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Drivers of Applying Ecological Modernization to Construction Waste Minimization in New South Wales Construction Industry

Sulala Al-Hamadani1-*, Temitope Egbelakin2, Willy Sher3, Jason Von Meding4

1School of Architecture and Built Environment, University of Newcastle, New South Wales, Australia, Sulala.AlHamadani@uon.edu.au
2School of Architecture and Built Environment, University of Newcastle, New South Wales, Australia, willy.sher@newcastle.edu.au
3School of Architecture and Built Environment, University of Newcastle, New South Wales, Australia, t.egbelakin@newcastle.edu.au
4School of Construction Management, Florida Institute for Built Environment Resilience (FIBER), Florida, USA, jason.vonmeding@ufl.edu

Corresponding author: Sulala Al-Hamadani, School of Architecture and Built Environment, University of Newcastle, New South Wales, Australia, Sulala.AlHamadani@uon.edu.au

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Abstract

The application of ecological modernization (EM) [to delink industry growth from environmental damage] to minimize construction waste has not been explored within construction industry in general, and the New South Wales (NSW) construction industry in particular. This study seeks to identify the drivers of applying EM to construction waste minimisation (CWM) in the industry. Also, to determine the CWM measures that are critical for each of the drivers. A survey was adopted in this study to target stakeholders engaged in the delivery of construction projects in NSW from design to completion. The survey was selected to reach a large number of respondents within a manageable period. A pilot study was conducted to ensure the reliability of the research design before a full-scale data collection was launched. The data from 240 valid responses was analysed using factor analysis, relative importance index and descriptive statistics. The results revealed five important drivers for EM’s application to CWM. These are agents of change, government policies, supply chain dynamics, skill building and technological innovations.

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The CWM measure that are critical for each of these drivers were also identified. The study provides insights into the application of EM to address the construction industry problem of waste generation as by-product of its growth. It also shows the ability to protect the environment while enabling continuous economic growth. Furthermore, it demonstrates the applicability of EM to minimize the construction waste of NSW construction industry.

**Keywords**

NSW; Construction Waste; Ecological Modernization; Industry Growth

**Introduction**

The problem of continuous generation of construction and demolition (C&D) waste continues to challenge the economy and environment in Australia. It has increased from 16.9 Mt in 2007 to 20.4 Mt in 2017 (Pickin, et al., 2018). Among the Australian states and territories, the state of New South Wales (NSW) is the main contributor for this problem, mainly because of its economic and population growth (NSW Environment Protection Authority, 2015; Pickin, et al., 2018; NSW Environment Protection Authority, 2019). The amount of C&D waste has increased continuously in NSW from 4 Mt in 2004 to 12.7 Mt in 2018 (Department of Environment & Climate Change NSW, 2007a&b; NSW Environment Protection Authority, 2019). Moreover, the quantities of C&D waste generated in NSW outweigh the other waste streams of MSW and C&I (NSW Environment Protection Authority, 2019a).

The problem of continuous increase of C&D waste in NSW explained above is related to growth of the state’s construction industry. It is projected that the NSW construction industry will continue to grow throughout the next decade (Australisan Construction Industry Forum, 2017, 2019). The continuous increase in waste in NSW, reaching 21.4 million tonnes in 2017-18, has been blamed on the growth in construction activities (12.7 million tonnes out of the 21.4 was C&D waste) (NSW Environment Protection Authority, 2019a). Although NSW construction industry is one of the industries that has not been impacted by COVID-19 pandemic restrictions (Infrastructure NSW, 2020), NSW government put plans to support the industry and its growth. It extended construction work hours to include weekends and public holidays (NSW Department of Planning, Industry and Environment, 2020). In addition, the NSW government has released plans to fast-track construction projects approvals to boost the industry growth (Johnston, 2020; Sanda, 2020). Overall, it is projected that the NSW construction industry will continue to generate significant amounts of C&D waste as a by-product of its activities, with a potential growth in generation of C&D waste (Perrottet, 2018).

To reduce the amount of C&D waste generated in NSW and its associated environmental and financial problems, there is a need for a strategic approach towards construction waste minimization (CWM). This aligns with guidance provided by the waste management hierarchy and key research outcomes highlighted in existing literature (Peng, Scorpio and Kibert, 1997; Tam, 2008; Udawatta, et al., 2015b). To adopt the strategic approach of CWM, industry growth and the environment need to be reconciled.

Various theories and concepts were found to contribute to the sustainability debate in light of growth. Examples include the ‘concept of de-growth or sustainable de-growth’, ‘sustainable consumption’, ‘sustainable development (SD)’ and ‘ecological modernization (EM)’. Among these is the theory of ecological modernization (EM), which could be applied to deal with the environmental problem of C&D waste in NSW. That is because EM not only accepts win-win relationships between the environment and economic growth, but supports environmental improvements for greater economic development (Baker and Eckerberg, 2008; Langhelle, 2000). This involves delinking the growth of the construction industry from the environmental damage its waste generates. EM encourages positive sum relationships (win-win) between industry growth and the environment (Mol, 1995; Christoff, 1996; Mol and Sonnenfeld, 2000).
EM contends that through human ingenuity, the economy can continue growing whilst simultaneously protecting the environment (Jänicke, 1985; Huber, 1991; Jänicke, Binder and Mönch, 1994; Mol and Spaargaren, 1993; Jänicke, Binder and Mönch, 1997). EM theorists state that economic growth can be delinked from environmental damage through EM core themes, representing changes in the role of technology, institutions, economic imperatives and government policies and interventions (Berger, et al., 2001; Jänicke and Jacob, 2004; Huber, 2008). This study conceptualizes that the application of EM could be applied to significantly minimise the environmental problems associated with C&D waste in NSW.

