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# Visualising a framework for enhancing material circularity in building construction projects: Drivers, barriers, and strategies

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ABSTRACT

Material circularity offers a novel perspective for industrial ecosystems, emphasising the reintegration of materials and products into the supply chain as valuable resources. This approach leads to a reduction in primary resource consumption and waste generation. Nevertheless, the incorporation of material circularity within the construction sector is hindered by barriers, necessitating careful analysis and practical solutions. Therefore, a clear roadmap with practical strategies that promote material circularity is needed. This study aims to identify the drivers, barriers, and strategies, concurrently formulating a framework to enhance material circularity in building construction projects. A sequential qualitative-quantitative mixed methods approach was employed to achieve this aim, which involved a literature review, 19 expert interviews, and two questionnaire surveys, which collectively yielded 230 responses. A literature review and expert interviews identified drivers, barriers, and strategies for implementing material circularity practices. Subsequently, using a five-point Likert scale, the first survey measured the importance of drivers and barriers. Then, the second survey was conducted to align strategies with corresponding barriers to enhance material circularity practices effectively. The results of the study indicated that cost savings primarily drive the adoption of material circularity. The most significant barrier was the underdeveloped marketplace for secondary products. The government plays a crucial role in addressing various barriers by implementing key strategies, including the introduction of regulations, policies, and economic incentives to promote material circularity. Finally, an evidence-based framework is proposed to assist practitioners and policymakers in creating a roadmap for implementing circular economy practices.

## 1. Introduction

### 1.1. Implementing material circularity practices in the construction industry

The building and construction sector consumes 40% of the world's natural resources, generates 40% of waste, and emits 33% of the world's emissions [1]. The construction sector is the foremost user of raw materials, consuming roughly three billion tons globally [2]. The sector is still predominantly based on a linear economy of high natural resource consumption and low resource recovery, often referred to as 'take-make-dispose' [3]. The linear economic model is inadequate for achieving sustainability and cleaner production of resources [4]. The alternative is the Circular Economy (CE), a broader concept that encompasses creating an economic system that is restorative and regenerative by design [5] and promotes the closed-loop system where resources (e.g., materials, energy, water) are continuously recycled and reused, reducing the dependence on virgin resources and minimising waste [6].

Material circularity is a key component of the CE; it refers to designing, producing, and consuming materials to minimise waste and maximise resource use [7]. The concept of material circularity tries to keep materials in use for as long as possible and minimise waste via recycling and repurposing [7,8]. Strategies aligning with this concept include intensifying product use, dematerialising products, and improving efficiency [9]. It replaces the 'end-of-life' concept with reusing, recycling, and recovering materials and components [10]. The concept of material circularity can be operationalised through several approaches: the adoption of secondary items instead of new ones [11], the use of prefabricated components, and implanting design for disassembly (DfD) [12].

Applying material circularity practices to building construction

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projects is essential as the world's cities have witnessed significant population growth recently, gaining billions of new residents. Consequently, the demand for buildings and associated amenities has intensified [13], resulting in increased generation of construction and demolition waste (C&DW) and the depletion of natural resources [14]. Adopting material circularity principles could reduce material consumption and waste generation, leading to more efficient use of resources. The World Economic Forum estimated that implementing circularity practices globally by 2025 could result in annual material savings worth over one trillion dollars by decreasing the dependence on new resources and bringing economic benefit through value retention [15].

### *1.2. Framework for enhancing material circularity in the construction industry*

Despite the advantages of material circularity practices, numerous barriers have affected its implementation in the building and construction industry [16]. Several countries are encountering difficulties in implementing material circularity practices due to insufficient information on the barriers to and effective strategies for achieving circularity [17]. Therefore, these barriers must be overcome for a smooth transition to material circularity [18]. The existing literature recognises that implementing circularity within the building and construction sector is an interlinked challenge involving the participation of various stakeholders, including those from the public and private sectors [19]. Therefore, enhancing material circularity requires adaptable strategies from various stakeholders across diverse economic, social, and policy sectors [20]. Furthermore, these strategies must encompass multiple social, economic, technological, and environmental aspects to expedite the paradigm shift [19].

Previous research on implementing CE practices within the building and construction industry has provided valuable insights into identifying barriers. For example, Mahpour [21] studied CE adoption in C&DW management to ascertain the barriers in this area. Similarly [18], assessed the barriers to adopting CE practices within the construction industry, specifically focusing on achieving zero waste. Further [22], investigated the barriers and enablers to adopting CE principles in the Australian architecture, engineering, and construction (AEC) industry.

However, most of these studies focus exclusively on identifying barriers and fail to consider the drivers and strategies that motivate the implementation of material circularity practices. Additionally, these studies all take a broad perspective, concentrating on industry-wide barriers while overlooking distinct drivers, barriers, and strategies experienced by different stakeholder groups. Accordingly, existing studies (1) overlook the identification of drivers that motivate material circularity, (2) fail to distinguish how the drivers and barriers differ between stakeholder categories, and (3) neglect to match the identified barriers with the appropriate strategies to overcome them.

Therefore, a rigorous study is imperative to examine the drivers and barriers to material circularity while exploring effective strategies to overcome the barriers and reinforce the drivers. This study seeks to bridge this gap by identifying the drivers, barriers, and strategies, concurrently formulating a framework to enhance material circularity in building construction projects. Answering the following research questions will help achieve this goal.

**RQ1**. What are the drivers, barriers, and strategies for enhancing material circularity in building construction projects?

**RQ2**. How do the drivers and barriers differ among stakeholder categories?

**RQ3**. What strategies help overcome barriers to material circularity practices in building construction projects?

Finally, a framework is proposed to aid construction industry practitioners and policymakers in creating a roadmap for implementing circular economy practices. Furthermore, the study presents policy implications to promote material circularity, considering various stakeholders' expectations.

The rest of this paper is structured as follows: Section 2 provides a literature review, Section 3 outlines the research methodology, Section 4 presents the results and discussion, Section 5 discusses the implications, and Section 6 concludes the paper.

## 2. Literature review

This section summarises the drivers, barriers, and strategies for material circularity identified via the literature review.

### *2.1. Drivers for achieving material circularity*

Drivers are the key opportunities that motivate stakeholders to promote material circularity practices. The following sections classify drivers into economic, social, and environmental categories.

#### *2.1.1. Economic drivers*

**Opportunities for new business development:** Material circularity enhances people's well-being by generating new employment opportunities and encouraging economic growth while minimising environmental effects [23]. New business opportunities created by the popularity of the material circularity concept include using robotics and artificial intelligence for waste sorting and online platforms to sell reclaimed materials [6].

**Cost savings:** When construction industry practitioners see the economic benefits of adopting material circularity practices, they are more likely to invest in them [24]. For example, companies can reduce the amount of waste they generate and its associated disposal costs by implementing material circularity practices such as reusing and repurposing materials.

#### *2.1.2. Social drivers*

**Enhancing the company image:** Many companies are exploring environmentally friendly strategic and operational solutions that reduce the adverse effects of organisational activities [25]. Hence, companies significantly emphasise incorporating material circularity practices such as recycling construction waste into their business strategies to enhance their images and reputations [26].

**Meeting ethical requirements:** The CE promotes social equity, ethics, and compliance by enhancing social welfare distribution [27] and incentivising economic and social growth by promoting sustainable development while satisfying the needs of present and future generations [28]. This drives material circularity by empowering individuals and communities to participate in circularity initiatives, such as recycling, reusing, and sharing resources [29] to support an equitable and responsible society.

