natural resources are subject to increasing pressure from the global construction boom and it has become vital to maximise the use of these natural resources to ensure sustainable construction methodologies (Paz et al. 2013). For example, major infrastructure projects in Melbourne (intended to support a population growth of around one million people in the past decade) are consuming 60 million tonnes of fresh rock per annum for the crushed rock aggregates the required to produce concrete, asphalt and other building materials (Dowling and Rooney 2019).

In the European Union, construction and demolition (C&D) waste is the source of up to 30% of all waste (European Union 2018). It also forms approximately 40% of all solid waste generated in the United States (US), Australia and China (Rundle, Bahadori, and Doust 2019; Ritchie 2016; Yates 2013). Between 55% and 58% of C&D waste is recovered in Australia for re-use or recycling (Davis 2018; Hickey 2015).

From 1996 to 2015, Australia's population increased by 28%, while during this same period, waste has exploded by 170%; refer to Figure 1 (Rundle, Bahadori, and Doust 2019, 47). Efficient waste management has become a matter of important environmental concern in Australia, with the OECD's fifth highest population growth in 2017 (World Bank 2017). Australia's population growth is 1.6%; considerably higher than countries with similar migration programs like Canada (1.2%) and the US (0.7%) (World Bank 2017). Australia is also one of the highest waste generators per capita in the OECD's 35 countries (OECD 2019).

Site waste minimisation will lead to reduced airborne pollutant emissions from the manufacture and transportation of the estimated 13% wasted physical construction materials (Faniran and Caban 1998). Construction waste reduction shall also benefit the environment by reducing the landfill footprint of approximately 2,000 or more unregistered landfill sites in Australia, many unlined and containing C&D waste (Ritchie 2016).

The Master Builders Association of Victoria (2004) research suggests that the cost of construction site waste adds approximately 10% to the cost of Australian building projects. Chandler (2016) posits that site waste for

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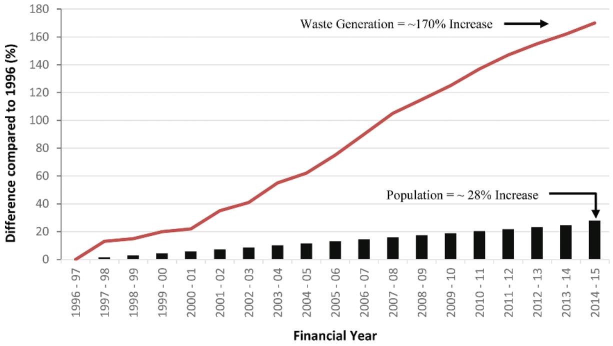

Figure 1. Population growth compared to waste generation from financial years 1996–97 to 2014–15.

residential construction in Australia, excluding high rise apartment dwellings, amounted to AUD 2.8 USD billion per annum. While Rundle, Bahadori, and Doust (2019, 82) argue that:

> The high cost impost on capital works projects due to physical material construction wastage, ranging from residential housing to mega multi-billion-dollar resource projects, would see massive savings to both the private and public sector building and construction industry if the two per cent savings that are mooted by following the 10 front-end strategies recommended by the University of Exeter were adopted.

Research into the examination of strategies to reduce or preferably remove physical site waste generation is warranted. Builder/contractor and owner stakeholders will commercially benefit from improved waste minimisation practices. Construction waste reduction is also an important factor in sustainable construction that will benefit the environment by reducing environmental pollution, minimising landfill use and maximising the utilisation of non-renewable raw materials for our future generations' built environment.

Despite the magnitude of the construction waste problem, the research has shown that limited improvement has occurred on the implementation of construction waste elimination strategies over the past 20 years. This is partly because government policy has focused on a recycling waste reduction strategy rather than strategies at the front-end of the cycle.

This technical paper reports on the qualitative research results of a Master of Science (Engineering Research) study of waste management practices on Australian construction sites conducted by engineer academics Dr Ken Doust and Peter G. Rundle, along with Associate Professor, Ali Bahadori at Southern Cross University, School of Engineering, Lismore, Australia (Rundle 2018). The objectives of the study were to (i) determine the relative potential sources of construction waste; (ii) identify suitable front-end waste minimisation strategies that would remove or reduce the creation of construction waste; (iii) provide innovative research knowledge that would benefit both practitioners and academics; and (iv) develop effective strategies to reduce site waste. For this research, front-end strategies are those that involve early engagement in the preliminary project design and development phase to remove or reduce site waste (Rundle, Bahadori, and Doust 2019, 2).