The objectives of this study thus is (i) to identify the drivers of applying EM to CWM within the context of the NSW construction industry, and (ii) to determine the CWM measures that are critical for each of the drivers. To identify these drivers and the critical measures, quantitative methods were employed on the measures that were identified from literature, and included in the survey. factor analysis was conducted to identify the drivers that are important when applying EM to CWM, whereas, descriptive statistics and relative importance index were used to identify critical measures to CWM. The next sections provide a literature review of EM and its applicability to CWM measures, and the methodological approach of the study. This is followed by the findings, which are presented and discussed before concluding the study.

Ecological Modernization Theory (EM)

Developed in the early 1980s within the geographical limits of Western Europe, EM continues to be developed to address issues related to economic growth and the environment (Jänicke, 1985; Huber, 1991). Since then, it has evolved considerably to deal with the scope of economic reforms along ecological lines (Mol, 1997; Mol, 1999). Mol (2006) reported that it was at this point (the evolution of EM as mainstream theory) that ecological rationality began to challenge the domination of economic perspectives. The applicability of EM has expanded to include a wide range of contexts and countries (Mol and Sonnenfeld, 2000; Sonnenfeld and Mol, 2002). EM originators acknowledge the severity of environmental problems and the economic costs of addressing them (Jänicke, Binder and Mönch, 1994; Mol and Spaargaren, 1993; Jänicke, Binder and Mönch, 1997). EM thus translates environmental problems into economic positive-sum games that protect the environment without compromising the economic growth. Wright and Kurian (2010, p.400) defined EM as ‘a modernistic and technocratic approach to deal with environmental problems by assuming that there is a ‘techno-institutional fix’ for economic and environmental problems’.

EM promotes technologies that make industries sustainable by both preventing and ameliorating environmental damage (Fisher and Freudenburg, 2001; Cohen, 2006; Huber, 2008). The economic imperative of EM provides an important role for market dynamics and economic agents as facilitators of ecological reform (Mol, 2000; Seippel, 2000; Berger, et al., 2001; Huber, 2008). EM advocates a transformed role for government: decentralised, less hierarchal and consensual with a focus on well-planned intervention (Spaargaren, 2003). It sees the role of the state as central in attaining sustainability (Buttel, 2000; York and Rosa, 2003; Jänicke, 2008). EM supports open policy-related decisions by increasing participation opportunities for wider groups of interest (Berger, et al., 2001). These opportunities align with an increased role for non-governmental bodies, economic agents and transformations in the institutional structures of society (Fisher and Freudenburg, 2001). EM can be adopted to analyse the shifts necessary to reduce ecological crises (Berger, et al., 2001). As in this study, the application of EM to CWM can be interpreted as an approach to delink construction industry growth from environmental problem of waste.

The applicability of EM to the construction waste problem

The applicability of EM to the construction waste problem can be viewed via the impact of its themes on CWM. According to Mol (1997), these themes are the core changes that form the basis of EM. The main contributors to EM have agreed on core themes of change that characterise EM (Mol, 1997; Mol
Spaargaren, 1998). These involve changes in the roles of technology to prevent environmental problems; increases in the roles of industry dynamics and economic agents in ecological restructuring/greening the industry; harmonious views of economic and environmental interests; reformist roles of environmental movements; and changes in the roles of government. Based on EM literature and its application to CWM, an EM-based theoretical framework for CWM is conceptualized in this study. This framework is illustrated in Figure 1. EM themes thus give rise to core changes applicable to the problems of construction waste through CWM measures as explained in Table 1.

![Figure 1. EM based theoretical framework for CWM](image)

**Methodology**

To investigate the drivers of EM application to CWM, and the critical CWM measures to promote them, the methodological approach of this study starts by explaining the justification for the research design adopted in this study. The survey design, approach to data collection and its analysis are then illustrated and justified.

