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Practical considerations of circular economy strategies in the residential sector in Australia using the ReSOLVE Framework

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ABSTRACT

The residential sector remains one of the highest greenhouse gas-emitting and resource-intensive sectors globally, including Australia. This arises from challenges in implementing a Circular Economy (CE) model, which optimises resource value by minimising waste and reducing the need for new materials. The fragmented focus by researchers, policymakers and the construction industry on individual life cycle stages, building layers, or technologies in CE strategies limits a holistic understanding of CE implementation. This study introduces a novel, comprehensive evaluation of CE strategies in Australia's residential sector by applying the ReSOLVE framework across seven building layers, addressing fragmentation in prior research by combining systematic and narrative literature reviews to explore theoretical and practical CE strategies. The systematic literature review identified 725 global studies, which, after screening, were narrowed to 68 and 37 publications were identified from the narrative review. The study highlights the significance of CE strategies, including design for deconstruction, reuse, digital tools, off-site construction, and stock management. However, broader adoption of existing strategies remains essential. Successful adoption requires policy alignment, CE incentives, stakeholder collaboration, sector-specific guidelines and behavioural changes. The findings highlight gaps in practical interventions, guiding policymakers while benefiting researchers and construction stakeholders. Future research should focus on reuse, policy interventions, and behavioural dynamics. Despite the focus on the Australian context, the implications are relevant globally.

1. Introduction

Housing is a basic human need which provides shelter, comfort, and social connection and encompasses physical elements such as location, materials and intangible connections to place and community [1]. The housing sector is vital to the global economy and is an important component of worldwide construction [2]. However, the housing sector has a history of negative environmental impacts. Overall, the built environment, including the housing sector, accounts for one-third of global greenhouse gas emissions [3], 50 % of raw materials depletion [4] and generates 25 % of global solid waste [5]. Residential buildings alone account for 58 % of total energy consumption within the built environment [6,7]. In Australia, the building sector contributes approximately 25 % of greenhouse gas emissions, while the residential sector represents 13 % [8,9]. These environmental burdens mainly stem from the construction sector's linear economic model of the "take, make, use, dispose" approach [10,11].

The linear economy, where resources are used and discarded as waste, has been the standard model for housing design and construction [12]. This model leads to resource depletion, climate change, and other environmental impacts [13]. Human-caused carbon dioxide emissions and other greenhouse gas emissions are widely accepted as drivers of climate change, influencing extreme weather and climate patterns in all regions [14]. Due to climate change, Australia will face more extreme weather events, including rising temperatures [15], making it essential to transition the residential sector to a closed-loop system for sustainability and resiliency [16,17]. With Australia's population projected to grow from 26.6 million in 2023 to 31 million by 2030, the demand for affordable and sustainable residences to meet climate and environmental targets will increase [18].

The Circular Economy (CE) offers a closed-loop system as an alternative to the linear economy by emphasising resource longevity,

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maximising value during use, and reusing goods and materials at the end of their traditional lifespan [11]. Implementing CE principles in the construction sector has gained traction globally due to its positive impact on triple-bottom-line sustainability by actively striving to generate social, economic, and environmental advantages defined in sustainable development [19,20]. However, current scholarly articles primarily address the theoretical aspects of CE, highlighting a lack of studies focused on the practical aspects of CE [21]. The incorporation of CE principles within the residential sector's life cycle has been limited and fragmented [22], often confined to a single phase of the supply chain, such as the end-of-life stage [23].

Specifically, a notable gap exists in the comprehensive incorporation of CE interventions encompassing all phases and components of a house [24]. This paper evaluates practical and theoretical CE strategies for the Australian residential sector by conducting a systematic literature review (SLR) and narrative literature review (NLR), drawing on a global context. This study defines the residential sector as including all domestic building types under the Australian National Construction Code, Class 1 dwellings (such as standalone houses, townhouses, and small boarding houses) and Class 2 buildings (such as apartment complexes with multiple units) [25]. This study applies the ReSOLVE framework, introduced by Arup and the Ellen MacArthur Foundation [11], to support the circularity in the built environment and classify CE interventions through six strategies: regenerate, share, optimise, loop, virtualise, and exchange. The review showed limited practical studies restricted to energy efficiency and waste recycling. It highlights the need for holistic approaches, particularly in selecting sustainable design choices, addressing embodied carbon, and reducing whole-life cycle carbon. The analysis emphasises the importance of converting theoretical concepts into practical strategies, such as design for deconstruction, material stock management, and reuse technologies. Aligning policies and fostering collaboration is vital for effective CE integration and exploring business models and behavioural changes that support circular practices.