#### *2.1.3. Environmental drivers*

**Green certifications and rating systems:** Green certifications establish credibility for companies by demonstrating their commitment to environmental sustainability. Leadership in Energy and Environmental Design (LEED), the most widely adopted green certification worldwide, promotes sustainable building development [30]. Notably, LEED v4.1 encompasses principles that drive material circularity practices. For instance, it introduces credits for C&DW reduction at source (e.g., reuse of salvage building materials, building reuse, and renovation of abandoned buildings) [6].

**Growing environmental consciousness:** Global discussions on resource depletion, waste management, and environmental pollution have gained significant momentum. Material circularity practices, including design for disassembly and adaptability (DfD/A) principles, use of renewable materials, and construction waste diversion aimed at slowing, narrowing, and closing material loops, have gained considerable attention as they offer potential solutions to the persistent challenges arising in the building industry [11,12].

The summary of the drivers for achieving material circularity discussed in the above section is depicted in Table A.1.

### 2.2. Barriers to achieving material circularity

Barriers are factors that hinder the implementation of material circularity in the construction industry. The following sections classify barriers into five categories: policy and regulatory, economic and cultural, financial, information and technological, and organisational.

#### 2.2.1. Policy and regulatory barriers

**Lack of policies and regulations on material circularity:** Current policy frameworks fail to instill the circularity practices imperative for promoting C&DW management and reducing resource consumption in the construction sector [31]. For example, the construction industry lacks appropriate policies to encourage the use of reclaimed materials and green design strategies [32]. Further, the lack of stringent regulations threatens the potential for material circularity adoption in the construction industry [18,20].

**Lack of a common goal to achieve circularity in construction:** Due to the lack of governmental goals on achieving material circularity, construction companies with a narrow view of corporate social responsibility exhibit an indecisive culture and fail to integrate circularity practices into the organisation's vision, mission, goals, and key performance indicators [33,34].

#### 2.2.2. Economic and cultural barriers

**Low demand for secondary products:** The construction industry has a widespread belief that reclaimed or recycled products and materials are of inferior quality compared to virgin building materials [35]. According to Jaillon and Poon [36], the lack of marketing for reclaimed materials is also a reason for the low demand for reclaimed materials. Hence, virgin materials are preferred over recycled products in the construction industry [33].

**Immature marketplace for secondary products:** The absence of secure and user-friendly market platforms accessible to buyers and sellers of recycled and reclaimed products remains a significant obstacle to the use of circular materials [24]. Without a centralised, dedicated, and reliable platform, sellers find it challenging to reach potential buyers and vice versa [37]. Hossain, Ng, Antwi-Afari and Amor [5] report that uncertainties in the supply of secondary products are also a problem associated with market underdevelopment.

**Resistance to change:** The preference for traditional construction methods and materials results in resistance to adopting innovative construction methods and materials [38]. Predominantly, the older generation dislikes changing how they work and adopting innovative construction methods. Such attitudes hinder the application of material circularity practices in the construction industry [33].

#### 2.2.3. Financial barriers

**High cost of implementing material circularity practices:** The cost of adopting CE strategies such as prefabrication, disassembly, deconstruction, use of secondary materials, and C&DW minimisation is significant [33]. For example, refurbished and recycled materials tend to be more expensive than virgin materials due to the costs associated with processing such materials into reusable forms, creating a significant barrier to using circular materials in the construction industry [39,40].

**Lack of financial incentives to promote circularity in construction:** The adoption of material circularity practices in the construction industry has been hindered by insufficient financial incentives to integrate circularity strategies into organisations, supply chains, and projects [41]. Construction projects with low-profit margins discourage adopting new circularity strategies, which would increase construction costs [42].

**Relatively low cost of disposing of material in landfills:** The profit-focused nature of the construction industry [43] discourages recycling construction waste as the costs of dumping waste at landfills are substantially lower. Further, the substantially lower costs of dumping waste at landfills motivate building owners and clients to demolish rather than deconstruct old buildings [44].

#### 2.2.4. Information and technological barriers

**Inadequate understanding of material circularity:** Lack of knowledge and awareness of the CE and the benefits of closed-loop approaches is common in the construction industry [18,40]; for example, the value of reuse and recycling of materials is underestimated [37]. This lack of knowledge leads to the low application of material circularity practices [45].

**Lack of information on circular construction materials, products, and strategies:** Circularity decisions in the construction industry are guided by statistical data on materials and waste [46]; this information is vital to planning and developing waste management strategies and predictions on the CE [47]. For example, predicting recycled concrete's durability and behaviour is difficult without adequate data [48]. The Environmental Protection Agency provides well-organised statistical data and forecast data on solid waste generation in countries such as Hong Kong, the United States, and Australia [49]. Nevertheless, there is a lack of statistical work dedicated to collecting data on reclaimed materials, construction waste generation, and the volume and composition of waste [50], which could identify barriers to applying material circularity practices.

**Lack of material recycling facilities:** Adopting material circularity in construction has also been stifled due to inadequate infrastructure to support construction waste management and material recovery. The lack of recovery or reprocessing facilities discourages material recycling [18]. Wuni [40] reports that the lack of application of technologies crucial for the efficient and effective separation, recovery, and recycling of construction waste has also contributed to the delayed adoption of material circularity practices.

#### 2.2.5. Organisational barriers

**Lack of top management commitment,** support**, and leadership:** Senior management holds the most influence in the decision-making process to execute innovative technologies and ideas [51]. Lack of senior management commitment and support in implementing circularity practices obstructs the allocation of resources and strategic planning necessary for a smooth transition to a material circularity within the construction industry [40]. Consequently, this hinders the integration and prioritisation of material circularity practices in construction projects [39].

The summary of the barriers to achieving material circularity discussed in the above section is depicted in Table A.2.

### 2.3. Strategies for enhancing material circularity

Strategies are factors that help overcome the barriers to implementing material circularity in the construction industry. The following section discusses the identified strategies, which have been classified into three categories: policy and market, educational and information, and technological.

#### 2.3.1. Policy and market strategies

**Introduce regulations and policies to promote material circularity:** Governments have a crucial role in enforcing policies and regulations related to circular construction. These policies should encourage practices such as the use of reclaimed, recycled, or sustainable materials, with the overarching goal of reducing waste generation and promoting responsible material consumption [52]. Supportively, Huang, Wang, Kua, Geng, Bleischwitz and Ren [31] suggest that updating existing construction building codes and policies to incorporate the use of circular materials will enhance the market acceptance of circular practices in material usage.

**Provide economic incentives to promote material circularity:** Financial support and preferential tax policies are crucial to offsetting the higher upfront investment of applying circular practices [43]. According to Stahel [23], the tax system should adapt to not taxing materials that can be reused, repaired, or remanufactured as it comprises downstream activities such as collecting, disassembly, cleaning, reassembly, and quality control, which are costly and labour intensive. Without economic support, industry practitioners will have no motivation to pursue higher circularity levels [53].

**Introduce quality standards for secondary materials:** Governments should develop national standards on the design, technical, and quality of secondary building materials with the support of industry practitioners and academics [53]. This would ensure that buildings made from reclaimed or recycled materials meet quality requirements and technical specifications for their designated applications [24]. This can bolster stakeholder confidence in the quality of the recycled material, resulting in increased usage in construction projects [54].

**Establish effective markets for secondary products:** Market development for secondary materials involves the establishment of a market for materials that can be reused, recycled, or repurposed. Developing online platforms and physical marketplaces where buyers and sellers interact to exchange secondary products (e.g., recycled waste materials) is essential for improving material circularity [5,54].