The primary focus of this technical paper is the research of front-end strategies, which are applicable to the initial stages of the logistics chain, to minimise construction waste on Australian projects. However, an overview of the key findings from the potential sources of construction waste research is also considered in this paper.

2. Existing waste management strategies

The literature review collated academic, practitioner, professional, regulatory and trade data on sustainability practices in construction waste management. At the completion of the detailed literature review, an analysis of the knowledge acquisition database by the researchers concluded that, based on the synthesis of information derived from the literature exploration, an examination of the possible effective and efficient front-end construction waste strategies would provide optimal triple-bottom-line commercial, environmental and community benefits to stakeholders.

2.1. *Waste* minimisation *strategies*

The construction waste management hierarchy, as outlined by Ferguson (1995), is the optimal approach to developing an initial construction site waste management strategy (Yeheyis et al. 2013; Faniran and Caban 1998). Faniran and Caban (1998, 182–183) found that the primary strategies for construction waste minimisation involved avoiding, eliminating or minimising waste at the source, and reusing or recycling waste materials in order to reduce the quantity of waste that is released into the environment.

Figure 2 provides a visual description of the construction waste management hierarchy. As advised by the literature, avoiding the production of construction waste is the highest priority as a waste management minimisation strategy (Rundle, Bahadori, and Doust 2019; Western Australian Waste Authority 2017; Chandler 2016; Yeheyis et al. 2013; Faniran and Caban 1998; Crittenden and Kolaczkowski 1995; Ferguson 1995).

Figure 3 illustrates that construction waste is categorised as either physical or non-physical waste (see Alarcon 1994). Physical construction waste is that which results from construction, renovation and demolition activities (Ferguson 1995). It includes, but is not limited to, concrete debris, bricks and blocks, glass, pallets and plastic wrapping, plasterboard, steel and timber offcuts, tiles and vegetation waste (Yates 2013). Non-physical construction waste results from process issues

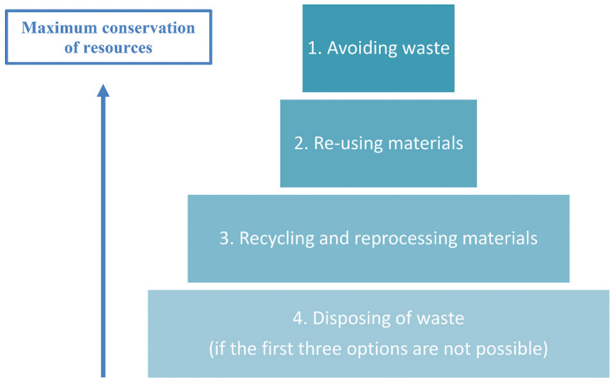

Figure 2. Construction waste management hierarchy (adapted from Rundle, Bahadori, and Doust 2019, 72).

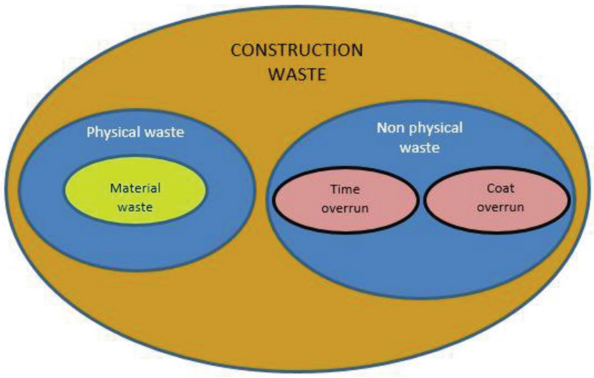

Figure 3. Physical and non-physical categories of construction waste (adapted from Nagapan, Rahman, and Asmi 2012, 2).

and delays that cause project cost and schedule over-runs; this can often involve equipment repairs and unnecessary labour costs (Nagapan, Rahman, and Asmi 2012). This paper only considers physical construction waste that has resulted from the project material logistics chain.

2.2. *Government policy sees recycling as key construction waste reduction strategy*

Over the past 20 years, Australian governments have prescribed to the recycling-focused waste management strategies that other OECD countries follow (Australian Council of Recycling 2016). Edge Environment (2012) reports that state governments have successfully reduced construction waste landfill. From the 2004–2005 financial year (FY) to the 2008–2009 FY, recycling rates of C&D residual waste increased from 7.6 million tonnes to 10.5 million tonnes, respectively (Edge Environment 2012). During this time, landfill rates of C&D showed a marginal increase from 7.5 million tonnes to 8.5 million tonnes (Edge Environment 2012). Since the collection of this data, recycling rates have continued to improve (State of the Environment Overview 2016).