The novelty of this study lies in its comprehensive and multi-layered approach to CE in the Australian residential sector by applying the ReSOLVE framework across seven building layers, bridging gaps in existing research that often focuses on isolated interventions. It highlights the need for policy alignment, stakeholder engagement, and sector-specific guidelines while connecting theoretical research with industry application. By combining empirical analysis and policy-driven recommendations, the study establishes a new pathway for integrating CE in residential construction, offering insights with both national and global relevance.

2. Research questions and objective

This study investigates CE interventions in the residential building sector, particularly the limited adoption and fragmented implementation observed in practice. By identifying the underlying barriers and challenges, the research aims to provide a more coherent understanding of CE integration in this context.

Hence, the study's objective is to evaluate theoretical and practical CE strategies identified in academic and grey literature and assess their effectiveness for implementation in the residential sector. Accordingly, the research question is formulated: *What are the key differences between theoretical and practical circular economy strategies, and what barriers and enablers influence their implementation in the Australian residential sector?*

3. CE principles and strategies in the residential sector

Many different, often interconnected, schools of thought have contributed to developing diverse definitions of the CE, all of which have common concepts [26]. This paper uses the definition of CE from the ISO standard on CE. In May 2024, the ISO 59000 series of standards was developed to standardise the understanding of the CE and to facilitate implementation and measurement, thereby contributing to the United Nations Agenda 2030 for Sustainable Development. The standards define CE as a systemic approach to sustaining a circular flow of resources (stocks and flows) by recovering, retaining, or enhancing their value. This approach supports sustainable development by minimising the use of virgin resources and ensuring the resource flow remains as closed as possible, reducing waste, losses, and emissions from the economic system [27].

Transitioning from a linear to a CE in the construction sector has gained momentum, notably with a series of publications from the Ellen MacArthur Foundation, underscoring the opportunities and advantages of adopting a CE approach [28]. The CE frameworks draw inspiration from prominent CE models such as the CE Butterfly approach [11], the three CE levels [29], R-frameworks, and the ReSOLVE framework [30].

The CE Butterfly approach aims to reduce waste and improve resource efficiency by circulating technical and biological resources within closed-reversible systems [11]. The three CE levels categorise resources into micro (firms), *meso* (symbiosis), and macro (regions) levels, with houses at the micro-level [29]. Various CE indicators span these levels, often being specialised and lacking implementation guidance [31,32]. Several R-frameworks, each commencing with the letter "r" stem from a hierarchical sequence of three or more CE operations, achieved in this context by adhering to the 3Rs, 6Rs or even 9Rs, which include refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover [33]. The ReSOLVE framework, introduced by Arup and the Ellen MacArthur Foundation [11], comprises six CE strategies as shown in Fig. 1. Arup [35] highlighted "Regeneration" enables circular building performance through renewable energy and materials; "Share" aims to maximise the efficient utilisation of assets; "Optimise" focuses on improving resource efficiency; "Loop" emphasises keeping products and materials in continuous cycles; "Virtualise" involves reducing physical resource use through digital technologies and "Exchange" emphasises choosing resources and technologies that prioritise user-oriented design.

Although the three CE levels and the Butterfly Diagram are commonly viewed as conceptual models, they have not been widely adopted as assessment frameworks [168]. In contrast, the R-strategies and the ReSOLVE framework are more commonly used in circular economy evaluations. Van Bueren, Iyer-Raniga [29] argued that scholarly articles overlook less-explored CE processes such as refusal, virtualisation, sharing, reuse, longevity, and regeneration, whereas the ReSOLVE framework comprehensively covers the CE processes. Braakman, Bhochhibhoya [34] recommended that the R-frameworks best suited for the construction sector are reuse, remanufacture, and recycle, and these principles are thus incorporated mainly into waste management strategies. The ReSOLVE framework is a comprehensive tool for addressing CE processes beyond waste management. In contrast, R-frameworks are often viewed as more limited, focusing primarily on waste-related strategies [29]. Furthermore, ReSOLVE is widely recognised in policy and industry discourse, making it a practical and policy-relevant tool for exploring CE transitions within the built environment [169]. ReSOLVE specifically addresses the micro-level, including individual houses, strongly emphasising value creation and business model innovation [168]. The ReSOLVE framework was adopted in this study to analyse CE strategies in the residential construction sector.