#### *2.3.2. Educational strategies*

**Promote collaboration among stakeholders:** Multi-stakeholder collaboration with organisations, both locally and globally, is essential [55] to facilitating effective knowledge diffusion and encouraging the application of CE practices [2,56]. Hence, collaboration and knowledge transfer between universities, organisations, investors, businesses, and communities are necessary. Allowing stakeholders to share best practices related to material circularity will encourage research and development on novel technologies and alternative materials to reduce material consumption [24].

**Conduct capacity-building programs to improve awareness:** For the successful implementation of material circularity practices in construction projects, construction professionals must possess sufficient knowledge of waste management practices, material selection, deconstruction, and adaptability technologies [57,58]. Therefore, achieving success in circular construction projects involves providing education, training, and capacity-building opportunities for the project team members, enabling them to acquire the necessary competencies and technical skills [59].

**Research and development to improve material circularity:** Researchers should devote more attention to the concept of material circularity to simplify its implementation. This can be achieved by developing comprehensive guidelines addressing the challenges that prevent material circularity adoption in the construction industry [2]. Further, interdisciplinary research on the tools and techniques to explore opportunities for the expansion of material circularity in the AEC industry is needed. For example, research is required to focus on achieving cleaner production of raw materials at the initial stages of the production process to improve circularity [60].

#### *2.3.3. Information and technological strategies*

**Integrate digital technologies:** Innovations in construction drive the application of material circularity practices. Digital technologies such as BIM, material passports, and material banks enable the data-based circular lifecycle management of construction components [53]. A collaborative BIM platform connecting with the material bank and material passport enables informed decision-making, improves efficiency, reduces waste, and promotes the use of environmentally friendly materials throughout the project lifecycle [61]. In addition, Blockchain is gaining increasing recognition as a viable means of enhancing material circularity by identifying inefficiencies in supply chains and improving their processes to reduce waste and improve material reuse [62]. Thus, digital technologies are essential enablers of circular construction [63].

**Develop an Industrial Symbiosis Network:** Industrial Symbiosis (IS) is a highly effective platform for transferring one's waste as raw materials to another [64]. This supports closed loops [65]. The IS platform, which provides real-time information on waste location and prices, can effectively promote the reuse of C&DW in the construction industry. Further, analytics tools such as big data and material flow analysis could improve waste-to-resource matching in IS systems by collecting and processing real-time material and information flows [66].

The summary of the strategies for enhancing material circularity discussed in the above section is depicted in Table A.3.

## 3. Research methodology

This research developed a multistage methodological framework incorporating a literature review, expert interviews, respondent Survey No. 1 and respondent Survey No. 2. A literature review was conducted to identify drivers, barriers, and strategies for implementing material circularity practices. Expert interviews were conducted to validate the literature findings and identify additional drivers, barriers, and strategies. Subsequently, using a five-point Likert scale, the first survey measured the importance of drivers and barriers. Then, the second survey was conducted to align strategies with corresponding barriers to enhance material circularity practices effectively. Finally, the framework was developed using the outcomes derived from the antecedent stages. The summary of these stages is presented in Fig. 1 and detailed in the following sections.

### *3.1. Stage 1—Literature review*

Initially, this study conducted a literature review to evaluate current research on drivers, barriers, and strategies for implementing material circularity practices in the construction sector. The following sections describe the details and steps of the literature review.

#### *3.1.1. Identification of articles*

Selecting databases is the first step in the article identification process. This study used the Web of Science and Scopus, the two most significant academic repositories for article retrieval. These two databases provide broad coverage of literature and help to carry out structured searches by developing search queries. Past studies in the AEC industry have used similar databases for article selection [67,68]. The following search query was employed for this study:

TITLE-ABS-KEY ((“circular economy” OR “material circularity” OR “circular econ*" OR “circularity” OR “materiality”) AND (“construction industry” OR “construction sector” OR “buil* environment” OR “building sector” OR “build* industr*") AND (“drivers " OR “barriers " OR " challengers” OR " enablers” OR “strategies ")).

#### *3.1.2. Screening of articles*

The articles considered for this study were limited to those published after 2000. The recent systematic literature review of [69,70] found that CE in the construction industry gained popularity in the early 2000s. Subject areas were limited to environmental science, engineering, materials science, and mathematics, which are relevant to the research domain. Articles related to the CE in other fields, such as psychology, arts, healthcare, and agricultural sciences, were excluded at this stage. Journal articles were prioritised under the document type since journal articles provide more in-depth knowledge than conference papers. Finally, non-English language articles were filtered out.

#### *3.1.3. Eligibility checking and the selection of relevant articles*

After removing the duplicates in the two search engines, the

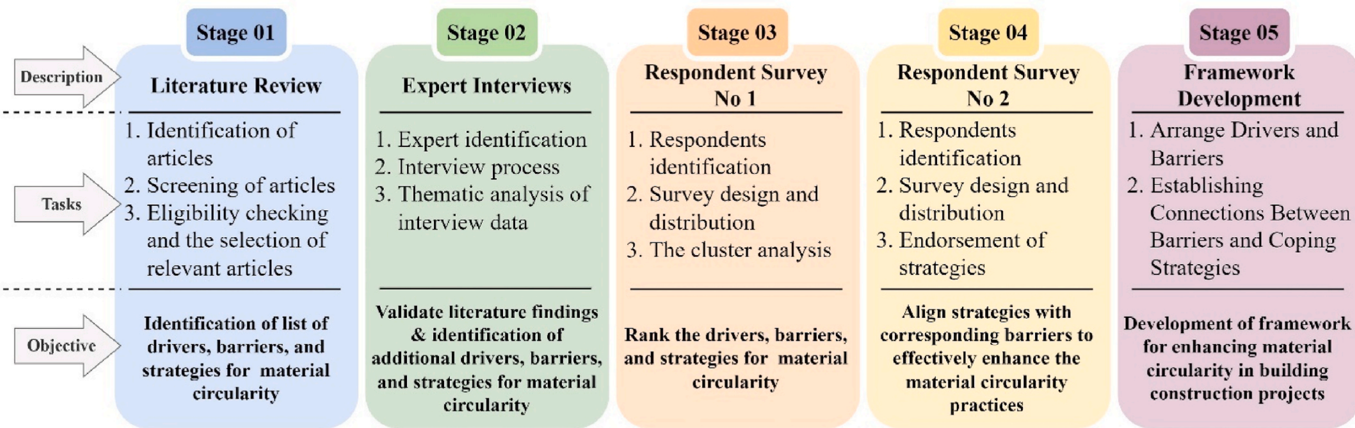



**Fig. 1.** Flowchart describing the research process.

eligibility checking was conducted following the title examination, keyword analysis, abstract reviews, and full-text reviews to select the relevant articles for this study.

### 3.1.4. Content analysis of articles

According to the content analysis followed by Ref. [71], the content analysis adopted in this process is initiated with open coding, which involves recognising, categorising, and describing events found within the studied literature. The researcher developed initial codes of drivers, barriers, and strategies based on literature findings. Subsequently, commonalities among the open codes, such as those with similar meanings, were identified and categorised into several axial codes. The final step in the process was selective coding, where the core category of drivers, barriers, and strategies was selected if a group of concepts reflected the respective core category.

This study shows the use of open, axial, and selective coding strategies as follows: Shooshtarian et al. [72] mentioned, "current policy frameworks fail to instil the circularity changes that are imperative for promoting CE in the construction sector." The researchers then gave an open code for this statement as "lack of policies on material circularity." Ghisellini et al. [32] stated, "the construction industry faces significant obstacles in embracing the principles of the material circularity due to the absence of policies promoting circular product usage." The researchers gave an open code of "no policies on material circularity." Both open codes from Shooshtarian et al. and Ghisellini et al. [32] can be categorised into an axial code, "lack of policies on material circularity." Since both axial codes are related to policy and regulatory barriers, they were categorised into a selective code, "policy and regulatory barriers."