However, to encourage this increase in recycling/recovery processes, landfill levies have also grown, resulting in negative consequences for the construction industry. Contractors from New South Wales (NSW) and Victoria have been transporting C&D waste over the Queensland border to take advantage of the lower levies; this has caused an increase in heavy vehicle movements, damage to roads, accident risk potential and carbon emissions, and a decrease in levy revenue for NSW and Victoria (Ritchie 2016).

Furthermore, in 2018, when China banned recyclable waste imports, recyclable commodity prices collapsed on a global level (Lasker 2018). The poor state of Australia's recycling facilities was exposed, revealing an urgent need to innovate and upgrade Australia's construction waste management strategies (Lasker 2018).

2.3. *Reducing waste on Australian projects using front-end strategies*

The aim of this paper is to investigate front-end strategies to reduce waste on Australian construction projects. Several informative Australian academic papers have been published over the past 15 years on various aspects of construction waste management (see Park and Tucker 2016; Udawatta et al. 2015; Zaman 2014; Tam 2009; Sugiharto, Hampson, and Sherid 2002). However, the literature review discovered a void in recent Australian academic research that solely investigated the avoidance of construction waste by using front-end waste management strategies, such as early project planning and prudent design. The purpose of this research is to add to the knowledge acquisition base and address this gap in the academic literature.

International academic literature in the new millennium has focused on construction waste management recovery and recycling strategies, duly encouraged by governments globally. That said, the global literature review uncovered several excellent papers on construction waste avoidance, such as Osmani, Glass, and Price (2008), which examined the views of architects from the UK about reducing site waste at the project design stage. Yates (2013) construction waste minimisation study provided an insight into recent USA developments in front-end waste reduction strategies for sustainable construction. Refer to Rundle, Bahadori, and Doust (2019) for further details of their research into front-end strategies to minimise waste on construction projects.

2.4. *Potential sources of site waste*

It became apparent during the literature review that to determine minimisation strategies for site waste it would also be necessary to evaluate the potential sources of this waste. Potential sources of construction waste were considered in detail as a component of the main body of the academic research (Rundle, Bahadori, and Doust 2019). However, to provide context, a brief overview is recommended of the seminal Australian construction waste research by Faniran and Caban (1998, 182), in which they argue that '[p]ractical waste minimization strategies require a detailed understanding of what causes construction waste. Effective methods for dealing with these wastes at their source can then be determined'.

3. Method

A qualitative methods approach was adopted for this study using a pragmatic research framework, which allows a combination of methods necessary to find research question answers (Rundle, Bahadori, and Doust 2019, 94). Data was collected by survey questionnaires asking for the respondents' demographical data, front-end site waste reduction strategies and potential sources of physical waste on construction sites. Refer to Figure 4, adapted from Rundle, Bahadori, and Doust