Arup [35] expanded the ReSOLVE framework using Stuart Brand's [36] layers diagram, creating a matrix to analyse the different components of a building. They introduced seven layers (7S): System, Site, Structure, Skin, Services, Space and Stuff (Fig. 2), which can be combined, separated, or removed, acknowledging that not all building components have the same lifespan [35,37]. The 7S framework includes: "System", refers to the structures and services that ensure the overall functioning of the building; "Site", is about the building's location; "Structure" denotes the foundation and skeleton; "Skin" represents the building's exterior; "Services" cover the mechanical systems; "Space"

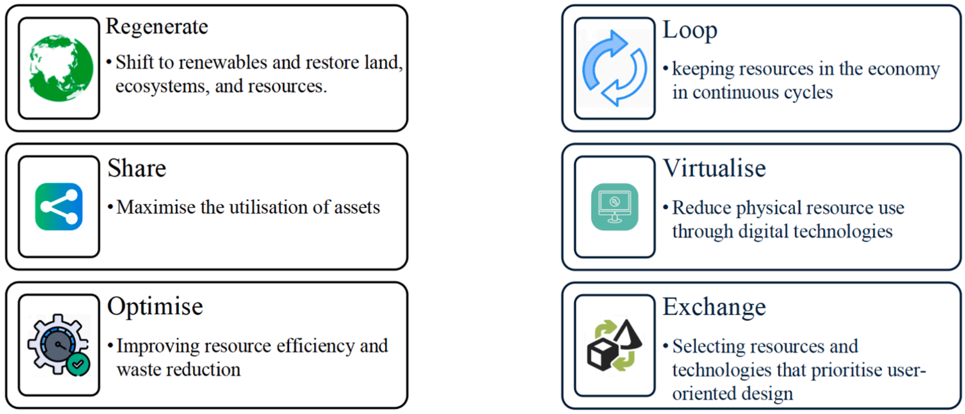

Fig. 1. The ReSOLVE framework adapted from [11].

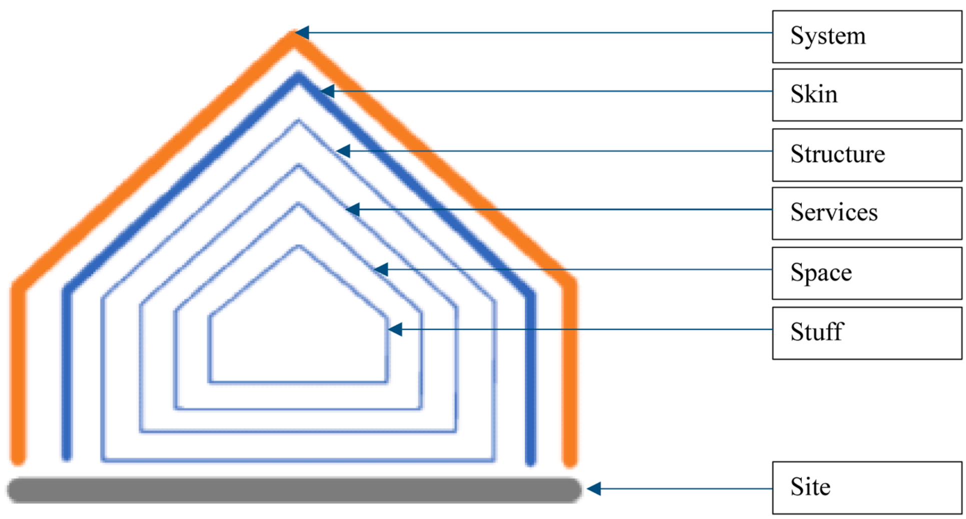

Fig. 2. Seven layers of a building, adapted from Stuart Brand's [36] layers diagram.

deals with the building's partitioning; and "Stuff" refers to the needed for interior operation [35–37].

Building layers is crucial because buildings function as closed-loop, holistic systems that support these layers to promote renewal, repurposing, and future disassembly [37]. Identifying a specific building layer for certain CE interventions, which consider the entire house or materials, can be challenging. This often leads to their classification under the broader "System" category.

4. Methods

Existing theoretical and practical CE interventions in the built environment are identified by SLR and NLR as shown in *Fig. 3*.