## 3.2. Stage 2 - Expert interviews

Expert interview methods are widely used for exploring the perspectives of individuals with expertise in a particular field [73] and can be effectively used to validate literature findings [71]. Hence, expert interviews were held as the second step in the data collection process to validate the drivers, barriers, and strategies for material circularity identified in the literature review. The interview process aimed to solicit expert viewpoints concerning the comprehensibility and clarity of the terminologies and descriptions used for the drivers, barriers, and strategies. The insights gained through the expert review process were used to design a questionnaire survey. Further, the expert review process facilitated a deeper understanding of drivers, barriers, and strategies applicable to material circularity practices in Australian building construction projects.

### 3.2.1. Expert identification

Participants were recruited through a snowball sampling approach. The study aimed to compose a sample of participants with more than five years of experience in CE, waste management, or resource recovery from different types of companies (i.e., consulting firms, construction companies, academic and research institutions, and government organisations). The participants were chosen to represent diverse roles (e.g., consultant-sustainability, researcher, construction manager, civil/structural engineer, policy analyst, recycling industry practitioner) in the Australian construction industry. Interviewees were initially contacted via email. Respondents were then asked to recommend other experts within the identified stakeholder groups who comprehensively understand the studied problem.

### 3.2.2. Interview process

Online interviews were held using an expert interview guideline with two sections: (1) background information and (2) drivers, barriers, and strategies for implementing material circularity practices. The initially categorised list of drivers, barriers, and strategies for material circularity practices was emailed to the first interviewee, allowing the expert to prepare their comments before the interview. The updated list was then forwarded to the next expert for further review, and so forth. The experts were allowed to suggest any additional drivers, barriers, and strategies they deemed relevant for inclusion. Two months were allocated for the expert interviews (February to March 2023). The interviews usually lasted between 30 and 45 min.

According to the succession of Salim, Stewart, Sahin and Dudley [71], all interviews were recorded with permission to aid analysis and ensure accuracy. Data collection was stopped according to saturation criteria, where the return of new information decreased [74]. This study interviewed 19 experts since [75] recommended that 12 to 20 participants are required for the interview when heterogeneity exists in participants' backgrounds. The interviews involved the participation of five academics/researchers, five contractors, five consultants, and four government officials. Table B.1 provides background information on the interviewees, including the type of organisation they are affiliated with and their years of experience.

### 3.2.3. Thematic analysis of interview data

Thematic analysis is a qualitative research method used to analyse interview findings [76]. It involves identifying and categorising patterns, themes, and concepts within the data to gain insights and develop a deeper understanding of the research topic. Researchers conducted several iterative steps, including transcribing interview recordings, familiarising themselves with the data, searching for themes, reviewing and refining themes, and interpreting and reporting the findings. The interview findings were thematically coded based on the drivers, barriers, and strategies found in the literature. Similarities and differences that reinforced or contradicted the drivers, barriers, and strategies were documented. Similar responses were grouped under each theme. Drivers, barriers, and strategies that emerged from the interview data and were new to the literature were documented and added to the analysis. The interviewees added an additional five drivers, seven barriers, and five strategies, which are discussed further in Section 4.

### 3.3. Stages 3 and 4 - Respondent surveys 1 and 2

Two respondent surveys were conducted. The first survey aimed to rank the identified drivers and barriers according to their importance. The second survey was conducted to align strategies with corresponding barriers to enhance material circularity practices effectively.

#### 3.3.1. Respondent identification

Respondent identification was undertaken for both surveys. The respondent groups relevant to this survey include contractors, consultants, government officials, and academics/researchers who engage in construction, resource conservation, construction waste management activities, and recovery processes. A purposive sampling method was used to identify survey participants. Academics/researchers were identified through construction management journals that focus on the CE. The industrial practitioners were identified through a LinkedIn search and relevant institutes and associations' websites. According to the suggestion of [77], a snowball sampling method was integrated to increase the response rate, and respondents were asked to suggest colleagues interested in participating in the survey.

#### 3.3.2. Survey design and distribution

Two online surveys were designed and distributed among the identified respondents.

*3.3.2.1. Survey no. 1.* In Survey No. 1, the participants were given a questionnaire that comprised six sections. The first section focuses on respondents' background information, while the second section focuses on stakeholder perceptions regarding the application of material circularity practices. In the third, fourth, and fifth sections, respondents were asked to express their professional opinion on the importance of drivers and barriers for implementing material circularity practices using a five-point Likert scale ('1' = not at all, '2' = to a small extent, '3' = to a moderate extent, '4' = to a great extent, '5' = to a very great extent). The Likert scale is a widespread method in construction management research for rating the relative importance of individual factors based on experts' perceptions [71]. The description of each driver, barrier, and strategy was included in the questionnaire to provide clarity for respondents. In the sixth section, respondents were asked to recommend other experts in their field to identify possible other respondents for data collection. **Appendix C** provides more details about the questionnaire.

The survey questionnaire was distributed via email to the identified respondents. Three months (April to June 2023) were allowed for the questionnaire survey. After a series of reminder emails, 249 responses were received, from which 160 (40 academics/researchers, 40 contractors, 40 consultants, and 40 government officials) were chosen for analysis after removing partially completed questionnaires.Table D.1 describes the background information of the survey respondents.

#### 3.3.3. Cluster analysis

The cluster analysis was performed using SPSS Statistics with the use of Survey No. 1 results, considering respondents' interest level and the extent of their influence in decision-making and policy design activities [78]. In section 2 of the questionnaire, respondents were asked to rank their organisation's level of interest in adopting material circularity practices and to assess the extent to which they believed their organisation could influence decisions regarding implementation and/or policy design concerning material circularity. Respondents who answered 'do not know/insufficient information to say' in the questionnaire were excluded from the analysis.

The unweighted mean importance was calculated based on the respondents' opinions of the importance of drivers, barriers, and strategies. This calculation utilised data from the questionnaire's third, fourth, and fifth sections, employing a simple descriptive statistic. These means were subsequently used to establish the ranking of each driver and barrier, facilitating a comparative analysis across different respondent categories.

*3.3.3.1. Survey no. 2.* Participants who completed Survey No. 1 were selected for Survey No. 2. Participants in this survey received a questionnaire with two sections. The first section gathered respondents' background information, such as their role, the type of organisation they are affiliated with, and their number of years of experience. In the second section, respondents were asked to select the most relevant strategy/strategies to overcome the barriers to material circularity.

There were 95 responses, from which 70 responses were selected (18 academics/researchers, 18 contractors, 18 consultants, and 16 government officials) for analysis after removing partially completed questionnaires. The response is acceptable because it is above the minimum threshold of 30 responses required for the central limit theory to make a credible conclusion [79]. Table D.1 describes the background information of survey respondents.

#### 3.3.4. Endorsement of strategies

Survey No. 2 mainly focused on identifying strategies to overcome the barriers to material circularity. Following the study analysis method conducted by Waltz, Powell, Fernández, Abadie and Damschroder [80], two types of strategies (Level 1 and Level 2) were identified. Strategies are classified into different levels based on the percentage of respondents who indicated their opinion that a particular strategy could overcome a given barrier. A strategy is classified as a Level 1 strategy if 50% or more of the respondents (i.e., more than 35 respondents) expressed their agreement that it could address the barrier. Conversely, a strategy falls into the Level 2 category if it receives support from 20% to 49.9% of the respondents (i.e., between 34 and 20 respondents). Any strategy that was supported by less than 20% of the respondents for a particular barrier was not included in the classification.