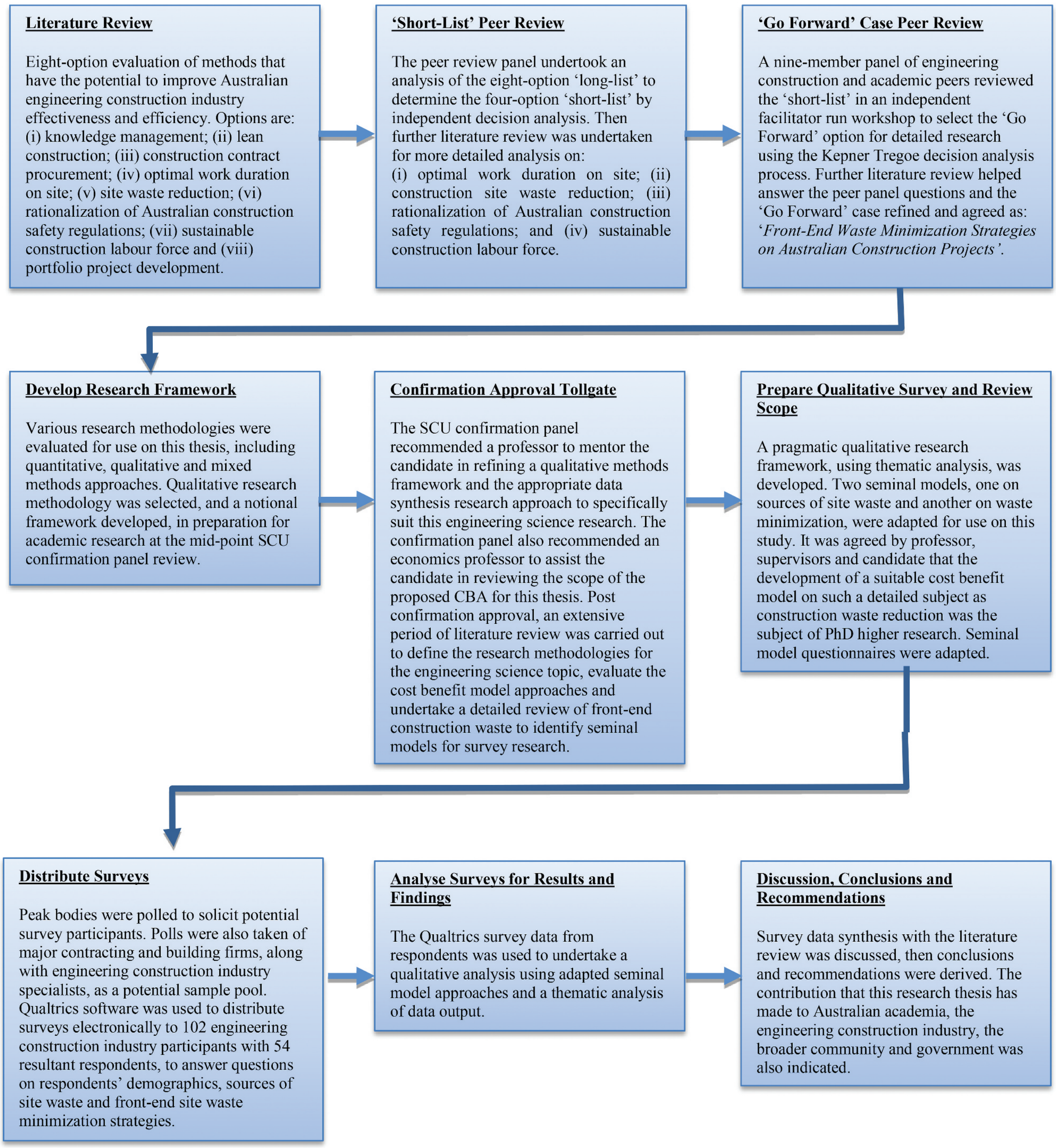

Figure 4. Research schematic (adapted from Rundle, Bahadori, and Doust 2019, 72).

(2019, 5), which provides a schematic of the research process.

3.1. *Front-end site waste* minimisation *strategies method*

Nine questions about front-end site minimisation strategies were derived from the literature review that adopted four Yates (2013) survey model questions related to front-end site waste minimisation strategies. Because the major contractor and building companies in the USA funded the Yates (2013) study, this questionnaire was a valuable research tool to compare Australian counterpart waste management strategies. The remaining four questions were included via a global literature review on front-end waste reduction. This questionnaire focused on upstream site reduction strategies.

Respondents answered 'yes', 'no', or 'don't know'. If respondents answered 'yes' to using a strategy nominated in these eight questions, then respondents recorded comments which were then synthesised using thematic analysis. Yates (2013) approach simply tabulated comments from respondents for analysis; this research adopted Yates' approach. Refer to Table 1 for a tabular presentation of these nine survey questions.

3.2. *Potential sources of site waste method*

The survey questionnaire was an adaption from Faniran and Caban's (1998) potential sources of construction waste model.

The research questionnaire used in this study evaluated the following potential sources of construction site waste: (i) design and detailing errors; (ii) client-initiated design changes; (iii) contractor-initiated design changes; (iv) procurement errors (over-ordering, under-ordering and supplier error); (v) improper materials handling (during fabrication, packaging, loading or delivery); (vi) improper materials storage; (vii) poor workmanship; (viii) poor weather; (ix) site accidents; (x) leftover material scraps from cutting materials to fit designs; (xi) packaging, pallets and other non-consumables; (xii) damage or theft; and (xiii) lack of on-site materials control and a waste management plan. The respondents were asked to evaluate these as being either: (i) 'not significant'; (ii) 'of minor significance'; (iii) 'significant'; or (iv) 'very significant', in accordance with the Likert-style questionnaire (Faniran and Caban 1998).

For each construction source, a severity index was calculated from the total percentage of 'very significant' responses and all 13 potential waste sources were rated. The research results and discussion shall only consider the most likely potential source of construction waste, as was derived from the synthesised model data.