**SURVEY**

Stakeholders engaged in delivery of construction projects from design to completion were used as the study respondents. To reach these participants, the study employed random sampling to select respondents (Gravetter, et al., 2020). Their contact details were obtained from the Australian business register database (Australian Business Register, 2019). Survey was selected to collect data in this study based on its ability to reach a large number of respondents within a manageable period (Walliman, 2005). The literature review of the important CWM measures contributed to development of survey. The CWM measures in the survey were selected to cover different areas that matched the core themes of EM. The survey covered general demographic information of respondents and questions in relation to importance of CWM measures. Likert scale was employed as a scale of measurement, as it enabled the measurement of opinions (Bowling, 2014). In this study, a Likert scale of 1 to 5 was employed to portray the degree of importance of CWM measures. 1 was for not important and 5 for very important. A pilot study was conducted with 20 professionals from the NSW construction industry to examine the clarity and feasibility of administering the survey. Pilot
| EM theme                                      | EM theme in the context of CWM | CWM Measures                                                                 | References                                                                 |
|----------------------------------------------|--------------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Preventive technology:                       | Prioritization and implementation support for waste preventive technologies that contribute to CWM | Prefabrication technology                                                    | [Tam, et al., 2007]; [Jaillon, Poon and Chiang, 2009]; [Udawatta, et al., 2015b]; [Formoso, et al., 2002]; [Saez, et al., 2013] |
| Changing role of technology from causing to preventing environmental damage | Building information modelling (BIM) | Information and communication technology (ICT)                               | [Ahankoob, et al., 2012]; [Liu, et al., 2015]; [Cheng, Won and Das, 2015]; [Lee, Kim and Yu, 2014]; [Mehran, 2016]; [Udawatta, et al., 2015b]; [Smith, 2014]; [Wong, Wong and Nadeem, 2009]; [Porwal and Hewage, 2013] |
| Prefabrication technology                     |                                | Modern methods of construction (MMC)                                         | [Udawatta, et al., 2015b]; Ilozor and Kelly, 2011; Osmani (2013); [Domingo, Osmani and Price, 2009] |
| Engagement with economic imperatives:        | Improved and increased role of project stakeholders and supply chain dynamics to effectively implement CWM measures | Supply chain alliances among stakeholders                                     | [Dainty and Brooke, 2004]; [Udawatta, et al., 2015b]; [Alwi, Hampson and Mohamed, 2002] |
| Increasing the role of industry dynamics and economic agents in ecological restructuring | Design out waste                | Commitment of project stakeholders to CWM                                   | [Greenwood, 2003]; [Coventry, Shorter and Kingsley, 2001]; Osmani, Glass and Price (2008); [Wang, Kang and Wing-Yan Tam, 2008]; [Nowosielski, Kania and Spilka, 2010] |
|                                             |                                | Design for deconstruction and material reuse                                 | [Johnston and Mincks, 1995]; [Lu and Yuan, 2013]; [Udawatta, et al., 2015b]; Osmani, Glass and Price (2008); [Lu and Yuan, 2013]; [Akinade, et al., 2017]; [Rios, Chong and Grau, 2015]; [Salama, 2017] |
| EM theme | EM theme in the context of CWM | CWM Measures | References |
|----------|--------------------------------|--------------|------------|
| Client’s demand to reduce and manage waste |  |  | (Dainty and Brooke, 2004); (Udawatta, et al., 2015a); (Udawatta, et al., 2015b) |
| On-site materials segregation of waste, reuse and recycling |  |  | (Al-Haji and Hamani, 2011); (Marinelli, et al., 2014); (del Río Merino, Izquierdo Gracia and Weis Azevedo, 2010); (Lu and Yuan, 2010); (Marinelli, et al., 2014); (Begum, et al., 2009) |
| Contractual arrangements related to CWM |  |  | (Dainty and Brooke, 2004); Osmani (2013); Ekanayake and ofori (2004); Negapan et al. (2013) |
| Design for adaptability |  |  | Osmani, Glass and Price (2008); (Udawatta, et al., 2015b); (Lu and Yuan, 2013); (Morgan and Stevenson, 2005); (McKechnie and Brown, 2007) |
| Effective communication amongst project stakeholders |  |  | (Teo and Loosemore, 2001); (Poon, Yu and Wong, 2004); (Wang, Kang and Wing-Yan Tam, 2008); (Gavilan and Bernold, 1994); (Manowong, 2012) |
| Effective site management and supervision |  |  | (Poon et al., 2004); (Poon, Yu and Jaillon, 2004); (Peng, Scorpio and Kibert, 1997); (Wang, et al., 2010); (Saez, et al., 2013); (Kulatunga, et al., 2006) |
| CWM arrangements in the tender process |  |  | (Wang, Kang and Wing-Yan Tam, 2008); (Udawatta, et al., 2015b); (Dainty and Brooke, 2004) |
| Prequalification of stakeholders based on CWM performance |  |  | (Udawatta, et al., 2015b); (Yuan, 2013a) |
Table 1. continued