### 3.4. Stage 5 - Framework development

Based on the results of the above stages, a framework is developed. The two primary steps followed to create the framework are explained in the following.

#### 3.4.1. Arrange drivers and barriers

A comprehensive literature review and expert interviews identify the drivers and barriers. Subsequently, these identified drivers and barriers are ranked using the results obtained from Survey No. 1. To construct the framework, the drivers and barriers are arranged based on their rankings. The highest-ranked drivers are positioned at the top of the list, with rankings descending as they move down through the list. Similarly, barriers are organised within the framework accordingly.

#### 3.4.2. Establishing connections between barriers and coping strategies

Strategies are classified into two categories: Level 1 and Level 2, as discussed in Section 3.3.4. In the framework, connections between barriers and coping strategies (Levels 1 and 2) illustrate how specific strategies can address particular barriers. By employing this classification system, the framework aims to provide a clear understanding of the level of endorsement and confidence in various strategies to tackle different barriers as perceived by the respondents. Further discussion is presented in sections 4.3 and 4.4.

## 4. Results and discussion

### 4.1. Stage 1 and 2 - Literature review and expert interviews

Section 2 presents the results of the literature review; expert interviews were based on those results. The interviews allowed interviewees to raise any additional drivers, barriers, and strategies not identified in the literature review. Accordingly, the interviewees identified five drivers, seven barriers, and five strategies. The final list of drivers, barriers, and strategies, including findings from both the literature review (Stage 1) and expert interviews (Stage 2), are provided in **Appendix E.**

### 4.2. Stage 3 - Respondent survey no. 1

Respondent Survey No. 1 was conducted with participants from four categories: academics/researchers, contractors, consultants, and government officials. The primary objective was to ascertain their perceptions regarding interest and influence toward material circularity. Additionally, respondent survey no. 1 aimed to determine their perceptions regarding the relative significance of drivers and barriers concerning material circularity. The subsequent sections provide a detailed analysis of respondents' interest and influence towards material circularity and mean importance attributed to drivers and barriers while interpreting variations across the respondent categories.

#### 4.2.1. Respondent interest and influence towards material circularity

There was remarkable consensus between respondent categories on the perception of material circularity (**Appendix F)**. Respondents' level of interest and influence towards the application of material circularity are mentioned in Table G.1. In general, all respondent groups expressed a high level of interest in promoting material circularity practices. This is because they believed that the application of material circularity practices would have a positive impact on their organisation either economically, environmentally, or socially. Consultants demonstrated the highest level of interest in applying material circularity practices. Consultants in the construction industry possess specialised knowledge and expertise in material circularity practices; they understand the potential environmental benefits and cost savings associated with material circularity, leading to their heightened interest and enthusiasm [71]. Further, all respondents believed that they could influence the implementation of material circularity practices by implementing policies, making strategic decisions, and conducting research activities. Government officials showed the highest level of influence on the implementation of material circularity practices. Governments have the authority to shape the construction industry and drive material circularity by establishing policies, regulations, and standards, as well as incentivising or mandating companies to adopt these practices.

#### 4.2.2. Drivers for achieving material circularity

There was remarkable unanimity between respondent categories on the perceived drivers (see Fig. 2). Mean scores and ranking for each

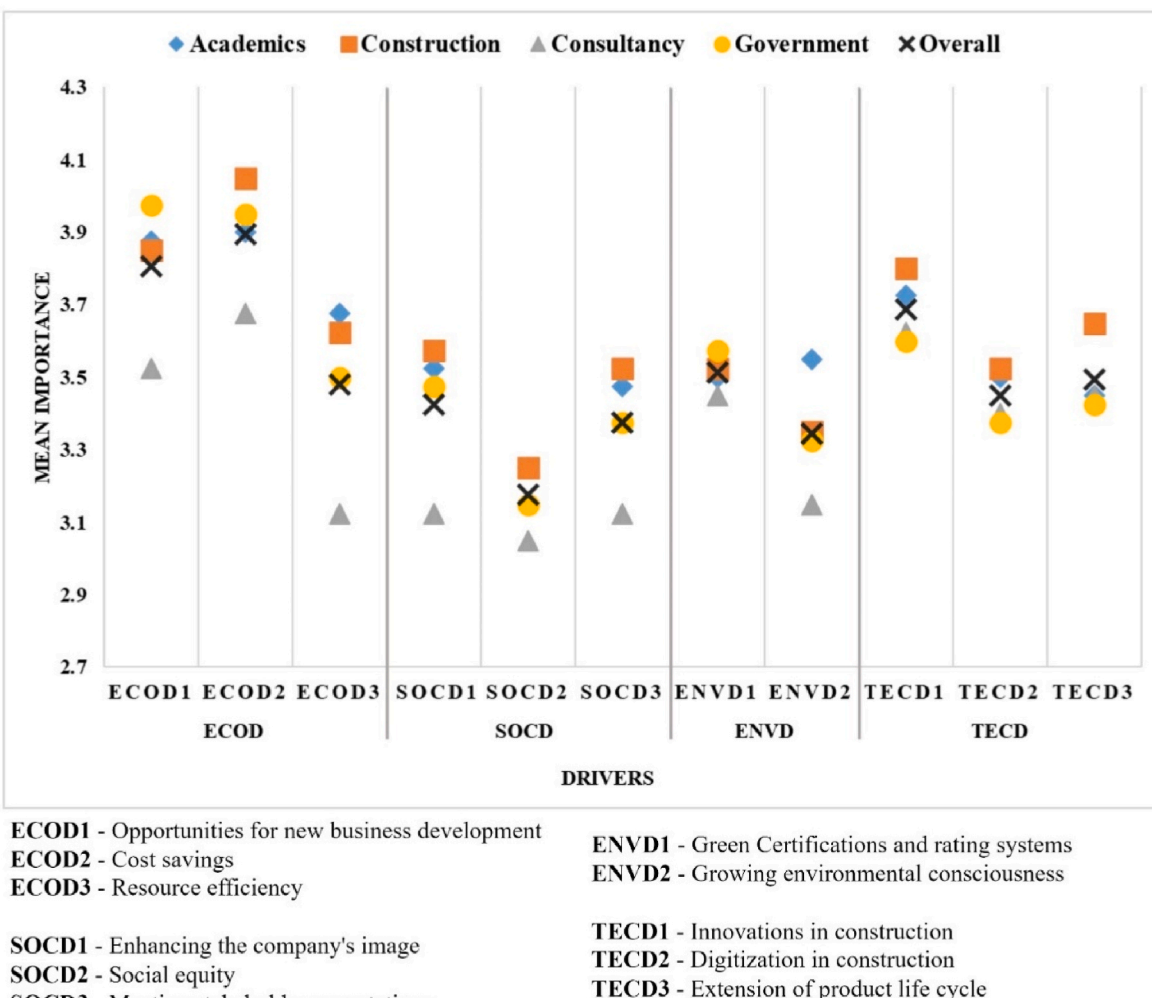
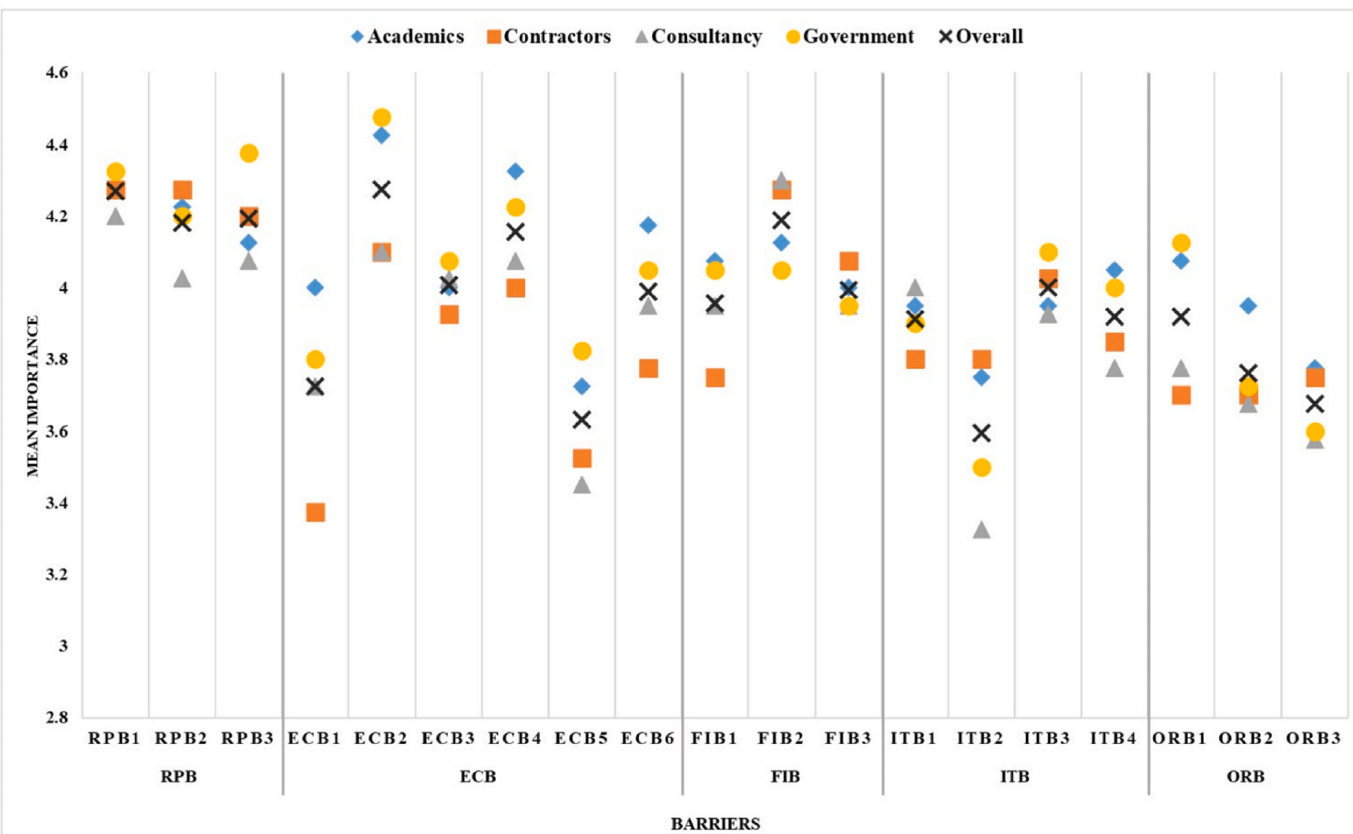