4.1. Systematic literature review

An SLR uses a transparent, reproducible process to organise information and identify bibliometric indicators such as publication count, citation count, and gaps in the literature, whether geographical, theoretical, or methodological [38]. This section adopts an SLR to summarise prior research on CE in the residential sector and identify knowledge gaps in academic articles. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [39] guidelines were used to identify, select, and report literature systematically [40]. PRISMA is a foundational guideline for documenting systematic reviews, especially for assessing various interventions [39].

An initial scoping exercise was conducted to understand the current state of research on the topic. This helped us identify the most relevant databases, search terms, whether similar reviews already exist and timeframes for the review. The SLR followed a four-step process for inclusion and exclusion: identification, screening, eligibility assessment, and inclusion, as shown in Fig. 2. In the identification, the Web of Science and Scopus databases, widely regarded as the most reliable citation indexes for construction research, were used to conduct the literature search due to their rigorous screening processes [41]. In both databases, a Boolean operator was used (AND/OR) to combine related terms into a single search query, formatted as,

("Residential" OR "house" OR "home" OR "dwelling")

AND ("circular economy" OR "circularity")

Two co-authors independently screened a subset of the retrieved studies using the predefined inclusion and exclusion criteria to enhance inter-reviewer reliability. The search was conducted on 1st February 2024 and covered literature published from 2013 to 2024, as interest in CE grew significantly after 2013, driven by the Ellen MacArthur Foundation's publications [42]. The search strategy involved a combination of defined keywords, limited to the 'Abstract field, and refined by the "circular economy" keyword. This yielded 208 studies in Scopus. In Web of Science, 517 studies were identified after refining the subject areas to environmental science, engineering, building construction, energy, materials, water, and public administration, since the platform does not categorise under "circular economy". The initial search from Scopus and

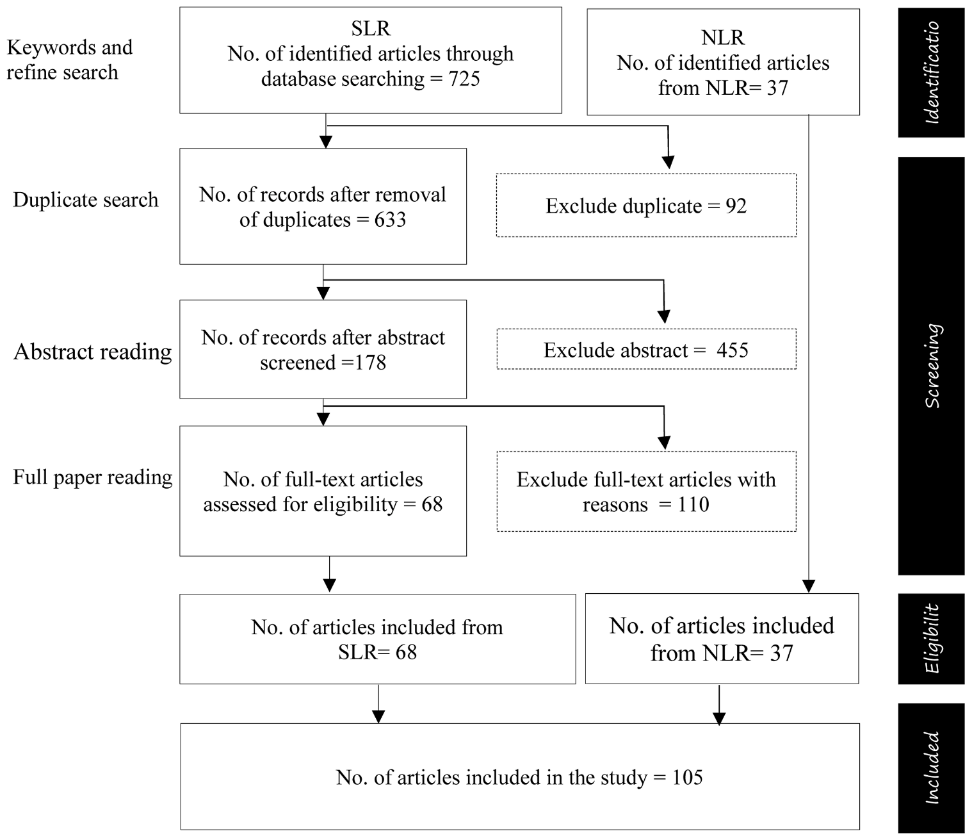

Fig. 3. Summary of the SLR and NLR.