| EM theme | EM theme in the context of CWM | CWM Measures | References |
|----------|--------------------------------|--------------|------------|
|          |                                | Resources dedication for CWM | [Dainty and Brooke, 2004]; [Lu and Yuan, 2013]; [Yuan, 2013a]; [Ajayi and Oyedele, 2017] |
|          |                                | CWM policies into company’s management plans | [Udawatta, et al., 2015b]; Osmani (2012) |
|          |                                | Supervision of onsite CWM practices with guidance | [Cha, Kim and Han, 2009]; Kulatunga, et al. (2006); [Udawatta, et al., 2015b] |
|          |                                | Market for reused and recycled materials/products | [Cha, Kim and Han, 2009]; [Wang, et al., 2010]; [Yuan, 2013b]; [Udawatta, et al., 2015b] |
|          |                                | Use the amounts of waste generated on site as KPI | Dainty and Brooke (2004); [Cha, Kim and Han, 2009] |
|          |                                | CWM-related incentives and penalties | [Adams, et al., 2011]; [Al-Hajj and Hamani, 2011]; [Dainty and Brooke, 2004]; [Domingo, Osmani and Price, 2009]; [Cooper, 1996]; [Jingkuang and Yousong, 2011]; [Osmani, 2013]; [Wang, Li and Tam, 2014]; [Cha, Kim and Han, 2009]; [Chen, Li and Wong, 2002] |
|          |                                | Waste efficient procurement practices | [Gavilan and Bernold, 1994]; [Faniran and Caban, 1998]; [Greenwood, 2003]; [Lu and Yuan, 2011]; [Al-Hajj and Hamani, 2011]; [Cha, Kim and Han, 2009]; [Marinelli, et al., 2014]; [Gamage, Osmani and Glass, 2009] |
| EM theme | EM theme in the context of CWM | CWM Measures | References |
|----------|-------------------------------|--------------|------------|
| Discursive change and transformed role of environmental movements: Harmonious views of economic and environmental interests / Reformist role of environmental movements | Promotion of equal views of environmental and economic interests of CWM, and improved role of industry trainers in relation to CWM education, training and contribution to policy. | Development and promotion of CWM culture | (Johnston and Mincks, 1995); (Yuan and Shen, 2011); Osmani, Glass and Price (2008); (Begum et al., 2009); (Zaman and Lehmann, 2011); (Wong and Yip, 2004); (Udawatta et al., 2015b); (Kulatunga et al., 2006) |
| | | Raise awareness about the benefits of CWM | (Lu and Yuan, 2013); (Yuan, 2013a) |
| | | Follow and disseminate CWM information | (Cha, Kim and Han, 2009); Ilozor and Kelly, 2011; Baldwin et al., 2007; Domingo, Osmani and Price, 2009 |
| | | CWM training and education | (Wang, Kang and Wing-Yan Tam, 2008); (Johnston and Mincks, 1995); Begum et al., 2009; Osmani, Glass and Price (2008); Formoso et al., 2002; Nowosielski, Kania and Spilka, 2010; Udawatta et al., 2015b; Teo and Loosemore, 2001) |
| Role of governments: Changing the role of government from command and control to contextual steering | Government’s role to promote and enforce C&D waste preventive policies and interventions | Site Waste Management Plan (SWMP) | (Tam, 2008); (McGrath, 2001); (McDonald and Smithers, 1998); (Johnston and Mincks, 1995) |
| | | Waste levy/ landfill tax | (Jaillon, Poon and Chiang, 2009); (Martin and Scott, 2003); (del Rio Merino, Izquierdo Gracia and Weis Azevedo, 2010) |
| | | Promoting CWM through environmental impact assessments of the project | (Yuan, 2013a); (Chen, Okudan and Riley, 2010); (Ajayi and Oyedele, 2017) |
| | | Governmental support to sustainable C&D recycling sector | Oyedele et al. (2009); (Cha, Kim and Han, 2009); (Ajayi and Oyedele, 2017) |

CWM: Construction Waste Minimisation; EM: Ecological modernization
study is recommended to improve the data collection instrument development (Johanson and Brooks, 2010). The pilot test contributed to refine and validate the CWM measures extracted from literature and present them in clearer way (Table 1).

**DATA COLLECTION AND ANALYSIS**

The survey was administered online. The online mode was selected as it was convenient to administer and allowed access to a large number of potential participants (92% of Australians have internet access (Australian Communications and Media Authority (ACMA), 2015). After series of emails, 240 valid responses were used for further statistical analysis. Of the respondents, 28% were project managers, 21% architects, 16% structural engineers, 15% contractors, 14% site managers and 3% quantity surveyors. It was also noted that 86% of respondents had more than six years of professional experience in NSW construction industry. As measure of data reliability (Tavakol and Dennick, 2011; DeVellis, 2016), ‘Cronbach’s Alpha test’ was implemented. Cronbach’s alpha may be expressed from 0 to 1. An alpha value of around 0.7 indicates satisfactory internal consistency, 0.8 shows good consistency, while 0.9 indicates excellent internal consistency (Tavakol and Dennick, 2011). The Cronbach’s Alpha in this study was 0.866, showing good reliability and internal consistency of survey items.