**Fig. 2.** Comparison of drivers between four respondent categories.

driver are summarised and compared in Table H.1. The study findings revealed that cost savings (ECOD2) primarily influence material circularity practices. The implementation of circularity practices can assist in reducing C&DW generation and associated waste management costs for companies. Instead of treating materials as disposable waste, companies can reintegrate them into the production cycle. Cost savings can be achieved by reducing expenses related to landfill fees, waste transportation, and waste disposal through recycling and repurposing materials [53]. Opportunities for new business development (ECOD1) also played a significant role in driving material circularity activities. The OECD [81] survey results highlight job creation as one of the most relevant drivers for the CE transition. Establishing circular businesses specialising in collecting, processing, and recycling materials and creating environmentally sustainable products from waste creates new job opportunities directly and indirectly. Material circularity is also driven by innovations in construction (TECD1), such as design for adaptability and disassembly, prefabrication, and off-site construction. These innovative practices facilitate the easy recovery and reuse of materials, reducing the demand for new materials [12]. Consultants and government officials are more optimistic about the benefits of green building certifications and rating systems (ENVD1) on material circularity practices than academics/researchers and contractors. These certifications, such as LEED and Building Research Establishment Environmental Assessment Method (BREEAM) systems, actively encourage waste reduction, material reuse, and recycling. They also drive the industry towards embracing material circularity practices by awarding points for the implementation of circular material activities. Contractors and consultants have a more positive view of the fact that extension of the product life cycle (TECD3) motivates material circularity than academics/researchers and government officials.

#### 4.2.3. Barriers to achieving material circularity

There was an agreement between different respondent categories concerning the importance of barriers. However, some variability of responses was noted (see Fig. 3). Mean scores and ranking of each barrier are summarised and compared in Table I.1. Respondents scored the barriers more moderately than the drivers, highlighting the persistently problematic situation in the Australian construction industry. According to academics/researchers and government officials, an immature marketplace for secondary products (ECB2) is the most significant barrier to implementing material circularity. A marketplace for secondary products would assist in streamlining and optimising supply chains by connecting relevant stakeholders such as suppliers, manufacturers, distributors, and consumers of reusable, reclaimed, or




**RPB1** - Lack of policies and regulations
**RPB2** - Lack of a common goal to achieve material circularity
**RPB3** - Lack of extended producer responsibility

**ECB1** - Low demand for secondary products
**ECB2** - Underdeveloped marketplace for secondary products
**ECB3** - Resistance to change
**ECB4** - Lack of economic benefits in short run
**ECB5** - Distance from urban areas to material recovery facilities
**ECB6** - Waste is not recognized as a valuable resource

**FIB1** - High cost of implementing material circularity practices
**FIB2** - Lack of financial incentives
**FIB3** - Relatively low cost of disposing materials in landfills

**ITB1** - Inadequate awareness and understanding
**ITB2** - Lack of information on circular construction
**ITB3** - Limited material recycling facilities
**ITB4** - Lack of reverse logistic networks

**ORB1** - Lack of top management commitment and leadership
**ORB2** - Lack of organizational data
**ORB3** - Lack of expertise professionals

**Fig. 3.** Comparison of barriers between four respondent categories.

recycled materials. It would enable the efficient flow of materials and products, minimising inefficiencies and waste. Without a physical or online marketplace that facilitates the exchange of these materials, it becomes more challenging for stakeholders to access the necessary inputs. This finding aligns with the research of Shooshtarian, Caldera, Maqsood, Ryley and Khalfan [37], which highlighted limited market opportunities for secondary products as a significant issue. Ratnasabapathy, Alashwal and Perera [24] further emphasise the lack of active and easily accessible market platforms for secondary materials as a significant barrier to the reuse of waste materials. There was a consensus about the regulatory barriers - lack of regulations and policies on material circularity (RPB1) as among the highest-rated problems. Shooshtarian, Hosseini, Kocaturk, Arnel and Garofano [22] corroborated this finding by identifying the absence of specific regulations as one of the most critical barriers to adopting CE practices. Without regulations, there is uncertainty and inconsistency in how material circularity is understood and implemented. This can lead to confusion among businesses and organisations, making it difficult for them to adopt and integrate circular practices effectively. Further, contractors and consultants emphasised the lack of financial incentives to promote circularity in construction (FIB2). Financial incentives help stakeholders overcome the initial investment costs associated with adopting material circularity strategies and make these practices financially viable in the long term. Hence, the lack of financial incentives is a barrier to the widespread adoption of material circularity practices.

### 4.3. Stage 4 - Respondent survey no. 2

Respondent Survey No. 2 was conducted with respondents from four distinct categories: academics/researchers, contractors, consultants, and government officials, with the primary objective of identifying relevant strategies to overcome the barriers to material circularity practices.