Web of Science identified 725 relevant studies. Following the initial search, 92 duplicate records were removed, resulting in 633 unique documents. After abstract screening, 178 articles were retained for full-text review.

Each full-text article was reviewed to assess its relevance to CE integration in residential housing. Some studies were retained despite featuring case studies on office or school buildings or lacking explicit clarification on residential application. Articles were included if they addressed at least one CE strategy or related concept within any building layer and provided sufficient detail to support analysis. Articles were excluded if they were review papers, business case studies, or focused on infrastructure projects (roads, bridges), urban mining, or other topics misaligned with the study's scope. Finally, 68 publications were included for detailed analysis after meeting the inclusion criteria, discussing CE or related subjects in housing or related terms. EndNote was used to manage references, assist in the removal of duplicates, and support initial screening through abstract and full-text reading. Excel was used to document inclusion/exclusion decisions and track the screening outcomes for records retrieved from Scopus and Web of Science.

4.2. Narrative literature review

In addition to the SLR, an NLR was undertaken to capture practical insights extending beyond academic publications. Given the study's objective, to identify practical CE interventions in the built environment, this dual-review strategy enabled a more holistic understanding of CE applications in residential housing, bridging the gap between academic discourse and practical implementation. The NLR serves the scientific field as a key bridge connecting the vast and scattered articles, especially by incorporating grey literature on a given topic [43].

The NLR incorporated journal articles, conference papers, book chapters, and grey literature. Reports and articles were sourced from Web of Science, Scopus, and Google Scholar databases. Grey literature was sourced via a Google search. A structured search strategy was employed to minimise selection bias. As with the SLR, the NLR included literature from 2013 to 2024 and a total of 37 articles were included, and the same search query was used:

("Residential" OR "house" OR "home" OR "dwelling")

AND ("circular economy" OR "circularity")

While this query formed the basis of the search, some articles were included even though they do not explicitly mention the term "circular economy"; however, they refer to specific CE interventions such as reuse and recycling. Documents were screened by title, abstract, and, where necessary, full text. Using citation tracking, a snowballing technique was also applied to identify additional relevant studies. To address the limited availability of practical CE studies in the residential sector, the review included sources from non-residential contexts (e.g., office and government buildings) where transferable CE strategies had been implemented. Furthermore, several sources used in the initial scoping exercise to align with the study's scope and selection criteria were also included to ensure comprehensive coverage of relevant CE interventions.

The NLR includes reports from private and non-governmental organisations on the CE concept, recognising that many practical CE initiatives often originate from non-academic sources [38]. Key documents were obtained from internationally recognised institutions and government organisations such as the World Green Building Council, the Australian Green Building Council, and the Australian Housing and Urban Research Institute. These materials were selected based on their credibility, relevance to the study's aims, and the authority of the issuing organisation. This broadened the analysis and supported the identification of adaptable practices for housing applications.

Annexe 1 presents a summary of the selected literature sources identified through the SLR and NLR, detailing the study, year, ReSOLVE strategy, CE intervention, search strategy, practical or theoretical orientation, method used, residential or non-residential focus, representative life cycle stage, country, and key findings or contributions.

4.3. *Data Analysis*

The articles from the SLR and NLR were arranged into a matrix derived from the ReSOLVE framework, integrating Stuart Brand's layers diagram [35], and both descriptive and content analyses were conducted to understand the perspectives and contexts of the studies. The descriptive analysis was based on key bibliometric indicators: the alignment of CE practices with the ReSOLVE strategies in the housing sector, the classification of studies as theoretical or practical and the geographical distribution of the studies. In addition, article distribution was examined across the seven building layers to contextualise the application of CE interventions.

The matrix was organised after reading and analysing the articles; a qualitative content analysis was conducted on the selected academic and grey literature to identify recurring themes and CE interventions relevant to the residential sector. The analysis followed an inductive approach, where data were coded manually using Microsoft Excel. Initial open coding was used to identify keywords and concepts related to the ReSOLVE framework across seven building layers. These codes were then grouped into broader categories aligned with the six ReSOLVE strategies. These six ReSOLVE strategies are then divided into sub-CE interventions while reviewing the content of the articles, enabling a comprehensive analysis of the selected articles. Examples include mapping strategies such as off-site construction under "Optimise" and the reuse of structural elements under "Loop."