In this study, factor analysis was conducted to identify the drivers that are important when applying EM to CWM. Factor analysis is a strong statistical technique which assumes that underlying factors can be used to explain complex phenomena (Norusis, 1993). It is used to identify the pattern of correlations among a set of observed variables in fewer underlying factors (clusters) (Norusis, 1993; Dolo, 2009; Lingard, Graham and Smithers, 2000; Dolo, et al., 2012). It also remodels a large amount of data into fewer coherent factors (Shen and Liu, 2003). Prior to conducting factor analysis, Kaiser–Meyer–Olkin (KMO) index and Bartlett’s test of sphericity, measures of sampling adequacy, were used to evaluate the suitability of the collected data for factor analysis (Williams, Onsman and Brown, 2010). The data had a KMO value of 0.874, exceeding the minimum acceptable value of 0.5 and within the acceptable range (Tabachnick, Fidell and Ullman, 2007; Field, 2013). Bartlett’s test indicates statistical significance with a value less than the maximum of 0.05 ($\chi^2 = 2926.143, p < 0.001$). These tests indicate the suitability of the data for factor analysis. To determine the number of important underlying factors (drivers), Principal Component analysis (PCA) was carried out on the CWM measures with ‘varimax’ as the factor rotation method (Corner, 2009). As an outcome of factor analysis, eigenvalues were utilized to signal the variance of each underlying factor from the total variance (Taylor, 2004). Factors with an Eigen value of 1.0 were retained (Nunnally, 1994; Brown, 2001). Variables with a factor loading below 0.4 were excluded to reduce cross-loading and to clarify the interpretation of outcomes (Lingard, Graham and Smithers, 2000; Akinade, et al., 2017; Hadi, Abdullah and Sentosa, 2016).

To identify the critical measures to CWM, relative importance index (RII) along with descriptive statistics were employed. Employing more than one method to identify the critical outcomes has been used in other studies (Poon, Ann and Ng, 2001; Chileshe, et al., 2015). The values of relative Importance Index (RII) were derived for each CWM measure based on the numerical scores from the survey responses. The values of RII were obtained based on the numerical scores from the survey responses. RII was calculated using the following equation:

$$\text{Relative importance index (RII)} = \sum w / (A*N) \quad (1)$$

In this equation, $W$ represents the weight for the rating scale of 1 to 5 provided by respondents, where 1 implies ‘not important’ and 5 implies ‘very important’. ‘$A$’ represents the highest weight on the scale (5), ‘$N$’, the total number of responses in the sample, and $0 \leq \text{RII} \leq 1$. A low index value of RII can show that the CWM measure is viewed as of less importance by the survey’s respondents, whereas a high index value
indicates more criticality of the CWM measure (Al-Tmeemy, Abdul-Rahman and Harun, 2012; Chileshe, et al., 2015). RII was employed in different studies to identify the relative importance and criticality of those studies variables (Le and Tam, 2008; Assaf and Al-Hejji, 2006; Chileshe, et al., 2015; Al-Tmeemy, Abdul-Rahman and Harun, 2012). Descriptive statistic of mean score rating was also used. Mean score rating is commonly used to determine the relative significance of a data set (Field, 2009). It was used to identify the top ranked variables, as deemed appropriate for large samples (Norman, 2010). To further demonstrate the criticality of these 16 measures, the Top 2 Box scores (T2B) method was used. T2B is a method of reporting and summarizing positive respondent views from a Likert scale survey questions by combining the highest two responses of the scale to provide a single percentage (Sambandam and Hausser, 1998; Cui, Peng and Flores, 2015). In this study, the percentage of T2B is the calculated combination of the percentage of respondents’ views that considered the CWM measures very important and important (Figure 2). All aforementioned statistical analysis were facilitated through IBM SPSS Statistics version 24 software.

Findings and Discussion

The factor analysis results revealed five important drivers for applying EM for CWM that accounted for 62.633% of the total variance (Figure 2). These drivers were labelled based on their contribution to EM and alignment with its themes. The drivers include:

- Agents of change (D1): The role of project stakeholders in applying EM via waste-efficient projects through their awareness, participation, action, and change in attitudes to CWM.
- Government policies (D2): The role of NSW state and local governments in applying EM to CWM via their CWM-related policies and regulations.
- Supply chain dynamics (D3): The role of supply chain dynamics in creating business opportunities inherent in CWM and encouraging project stakeholders to act on the ecological change.

![Figure 2. Drivers of EM application to CWM](image-url)
Table 2. Findings of Relative importance index (RII) and descriptive statistics for the importance of CWM measures