The connections between barriers and coping strategies are outlined in Table 1 and further discussed in Table J.1. For example, an immature marketplace for secondary products (ECB2) was identified as the most critical barrier. Establishing effective markets for secondary products (PMS4), introducing the quality standards for secondary materials (PMS3), and providing economic incentives to promote the CE (PMS2) were identified as Level 1 strategies to overcome ECB2. Developing an IS network (ITS2) and improving reverse logistics in the construction supply chain (ITS4) were identified as Level 2 strategies. Among the total of 70 respondents, 59 participants (84.2%) identified establishing effective markets for secondary products (PMS4) as a Level 1 strategy for overcoming ECB2, while 24 respondents (34.3%) acknowledged the importance of developing an IS network (ITS2) as a Level 2 strategy in the same context.

### 4.4. Stage 5 - Framework for enhancing material circularity in building construction projects

This study developed a framework for enhancing material circularity in building construction projects (see Fig. 4). The participants' viewpoints were used to rank the importance of drivers and barriers (see **section 3.4.1**). Strategies were aligned with the corresponding barriers to effectively enhance material circularity practices in the building construction projects (see **section 3.4.2**).

The status quo can be described as follows: barriers, such as regulatory gaps, market and economic challenges, and technological limitations, can demotivate construction industry practitioners, government officials, and academics/researchers from actively pursuing material circularity. When faced with hurdles and obstacles, the drivers for material circularity may weaken, reducing the overall commitment to adopting circular practices. For example, if circular approaches are not economically viable or technologically feasible, the drivers for material circularity may be compromised. This can result in a lack of motivation to invest in circular initiatives or promote circular behaviour.

Hence, identifying the drivers that motivate stakeholder decisions and behaviours is critical. Drivers can be effectively used to influence stakeholders' behaviour to promote material circularity. For example, highlighting the cost savings (ECOD2) associated with material circularity practices, such as reduced waste disposal costs, can increase stakeholder interest in material circularity practices. By addressing barriers, such as economic challenges, investing in technological advancements, improving regulations, and fostering awareness, the drivers for material circularity can regain momentum. Further, identifying and ranking barriers helps illustrate the challenges that hinder the adoption and implementation of material circularity practices in construction. Identifying barriers also helps to develop mitigation strategies to effectively overcome obstacles by ensuring that efforts and resources are focused on the most critical areas, maximising the chances of enhancing material circularity. Finally, identifying strategies provides practical solutions for transitioning from linear to circular practices. Accordingly, by effectively utilising the findings of this framework, the building construction projects can effectively transition to enhanced material circularity and contribute to a more sustainable future.

## 5. Research implications

### 5.1. Theoretical implications

This study has important implications for material circularity, CE, and other related fields. Firstly, this study builds on and extends the prevailing literature on drivers, barriers, and strategies for implementing material circularity. Previous research in CE has primarily focused on barriers [18,21,24,48,82]. This study takes a step further by incorporating drivers and strategies into the analysis.

Secondly, the researchers extend the existing literature by quantifying the extent of drivers and assessing the significance of barriers using a five-point Likert scale. This was achieved by conducting the first survey, which garnered 160 responses. Additionally, strategies were aligned with corresponding barriers to enhance material circularity practices by conducting the second survey. The second survey was conducted, receiving 70 responses. In previous research within the field of CE, a questionnaire survey with 132 responses was employed to identify the main barriers and enablers of CE in the Australian AEC industry [22]. This study offers a comprehensive summary of findings obtained through a literature review, 19 expert interviews, and two questionnaire surveys, resulting in a total of 230 responses. Notably, the

**Table 1**
An extract from the aligning strategies with barriers.

| Barrier | Strategy | | | | | |
|---|---|---|---|---|---|---|
| | Level 1 | | | Level 2 | | |
| | Description | Number of responses | Percentage | Description | Number of responses | Percentage |
| Immature marketplace for secondary products (ECB2) | Establish effective markets for secondary products (PMS4) | 59 | 84.3 | Develop an IS network (ITS2) | 24 | 34.3 |
| | Introduce the quality standards for secondary materials (PMS3) | 46 | 65.7 | Improve reverse logistics in the construction supply chain (ITS4) | 20 | 28.6 |

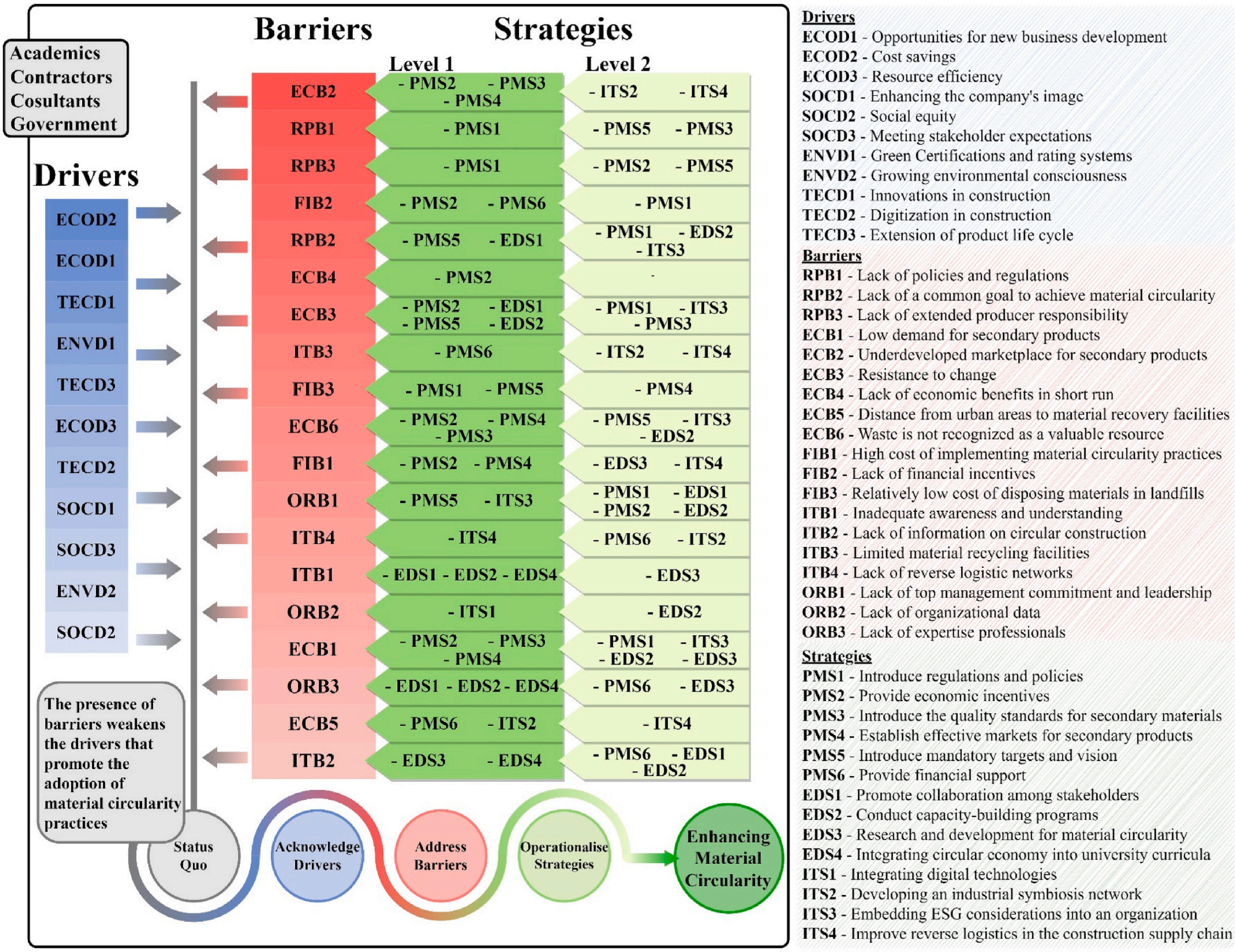



**Fig. 4.** A Framework for Enhancing Material Circularity in building construction projects.

sample size of this study surpasses that of previous research studies.