3.3. *Demographics method*

There were 102 participants for this study sourced from the Australian Constructors Association, the Australian Construction Industry Forum, the NSW Master Builders Association and other industry practitioners. The high response rate of 52% (53 respondents) showed that the participants were interested in the study topic. Figure 5 illustrates the high level of experience and expertise of this sample pool; 48% had more than 25 years' experience working in the engineering construction industry and 46% had worked on projects exceeding AUD 2 USD billion.

The sample pool also represented the breadth of the industry. There were participants from heavy infrastructure, process and mining projects, along with those who had worked on residential, commercial and high rise buildings. The survey also received responses from architects, commercial, design and project management specialists, board and project directors and public and private sector clients.

Table 1. Questions used in the survey questionnaire for site waste minimisation strategies (adapted from Rundle 2018, 311–312).

Question No.	Part 3 Survey Questions on Site Waste Minimisation Strategies
26	Is your firm using techniques that improve resource efficiency, equipment efficiency, material resource efficiency and allow for training of manual labour?
27	Are innovative designs, construction components, or construction processes, being integrated into your projects to reduced site generated waste?
28	Do you adopt a structured approach both for engineering design and in the determination of construction methodologies that involve waste minimisation strategies?
29	Do you address waste generation reduction during project pre-planning to utilise designs that minimise waste using any of the following techniques: precast; prefabrication; pre-assembly or modularisation?
30	As builders, contractors and engineering consultants, do you ensure that a minimum amount of permanent and temporary materials are expended in the effective provision of client conforming construction/building products?
31	Regarding the use of temporary construction materials, do you consider waste minimisation processes? For example, for concrete construction, do designers specify concrete elements of similar dimensions, where practical; are steel shutters used on repetitive formwork; is formwork adequately treated and robustly fabricated, to allow re-use and are orders 'just in time', to reduce material losses on site?
32	Do the contractors/builders, consultants and vendors, constructively work with the clients to minimise change orders that make pre-ordered products, redundant and suitable only for waste?
33	Does the contractor/builder and/or client have a mandatory waste minimisation plan developed as part of the project execution plan?

Adapted table approved for use by Peter G. Rundle, author of this 2018 Research.

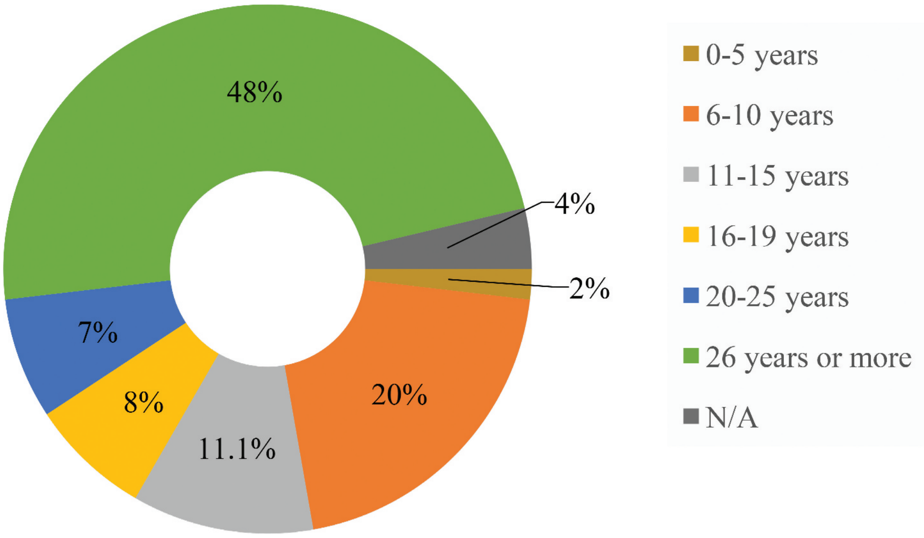

Figure 5. Work experience of the respondents in the engineering construction field (adapted from Rundle 2018, 169).

4. Results

4.1. *Front-end site waste* minimisation *strategies results*

4.2. *Potential sources of site waste results*

5. Discussion

5.1. *Discussion of front-end site waste* minimisation *strategies data synthesis*

Refer to Table 2 for the respondent answers to the front-end site waste minimisation strategies. A critical finding of the respondent survey was very low (37.5%) utilisation of a mandatory waste management plan on projects as a strategy embedded in the project execution plan. Notwithstanding this, nearly 48% of respondents reported that innovative designs and construction processes were being integrated into projects to mitigate site waste generation. While 56.25% of respondents adopted front-end pre-planning construction waste reduction strategies by utilising designs that allowed for pre-cast, prefabrication, pre-assembly or modularisation.