| Measure ID | Construction Waste Minimization Measures                                                                 | Relative importance index (RII) | Mean Rating |
|------------|----------------------------------------------------------------------------------------------------------|--------------------------------|-------------|
| M1         | Promoting CWM culture amongst project stakeholders                                                      | 0.878                          | 4.39        |
| M2         | Engaging all project stakeholder with CWM                                                                | 0.856                          | 4.27        |
| M3         | Considering CWM partnerships through supply chains                                                        | 0.848                          | 4.24        |
| M4         | Training and educating about CWM                                                                         | 0.843                          | 4.23        |
| M5         | Implementing waste efficient designs                                                                     | 0.837                          | 4.22        |
| M6         | Using Building information modelling (BIM)                                                               | 0.830                          | 4.15        |
| M7         | On-site segregation of waste, reuse and recycling                                                        | 0.825                          | 4.13        |
| M8         | Using prefabrication technology                                                                         | 0.824                          | 4.12        |
| M9         | Client’s requirement of CWM                                                                             | 0.823                          | 4.11        |
| M10        | Prequalifying stakeholders based on CWM performance                                                       | 0.819                          | 4.10        |
| M11        | CWM to avoid cost associated with waste levy                                                            | 0.815                          | 4.08        |
| M12        | Including CWM-related contractual clauses                                                                | 0.812                          | 4.06        |
| M13        | Considering CWM in materials selection, purchase and delivery                                            | 0.809                          | 4.05        |
| M14        | Implementing Site Waste Minimization & Management Plan (SWMMP)                                           | 0.808                          | 4.04        |
| M15        | Supervising onsite CWM practices with guidance                                                           | 0.807                          | 4.03        |
| M16        | Offering CWM financial incentives and implementing penalties                                              | 0.802                          | 4.02        |
| M17        | Communicating effectively amongst project stakeholders                                                   | 0.754                          | 3.81        |
| M18        | Effective site management and supervision                                                                | 0.750                          | 3.79        |
| M19        | Supporting the market for reused and recycled materials/products                                          | 0.724                          | 3.62        |
| M20        | Using modern methods of construction                                                                     | 0.715                          | 3.58        |
| M21        | Considering deconstruction in design                                                                     | 0.688                          | 3.44        |
| M22        | Using information and communication technology to collaborate                                            | 0.683                          | 3.42        |
| M23        | Promoting CWM arrangements in tender process                                                              | 0.678                          | 3.40        |
| M24        | Raising awareness about the benefits of CWM                                                              | 0.669                          | 3.35        |
| M25        | Monitoring quantities of waste generation on site as a ‘key performance indicator’ (KPI)                 | 0.667                          | 3.33        |
| M26        | Adopting dedicated resources for CWM                                                                      | 0.654                          | 3.25        |
• Skill building (D4): The role of stakeholders to contribute to the application of EM for reducing waste though enhanced CWM education and training.

• Technological innovations (D5): The promotion of EM for CWM via the prioritization of waste preventive technologies.

It is important to identify the CWM critical measures in the context of the NSW construction industry. Such findings could contribute to the application of EM drivers identified. They could also contribute to efforts to improve their implementation within NSW by relevant construction stakeholders. Out of 29 measures, the top 16 CWM measures had high RII and average mean values of 4 and above. These measures were considered critical for CWM for NSW construction projects.

To further demonstrate the criticality of these 16 measures, the Top 2 Box scores (T2B) method was used. T2B explains the combination of the percentage of respondents’ views that considered the CWM measures very important and important (Figure 3). The rationale for focusing only on the critical CWM was to enable a more detailed discussion of these critical measures in light of EM. Such a rationale has

| Measure ID | Construction Waste Minimization Measures                                                 | Relative importance index (RII) | Mean Rating |
|------------|-----------------------------------------------------------------------------------------|---------------------------------|-------------|
| M27        | Incorporating CWM policies into company’s management plans                                | 0.647                          | 3.23        |
| M28        | Keeping up to date and disseminating CWM information                                     | 0.639                          | 3.20        |
| M29        | Including CWM in the Statement of Environmental Effects (SEE) of development application | 0.573                          | 2.88        |

Figure 3. T2B scores for CWM critical measures
been adopted by several studies related to the issues of the construction industry and its waste (Chileshe, et al., 2015; Akinade, et al., 2017; Ajayi, et al., 2017b; Wang, Li and Tam, 2014; Yuan, 2013a). The following sections discuss the drivers of EM application to CWM and the critical measures within them.

**AGENTS OF CHANGE**

The economic imperative of EM attaches an important role to economic agents (such as designers, clients, suppliers, contractors, and sub-contractors in this study) as facilitators of ecological reform (Mol, 2000; Mol and Sonnenfeld, 2000; Mol and Spaargaren, 2000; Seippel, 2000; Berger, et al., 2001; Huber, 2008). Supporters of EM theory believe that a protected environment is important for economic benefits, and that the role of economic agents is vital to stimulate ecological development (Fisher and Freudenburg, 2001). Based on the outcomes of the factor analysis, the role of project stakeholders emerged as a driver of EM for CWM with an eigenvalue of 7.867 that accounted for 31.46% of the total variance (Figure 2). Project stakeholders thus are agents of change for applying EM for CWM, and their role is critical in the pursuit of an ecologically modernized NSW construction industry. This could be achieved through their roles in the engagement of all project stakeholders into CWM (M2); implementation of waste efficient designs (M5); promotion of CWM culture among project stakeholders (M1); supervision of onsite CWM practices with guidance (M15); pre-qualification of stakeholders based on CWM performance (M10); and demand for CWM as project clients (M9).