The matrix categorises the seven building layers and distinguishes interventions as either practical implementations or theoretical concepts based on the content analysis of the articles. The practical implications of this study are reflected in CE interventions that have already been implemented and are considered market-ready solutions [44]. Some prototype case studies and pilot projects are also classified as practical, as they have been tested in real-world settings. In contrast, the theoretical category includes CE interventions that primarily discuss theoretical/conceptual frameworks or present case studies used to develop and refine circular economy concepts. The SLR and NLR were analysed separately to highlight differences in article distribution and provide a comprehensive understanding of the variations.

5. Results and analysis

This section presents the results and analysis of both literature reviews, divided into two parts. First, a descriptive analysis of the bibliometric results is provided to contextualise the content identification findings. The content analysis focuses on the CE interventions listed in the matrix, which are comparatively evaluated to assess their potential implementation in the residential sector in Australia.

5.1. *Descriptive analysis*

The 105 publications were organised within the matrix (see *Table 1*). To present the findings systematically and transparently, the matrix shows the ReSOLVE framework, which categorises circular economy strategies into six actionable areas and sub-strategies and whether the CE intervention is practical or theoretical. This framework was selected for its ability to capture a wide range of CE interventions relevant to the built environment and to ensure conceptual consistency across studies. These strategies are cross-referenced with Stuart Brand's building layers to contextualise each intervention within the different layers of the house. The separate analysis of SLR and NLR results enabled a comparison between conceptual development and applied practice across global and Australian contexts, thereby strengthening the robustness of

Table 1
ReSOLVE Framework vs seven Building Layers: Article Matrix. The numbers in the table show the number of relevant articles.

ReSOLVE	CE Intervention	Systematic Literature Review														Narrative Literature Review														Total
	7 S ->	Building Layers																												
		System		Site		Structure		Skin		Services		Space		Stuff		System		Site		Structure		Skin		Services		Space		Stuff		
	T - Theoretical P - Practical	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	
Regenerate	Regenerating and restoring natural capital					1		3	1										1		1									7
Share	Maximising asset utilisation																												1	1
	Pooling the usage of assets	1																												1
Optimise	Energy efficiency	7				2		3		2				1		1				2		1		1	2					22
	Material/ water efficiency	2				2		4								2				2										12
	Waste elimination	1														1	1						1							4
	Integration of low carbon systems	2																				1								3
	Promote reuse and repurposing.															1														1
	Prolonging an asset's life, designing for longevity ensures durability	3														1	1													5
	Decreasing resource usage, Off-site construction and modular components	4	1			2		1								1				2										11
	Implementing reverse logistics																1													1
Loop	Reuse					1	1	1				1																		4
	Designing buildings for disassembly	1	1				1														1									4
	Material circularity and material passport	3														2	1			1								1		8
	Recycling materials	5	2			2		2								1			1				1							14
Virtualise	Replacing physical products and services with virtual services	2														2														4
Exchange	Using alternative material inputs								2							1														3

the review.

Table 1 highlights that "Optimise" and "Loop" are frequently discussed topics in the literature, with energy efficiency, recycling, modularity/offsite construction and material efficiency being the most prominent interventions. Share, Virtualise, and Exchange strategies are infrequently discussed in the literature.

Most of the published articles in the study are theoretical. Regarding the SLR, only 15 % of the sources represent practical research, as shown in *Fig. 4*. In contrast, the NLR includes a higher proportion of practical sources (45 %), as it primarily focuses on reports from public, private, and non-governmental organisations.

The majority of sources reviewed in both literature reviews focus on the building's "system," "structure," and "skin" layers. In contrast, fewer studies address the "site," "service," "space," and "stuff" layers, indicating a gap in research coverage for these aspects, as shown in *Fig. 5*.

Europe stands out as the leading continent in the field of CE research within this review, contributing 56 % of the total reviewed articles, as shown in *Fig. 6*. Among the 68 articles reviewed in the SLR, only two papers were found from Australia, with one representing practical research. However, 11 articles from Australia are included in the NLR, as this review focused more on grey literature that emphasises practical practices.

5.2. *Content analysis*

In this section, both theoretical and practical CE strategies presented alongside global and Australian sources are identified for the residential sector and analysed separately within the six ReSOLVE tactics. This qualitative content analysis was applied to both academic and grey literature, allowing for inductive theme development and classification of interventions as either theoretical or practical under each ReSOLVe strategy. This section categorises the results according to the ReSOLVE framework, with each CE strategy further divided into sub-strategies.