Jaillon, Poon, and Chiang (2009) suggest that prefabrication techniques can reduce site material waste by around 52%. There is a recurrent theme in respondent remarks indicating the use of precast concrete on, for example, high rise commercial buildings and for pre-assembly, modularisation and prefabrication on heavy construction projects. However, the Master Builders Association respondents did not provide comments regarding residential work and the use of

Table 2. Respondent answers to front-end site waste minimisation strategies (adapted from Rundle 2018, 187–188).

		Respondent Answer (%)		
No.	Question Description	'No'	'Don't Know'	'Yes'
26	Is your firm using techniques that improve resources efficiency, equipment efficiency, material resource efficiency and allow for training of manual labour?	39.58	18.75	41.67
27	Are innovative designs, construction components or construction processes, being integrated into your projects to reduce site generated waste?	31.25	20.83	47.92
28	Do you adopt a structured approach both for engineering design and in determination of construction methodologies that involve waste minimisation strategies?	29.17	20.83	50.00
29	Do you address waste generation reduction during project pre-planning to utilise designs that minimise waste using any of the following techniques: precast; prefabrication; pre-assembly and modularisation?	29.17	14.58	56.25
30	As builders, contractors and engineering consultants, do you ensure a minimum amount of permanent and temporary materials are expended in the effective provision of client conforming construction/building product.	31.25	31.25	37.50
31	Regarding use of temporary construction materials, do you consider waste minimisation processes? As an example, for concrete construction, do designers specify concrete elements of similar dimensions, where practical? Are steel shutters used on repetitive formwork; is formwork adequately treated and robustly fabricated to allow re-use; are orders 'just in time', to reduce material losses on site?	18.75	29.17	52.08
32	Do the contractor/builder, consultants and vendors constructively work with the client to minimise change orders that make pre-ordered products, redundant and suitable only for waste?	35.42	22.92	41.67
33	Does the contractor/builder and/or client have a mandatory waste minimisation plan developed as part of the project execution plan?	33.33	29.17	37.50
Total of Respondent Answers		**247.92**	**187.50**	**364.59**
Average for Each Respondent Answer		**30.99%**	**23.44%**	**45.57%**

Adapted table approved for use by Peter G. Rundle, author of this 2018 Research.

Table 3. Potential sources of construction waste severity index (adapted from Rundle 2018, 211; Faniran and Caban 1998).

Question Number	Possible Source of Site Waste	Severity Index = # 'Very Significant'/ Total Respondents	Severity Index Ranking
1	Lack of on-site material planning and control.	24%	1
2	Packaging and pallet waste.	20%	2
3	Design and detailing errors.	20%	2
4	Client-initiated design changes.	20%	2
5	Procurement ordering and take-off errors.	16%	5
6	Improper materials storage.	14%	6
7	Poor workmanship.	14%	6
8	Improper materials handling.	10%	8
9	Contractor-initiated design changes.	8%	9
10	Site accidents.	4%	10
11	Leftover off cuts.	4%	10
12	Poor weather.	2%	12
13	Criminal waste caused by vandalism or pilfering.	2%	12

precast concrete or preassembly. The minimal use of precast concrete and preassembly utilisation in Australian residential construction was remarked upon by industry body attendees during a 31 January 2019 key note address given by the author on front-end construction waste minimisation strategies at a National Precast Concrete Association of Australia Gold Coast conference.

Of the respondents, 50% followed a structured approach to determine design and construction methodologies, which include construction waste minimisation considerations. Over 52% of respondents used strategies that reduced temporary material waste, such as specifying repetitive steel formwork.

Pursuant to the above, although a surprisingly low number of respondents acknowledged their projects adopted mandatory site waste management plans, around half of these survey participants were using early front-end design and construction strategies that potentially reduced site waste. Respondent comments indicated that these processes were largely driven by the assigned design manager, project manager and construction manager. Owen and Burstein (2005) argued that the business culture of an engineering consultant and/or contractor plays an important role in the development of a knowledge management system that encourages employees to become members of a formal community of practice. This is preferable to the distribution of knowledge through an informal personal network (Owen and Burstein 2005). To identify and mitigate potential risks, it is crucial that construction companies implement prudent pre-planning of a project, prior to the execution phase.