Engaging all stakeholders in CWM (M2) is an important aspect for waste-efficient projects. To encourage this, promoting a CWM culture among project stakeholders (M1) is needed. This shift in attitudes and behaviours to CWM on Australian construction projects was echoed by Udawatta, et al. (2015a) and Udawatta, et al. (2015b). Such changes require actions to be taken by contractors on project sites. In this study, survey respondents outlined ‘supervise onsite CWM practices with guidance (M15)’ as a critical measure. The importance of these onsite CWM related actions was mirrored by Ajayi, et al. (2017b). CWM can be through ‘pre-qualifying stakeholders based on CWM performance’. Respondents indicated the importance of the CWM prequalification process. There is general agreement that designers can play a major role in relation to CWM by ‘implementing waste efficient design’ (Greenwood, 2003; Osmani, Glass and Price, 2008; Baldwin, et al., 2009). This study found ‘waste efficient design (M5)’ an important CWM measure. Clients can be considered as one of most important stakeholders for promoting CWM (Udawatta, et al., 2015a). This is because the costs of wasted materials as well as of waste disposal are borne by them (Ekanayake and Ofori, 2003; Domingo, 2011). This study found that the role of clients in CWM (M9) is critical. Shen et al. (2004) stressed the role of clients in influencing other stakeholders to adopt CWM approaches. Dainty and Brooke (2004) highlighted the importance of developing a CWM culture among clients reflected through CWM requirements from other project stakeholders.

**GOVERNMENT POLICIES**

EM sees the role of the government as central in attaining sustainability (Christoff, 1996; Buttel, 2000; York and Rosa, 2003; Jänicke, 2008). EM promotes a government’s adoption of contextual steering policies, with a focus on changing curative and reactive policies to preventative ones (Berger, et al., 2001). In the context of this study, this theme suggests that governments should focus on waste prevention policies and interventions. As shown in Figure 2, the role of the government via its CWM-related policies is vital for applying EM to CMW, having an eigenvalue 3.836 that explained 15.34% of the total variance. The role of the government (D2) in applying EM to CMW can take place via increased influence and implementation of waste levies (M11) and site waste minimization and management plans (SWMMP) (M14).

Since its introduction in 1971, the NSW government has gradually raised the waste levy to $138.20/tonne in 2017-18 for metropolitan areas, and from $10/tonne in 2009-10 to $76.70/tonne in 2017-18.
for regional regulated areas (POEO, 2015; NSW Environment Protection Authority, 2020). The NSW construction industry spent about $133.4 million on waste levies in the 2018-19 fiscal year, and is expected to spend a $726.7 million up until 2022 (Perrottet, 2018). The levy is the government’s key economic instrument to encourage CWM and resource recovery and, as a result, less waste sent to landfills (NSW Office of Environment and Heritage, 2011; NSW Environment Protection Authority, 2020). Osmani (2012) and Martin and Scott (2003) stressed the role of landfill tax as a legislative measure to promote CWM. Participants in this study viewed the waste levy (M11) as critical measure for CWM.

SWMMP is a tool to manage and minimize waste on construction sites (NSW City of Newcastle, 2019; NSW City of Sydney, 2019). In NSW a SWMMP is one of the requirements of development applications (DA) (NSW City of Newcastle, 2019; NSW City of Sydney, 2019). The DA stresses that the plan should consider waste avoidance and minimization, reuse, recycling and the means of waste disposal. In line with this study finding of SWMMP as critical measure to more waste-efficient projects, Udawatta, et al. (2015b) stressed its importance as a critical solution for waste management on construction projects in Australia.

SUPPLY CHAIN DYNAMICS

As a core theme of EM, the economic imperative suggests an increase in the role of industry dynamics in ecological restructuring (Mol, 1999; Welford and Hills, 2003; Huber, 2008). Supply chain dynamics are important to drive the application of EM for CWM; this was shown from the results of factor analysis, with 1.589 of eigenvalue that explained 6.35% of the total variance (Figure 2). The findings indicated that all the measures contributing to CWM through supply chain dynamics were critical to CWM. The application of EM to CWM through supply chain dynamics could be through: CWM partnership through supply chain (M3); On-site materials segregation of waste, reuse and recycling (M7); CWM-related contractual clauses (M12); CWM financial incentives and penalties (M16); and consideration of CWM in materials selection, purchase and delivery (M13). The respondents’ opinions thus support their increase uptake as a contributor to CWM.

Respondents highlighted the importance of supply chain partnership (M3) in relation to CWM. Dainty and Brooke (2004) found that effective measures associated with CWM were those that supported ‘waste minimization partnerships’ throughout supply chains. Mendis (2011) stressed the positive relationship between contractual obligations and CWM. It is argued that CWM partnerships among stakeholders can be strengthened via contractual arrangements and incentives, where these measures were identified as important to CWM. Udawatta, et al. (2015b) found financial rewards to be one of the most important solutions to promote CWM. CWM may also be considered through materials procurement processes (Nagapan, et al., 2012; Ajayi, et al., 2017a). This was mirrored by the respondents of this study. As much as CWM supply chain partnerships with materials suppliers are important, they are also required with waste contractors (Dainty and Brooke, 2004; Ajayi, 2017). Authors have stressed the importance of on-site materials sorting (Domingo, 2011; Ajayi, 2017; Dainty and Brooke, 2004). Respondents agreed that on-site materials sorting is important for CWM within NSW construction industry.