Thirdly, this research compares the ranked drivers and barriers among four respondent categories: academics/researchers, contractors, consultants, and governmental entities. This comparison provides valuable insight into the diverse perspectives of these respondents. Previous studies have often assumed that the same barriers and enablers apply to all stakeholder categories.

Fourthly, this study maps strategies to the corresponding barriers, thereby addressing the obstacles hindering the implementation of material circularity practices. Wuni [40] conducted a systematic review study to map strategies to mitigate barriers to CE adoption. This research contributes to the existing literature by systematising strategies to overcome barriers through the use of a literature review, expert interviews, and survey findings. This detailed analysis provides a holistic theoretical understanding, paving the way for the operationalisation of material circularity practices in building construction projects.

### 5.2. Practical implications

This study provides some crucial practical implications. Firstly, empirical findings suggest eleven drivers (seeTable E.1) that motivate the material circularity practices. These include cost savings (ECOD2), resource efficiency (ECOD3), and the extension of the product lifecycle (TECD3). It has been proven that construction companies can reap multi-faceted benefits by adopting material circularity practices. Therefore, industry practitioners can devise realistic goals, measure progress, and adjust strategies as needed by considering these drivers. For example, companies can reevaluate their supply chains to ensure the sourcing of circular materials to gain cost benefits and improve the company's image [24,26]. Further, the application of these drivers helps practitioners to ensure the efficient use of resources and extend their availability for future generations.

Secondly, the present study paves the way for construction industry practitioners to conveniently identify barriers that exist when implementing material circularity practices. Knowledge of such barriers (seeTable E.2) can encourage industry practitioners to take relevant preactions. For example, the key barriers include an immature marketplace for secondary products (ECB2) and a lack of financial incentives to promote circularity in construction (FIB2). Hence, construction companies should develop their financial plans in conjunction with market analyses. This should consider all elements to address potential financial constraints and material sourcing issues, such as the estimated cost of applying material circularity practices, financial arrangements to cover the upfront cost, and material availability in the market. Suppose the industry fails to recognise barriers related to the application of material circularity. In that case, it may struggle to implement circularity practices and be unable to reduce organisational costs and environmental pollution [83].

Thirdly, the findings of this study enable construction industry practitioners to accurately identify strategies for overcoming barriers and effectively enhancing material circularity practices in building construction projects (see Table J.1). This includes an examination of how managerial practices implement material circularity, as well as how emerging technologies and digital platforms can be leveraged to facilitate material circularity. For example, information and technological barriers (e.g., inadequate understanding of material circularity (ECB3)) necessitate proactive measures, including capacity-building programs (ITB1), to bolster the capabilities of employees and provide them with the necessary knowledge for effective implementation. A collaborative BIM platform connecting with the material bank and material passport (ITS1) enables informed decision-making [84] by overcoming barriers such as lack of organisational data (ORB2).

### 5.3. Policy implications

Different stakeholder groups, such as academics, contractors, consultants, and government officials, have unique perspectives and roles in enhancing material circularity. Comparing their viewpoints allows policymakers to better understand the drivers, barriers, and strategies involved in promoting material circular practices. For example, the lack of financial incentives to promote circularity in construction (FIB2) is one of the most critical barriers for contractors and consultants. This study highlights the crucial role of the government in the transition to material circularity in building construction projects. Notably, the government emerges as a key player in addressing various barriers, encompassing policy and regulatory issues (e.g., the lack of policies and regulations on material circularity (RPB1)) as well as financial barriers (e.g., the lack of financial incentives to promote circularity in construction (FIB2)). As a result, policymakers should develop policies to enhance the attractiveness of material circularity practices. Construction companies that rely on raw materials for their projects could be subject to additional taxes. These taxes should be increased (beyond a certain threshold) by formulating policies to incentivise the use of more environmentally friendly raw materials [85]. Construction firms that incorporate circular materials into their building processes should be granted a reduction in the applied value-added tax. Furthermore, monetary rewards should be provided for construction companies that engage in circular practices such as recycling and reusing building materials [23].

Different stakeholders may face distinct barriers. By comparing barriers across stakeholder categories, policymakers can develop policies tailored to each group's specific needs and circumstances. This increases the likelihood of policy acceptance and effectiveness. Further, it ensures that policies are developed with input from all relevant parties and that the decision-making process is transparent and accountable. According to the findings of this study, government officials identified an immature marketplace for secondary products (ECB2) as the most significant barrier to implementing material circularity. Contractors and consultants, on the other hand, rated the lack of regulations and policies on material circularity (RPB1) as one of the most significant barriers. It is essential to pay equal attention to establishing a proper marketplace for secondary products, implementing EPR policies that consider the entire product life cycle, including collection and proper disposal, and adopting green procurement policies that prioritise products with high circularity and low environmental impact [86]. This approach addresses the issue of the lack of policies and lack of market for secondary products concurrently. Recognising that a single strategy is insufficient to meet the diverse requirements of different stakeholders, it becomes clear that several strategies must be implemented simultaneously to enhance material circularity. By considering the perspectives of various stakeholders, policymakers can mitigate adverse impacts on specific groups, ensuring that circularity initiatives are fair and just. Engaging with multiple stakeholders is crucial for policy success, as comparing their viewpoints enables policymakers to identify common ground.

## 6. Conclusion

This study addresses the lack of understanding regarding the drivers, barriers, and effective strategies for achieving material circularity in construction projects. Consequently, a framework has been developed to enhance material circularity in building construction projects by identifying driving forces, addressing barriers, and implementing strategies effectively. The study revealed key drivers for material circularity including cost savings (ECOD2) and new business opportunities (ECOD1). The primary barriers identified were underdeveloped secondary product markets (ECB2) and lacking policies (RPB1). Two crucial strategies emerged: creating efficient secondary product markets (PMS4) and implementing supportive policies and regulations (PMS1).

Identifying drivers contributing to economic, social, and environmental benefits promotes investments in circular practices, fostering sustainable economic growth. A detailed analysis of prioritised barriers offers a comprehensive understanding of the factors contributing to the limited adoption of material circularity practices and the prevalence of linear economic activities in Australian building construction projects. This analysis helps pinpoint fundamental issues that require attention, emphasising the need to address high-priority barriers first. The absence of strategies to overcome these barriers could perpetuate unsustainable practices in the construction sector. Consequently, the strategies identified in this study can effectively expedite the transition toward achieving high levels of material circularity. Additionally, this study presents policy implications to promote material circularity, considering the expectations of various stakeholders. Accordingly, the findings offer a comprehensive agenda for enhancing material circularity practices in Australian building construction projects.

To reduce the scope of the research to a manageable quantity, this study only concerns material circularity, a subsect of CE. Other aspects of the CE (e.g., water and energy circularity) are excluded from the analysis. This study has certain limitations. The empirical data was collected in Australia, primarily focusing on building construction projects. These limitations could potentially be converted into opportunities for future research. Similar studies could be formulated for diverse geographical locations, encompassing various industries and employing a broader scale of qualitative and quantitative data collection, building upon the insights gained from this study.

## CRediT authorship contribution statement

**Isuri Amarasinghe:** Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Ying Hong:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Rodney A. Stewart:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2024.111359.

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