Engineering construction specialists can improve their preparation processes by implementing knowledge management strategies (Ribeiro and Ferreira 2010). However, it is historically difficult to transfer knowledge within the construction sector (Argote et al. 2000). The authors argue that the most appropriate means of transferring a company's design and construction knowledge acquisition database on site waste management for proposed future work is by adopting a mandatory construction waste management plan.

5.2. Discussion of potential sources of site waste model data synthesis

Refer to Table 3, which indicates that the lack of on-site planning and control was determined as the most significant source of construction waste. In considering the 13 potential sources of waste, several sources can be attributed to a lack of planning and control. The procurement function is a critical component of the construction process.

Ordering construction materials must be made under an appropriate procedure that ensures the correct purchase, fabrication, shipment, site storage and installation of the particular component. Accordingly, the following matters are also fundamental considerations for competent on-site planning and control: material damage due to inclement weather; adequate laydown areas for waste skips segregated into recyclable and other waste; adequate material laydown areas and warehouse storage; the planning of material deliveries in accordance with the project schedule; and adequate site access and haul roads.

Table 3 summarises that respondents equally ranked the next most common causes of site waste as (i) packaging, pallet waste and other non-consumables; (ii) design and detailing errors; and (iii) client-initiated design changes.

5.3. Comparison of results between the author's research and other studies

5.3.1. Front-end site waste minimisation study comparisons

Table 4 provides a comparison between Yates (2013) results and this research. It shows that 50% of survey participants adopted a waste management plan. This is consistent with the Faniran and Caban (1998) study, in which 57.1% of respondents answered in the affirmative. However, both results were significantly

Table 4. Assessment of the differences between this research and Yates (2013) findings (adapted from Rundle 2018, 333–334; Yates 2013).

		This Thesis Research Respondent Answers to Part C Survey (%)			Yates (2013) Research Data Using Same Survey Questions (%)		
Question No.	Question Description	'No'	'Don't Know'	'Yes'	'No'	'Don't Know'	'Yes'
26	Is your firm using techniques that improve resource efficiency, equipment efficiency, material resource efficiency and allow for training of manual labour?	39.58	18.75	41.67	26	29	56
27	Are innovative designs, construction components, or construction processes being integrated into your projects to reduce site generated waste?	31.25	20.83	47.92	19	42	39
28	Do you adopt a structured approach both for engineering design and in the determination of construction methodologies that involve waste minimisation strategies?	29.17	20.83	50.00	23	19	58
33	Does the contractor/builder and/or client have a mandatory waste minimisation plan developed as part of the project execution plan?	62.5% did not know and did not have mandatory waste management plan		37.50	50% did not know and did not have mandatory waste management plan		50

higher than the current study, with only 37.5% of respondents acknowledging the use of a mandatory site waste plan.

Further, the Table 4 comparison between Yates (2013) and this research indicates that USA contractors/commercial builders place an increased emphasis (56.0%) on executing work-maximising personnel, equipment and resource efficiencies, in comparison to their Australian counterparts (41.7%). On average, USA projects are constructed 37% more efficiently than similar high rise Australian construction projects (Langston 2012).

Faniran and Caban (1998) study on Australian sources of site waste reported that 42.9% of their participants did not have specific project waste plans, while 57.1% of respondents did. Similarly, 50% of the respondents to Yates (2013) USA study used a waste management document. However, Udawatta et al. (2015) reported a comparatively low rate of 37.5% of their respondents having a plan.

Udawatta et al. (2015) reveal that 'good company policies on construction waste management' was rated the tenth most important waste reduction strategy by their Australian participants, while the 'incorporation of waste management procedures' was rated the fourth. They stated that:

> Government and company senior management have a responsibility to develop strategic guidelines for [waste management] and to facilitate effective onsite [waste management] plans by enhancing company policies and regulation relating to construction [waste management] (Udawatta et al. 2015, 82).

5.3.2. Potential sources of site waste study comparisons

If the severity index data for 'client-initiated design changes' and 'contractor-initiated design changes' were combined for this research, then the consolidated 'design changes' item for this study would be the top potential source of waste, per respondent remarks. This combined item ('design changes') would be in alignment with both the Faniran and Caban (1998) and the Nagapan, Rahman, and Asmi (2012) research; both these comparative studies use a similar model to this research paper that showed that the primary potential source of site waste was 'design changes'. Sugiharto, Hampson, and Sherid (2002), an Australian study on construction waste, also concluded that 'design changes' was a major potential cause of site waste.