SKILL-BUILDING

Skill building in relation to CWM can significantly contribute to the application of EM to reduce waste. As demonstrated in figure 2, the outcomes of the factor analysis showed that there is significant role for the industry trainers to drive change to EM via CWM training and education. This driver has an eigenvalue of 1.338 that comprised 5.35% of the total variance. Training and education about CWM can be conducted by several organizations and bodies, including the construction companies themselves. In NSW, the education and training associated with the construction industry is provided by universities, technical and further education institutions (TAFE), and relevant trade/industry associations (industry trainers), along with
construction companies themselves. Training and education about CWM (M4) was found to be critical to CWM. Education and training are essential components contributing to CWM (Osmani, Glass and Price, 2008; Begum, et al., 2009; Lu and Yuan, 2010; Udawatta, et al., 2015b). Therefore, this study suggests that industry trainers can potentially contribute to CWM through their knowledge providing capabilities, direct or embedded awareness programmes, and education and training of industry stakeholders. Meanwhile, some of them as ‘industry associations’ can serve as dissemination platforms for CWM related information alongside training. In alignment with this, Udawatta, et al. (2015b) highlighted the significance of education and training for all project stakeholders to enhance CWM practices on Australian construction projects. For industry associations, some authors outlined their role in relation to environmental improvements, heightened awareness, motivation for improvement of environmental behaviours, and effective means of communicating environmental messages to companies (Smith A, 1998; Hunt, 2000; Revell and Rutherford, 2003). This mainly due to their close links to industry and ability to provide sector specific information.

TECHNOLOGICAL INNOVATIONS

Technological innovation is a core theme at the heart of EM. In this study, the role of technology in waste minimization is conceptualised as the need for waste preventative technology to minimize construction waste. Technological innovations play a significant role in the shift to EM (Howes, et al., 2010). EM supports the preventative roles of technological innovations to environmental damages (Revell, 2007; Howes, et al., 2010). The results of the factor analysis showed that technological innovation emerged as a key driver to be applied to EM, having an eigenvalue of 1.029 that accounted for 4.11% of the total variance (Figure 2). The results of the study showed that prefabrication technology (M8) and building information modelling (BIM) (M6) are critical measures of technological innovation to CWM.

Prefabrication technology such as prefabricated wall and floor panels, columns, stairs, and facade panels has been increasingly adopted in different construction industries around the world, and CWM is one of the advantages that encourages its use (Jaillon, Poon and Chiang, 2009; Lu and Yuan, 2013). In this study, prefabrication technology (M8) has been found to be a critical measure to CWM in the NSW construction industry. To enhance the efficiency of the Australian construction industry, prefabrication was promoted in the ‘Australian Construction Vision 2020’ as one of eight key visions (Hampson and Brandon, 2004; Steinhardt, Manley and Miller, 2014). This indicates recognition of the benefits of prefabrication as an approach to improve the efficiency of construction industry. In alignment with this study findings, Udawatta, et al. (2015b) emphasized the importance of prefabrication to make the Australian construction projects more waste efficient. In relation to BIM, variant studies identify BIM as enabler for project stakeholders to effectively minimize waste on their construction projects (Ahankoob, et al., 2012; Liu, et al., 2015; Cheng, Won and Das, 2015). In this study, the use of BIM (M6) has been identified as critical, and its use can make significant contributions to CWM. BIM thus should be considered as a compelling business case for companies within NSW.

Conclusions

This study investigated the application of EM to reduce the continuous growth of C&D waste currently plaguing the construction industry of NSW. Five important drivers for EM’s application to CWM were identified. These drivers conform to the conceptualization of EM’s application to CWM via its themes, as represented in the EM-based CWM framework (Figure 1). These drivers were: ‘agents of change (D1)’, ‘government policies (D2)’, ‘supply chain dynamics (D3)’, ‘skill building (D4)’, and ‘technological innovations (D5)’. The role of project stakeholders as agents of change (D1) was found to be important in driving the application of EM to CMW. As agents of change, project stakeholders, such as designers,
contractors, sub-contractors, suppliers, and clients can have an important role as conductors of ecological restructuring via the implementation of CWM. Such a role is critical in the pursuit of an ecologically modernized NSW construction industry. The role of the NSW state and local governments (D2) via their CWM-related policies was identified as vital for applying EM to CMW. Supply chain dynamics (D3) to create business opportunities inherent in CWM were also identified as a driver for the application of EM for CMW. It was found that skill building in relation to CWM (D4) can significantly contribute to the application of EM. Technological innovation (D5) emerged as a key driver for applying EM to CWM as well. The critical measures for each of the drivers for applying EM to CWM within the context of the NSW construction industry were also identified.

The outcomes of this study provide a guide for applying EM to CWM for the NSW construction industry. That is, to delink construction industry growth from construction waste generation, and, as a result, enable NSW construction industry growth to occur without compromising and damaging the environment. They can also contribute to reduced C&D waste recycling and gradual diversion of waste sent to the state’s C&D landfill sites. Furthermore, the outcomes presented in the study can be used as a yardstick to inform CWM-related policymaking and future CWM-related studies. Data gathering from NSW in Australia and the unexplored potential of EM application to CWM were limitations related to this study. Future studies can investigate the application of EM for other types of waste on construction projects, such as workers, costs, construction machinery, time and materials. They can also examine the application of EM to delink the growth of the construction industry from other aspects of environmental harm, such as energy consumption or greenhouse gas emissions.

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