5.4. Discussion of insights from this research

A deeper dive into the respondents' answers in Table 4, inclusive of the questions in Table 1 and an additional questions 34 ('[p]rovide other examples of situations where methods, processes or ideas were implemented on your construction site projects that minimized waste'), was undertaken during the study. This analysis utilised a thematic schema developed from the types of responses that came from the respondents' answers to

Table 5. Summary of the thematic analysis of themes for front-end waste minimisation strategies (adapted from Rundle 2018, 313).

	Number of Respondent Comments on a Theme per question									
Themes	Q. 26	Q. 27	Q. 28	Q. 29	Q. 30	Q. 31	Q. 32	Q. 33	Q. 34	Total
Management	10	15	5	17	8	10	13	5	9	92
Procurement	4	2	1	1	2	3	2	1	3	19
Design	3	6	14	4	4	6	1	9	2	49
Workers	1	-	-	-	-	2	1	1	_	5
Recycling	1	1	-	1	1	2	-	1	10	17

a question seeking opinions on other sources of waste, which was then applied to categorising the respondents' answers in questions 26 to 34. The results are summarised in Table 5.

The research findings showed that 52% of responses were within the 'management' theme, 26% were within the 'design' theme and 10% were within the 'procurement' theme. The 'management' theme included the need for good planning, the latest BIM engineering and document control systems, management structures with the foresight to plan from inception through the whole life cycle, integrated waste minimisation planning and a commitment between the clients, contractors and designers. The 'design' theme was inclusive of the need for adequate preliminary design and project development as early as possible and waste minimisation thinking in the design and fabrication (for example, from offsite modularisation of steel fabrication using value engineering workshops). The 'procurement' theme covered the need to minimise poor material control and logistics, such as storage and transport to the site and of storage and handling at the work face. A reoccurring aspect of the 'procurement' theme was the need for an integrated materials supply chain to drive efficient material flows.

Overall, the research implies that over the past 20 years, project waste management plans have been poorly implemented (less than 50% of the time). Ideally, these plans should form an important aspect for all stakeholders on every Australian capital works project. However, this requires regulatory change. Mandatory federal legislation would guarantee the enforcement of waste management procedures, starting with early project design preparation, for all projects.

This highlights another issue about how to implement and encourage engagement by the project management team, inclusive of their design team. Comments made by respondents during this research identified front-end engineering design (FEED) as an important process that has the potential to address criteria under which designs shall be conducted. Between them, the authors have participated in a range of major construction projects, including large metropolitan rail industry projects. In one such case, an initiative by both an NSW government agency and a major contractor provided some insight into how this could be improved.

Many projects have management plans included in the documentation that is assembled to win a project. However, once the project is secured, the plan is often considered as secondary importance during the design and delivery stages. The introduction of a mandatory management driven design and delivery process, underpinned by systems engineering based design reviews, would be a key change (Doust and Wilson 2013). All requirements, along with those of the waste management plan, would be part of the mainstream design thinking that is front and centre in the minds of the team members leading up to design reviews. However, experience has shown that this requires the project and design management team at the top level to create a culture of 'design to these requirements' as part of the principal contractor's internal stage gate reviews.

6. Conclusions

The construction industry is both the world's largest consumer of raw materials and a major generator of hazardous waste. Therefore, it must endeavour to urgently reduce site waste by applying innovative design methods. Although there will always be a place for recycling, a new strategy that focuses on the prevention and reduction of front-end construction waste is vital.

As shown by this research, Australia's major potential sources of site waste have not changed over the past two decades. During this time, the production of waste has exploded, with C&D waste making up 40% of all waste produced by Australia. Considering Australia's population growth (the fifth highest in the OECD), this presents a worrying future for Australia's sustainability. This problem is likely to be made worse with the need to reconstruct infrastructure and buildings that have been damaged or destroyed due to climate change driven weather events. The 2019 fire season in Australia is a stark example of the additional pressure on waste streams and use of resources, emphasising the need to develop more effective front-end strategies that enable both less use of resources during construction and more resilient infrastructure and structures in the face of these events.

The authors recommend the implementation of federal legislation that ensures mandatory waste management plans for all capital works projects. Additionally, they propose the implementation of internal management, design and procurement processes that enable mainstreaming of a focus on waste minimisation from inception and throughout the project life cycle. Processes such as FEED, Requirements Management and System Engineering are seen to provide the mechanisms. However, the reality is that adoption by all staff and key project stakeholders will require championing from the top level in the project team. Ideally, these measures must be initiated together to be successful. In the interim, there is also the opportunity for project directors to recognise the value and competitive edge that their projects have when adopting these processes and driving the cultures within their projects to deliver on waste management plans.

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