5.2.1. *Regenerate*

According to the findings in *Table 2*, most results primarily focus on regenerating materials. While all interventions related to the residential sector are theoretical, three practical interventions pertain to the non-residential sector. They represented building layers of structure, skin and site.

Regenerative materials such as wool fibres, hemp shives, date palm fibre, and jute fibre from recycled jute bags, used in plasters, mortars, and insulating panels, play an important role in enhancing thermal efficiency in buildings while reducing environmental impacts [47]. Two articles highlight hemp's application in construction, particularly its use in hempcrete blocks [46] and other hemp-based materials capable of capturing CO_2 [45]. Additionally, hempcrete captures approximately 108 Kg of CO_2 per cubic meter over the building's lifetime, underscoring its environmental benefits [46]. Date palm fibres are accessible natural insulators that can reduce annual cooling and heating needs by 25 % and 18 %, resulting in financial savings and lower CO_2 emissions [48].

In the built environment, regenerating biological resources from waste helps divert waste from landfills, reducing environmental impact and costs. Organic waste from the agri-food industry, such as spent coffee grounds and bio-waste from the paper-pulp industry, can improve environmental and building energy performance [49].

Regenerating contaminated brownfield lands reduces human and environmental health risks associated with their former uses. Nightingale Village in Victoria represents one of Australia's flagship sustainable housing projects that uses brownfield development [17]. One of its projects achieved a 7.5-star NatHERS (Nationwide House Energy Rating Scheme) rating, with thermal energy loads 40 % lower than the national minimum requirement. The design incorporates passive solar principles, locally manufactured and recycled materials, double-glazed windows, and timber doors, alongside solar photovoltaic and hot water systems. Additionally, Nightingale promotes shared amenities, such as rooftop gardens and communal laundries, aligning with multiple ReSOLVE strategies, including "Regenerate", "Optimise", "Loop", and "Share".

5.2.2. *Share*

"Share" aims to maximise the utilisation of assets such as spaces, infrastructure, and vehicles, promoting more efficient use. The literature includes an example, the car-sharing initiative in Australia, which encourages sustainable practices by providing residents with access to shared cars and electric charging stations [51] as shown in *Table 3*.

Keena, Friedman [52] addresses a circular web application that integrates housing data into housing passports, providing visual estimates and highlighting a building's circularity and environmental improvement potential. Notably, no practical or theoretical articles were found related to asset reuse. However, the concept of sharing is less evident in this sector.

5.2.3. *Optimise*

The "Optimise" strategy includes four key areas, as shown in *Table 4*: optimising system performance/efficiency, prolonging asset life, reducing resource usage and implementing reverse logistics. The study identified 59 sources related to the Optimise tactics, with 7 representing practical interventions. Notably, half of these practical actions pertain to

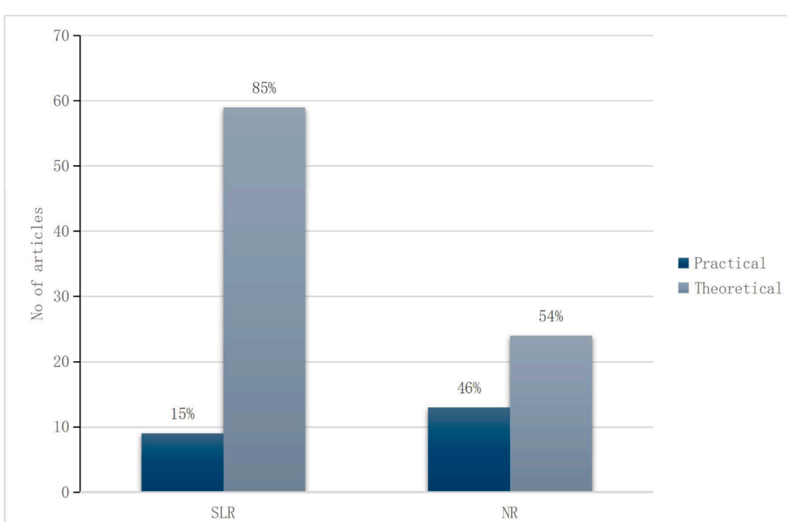

Fig. 4. Practical and theoretical nature of the articles in SLR and NLR.

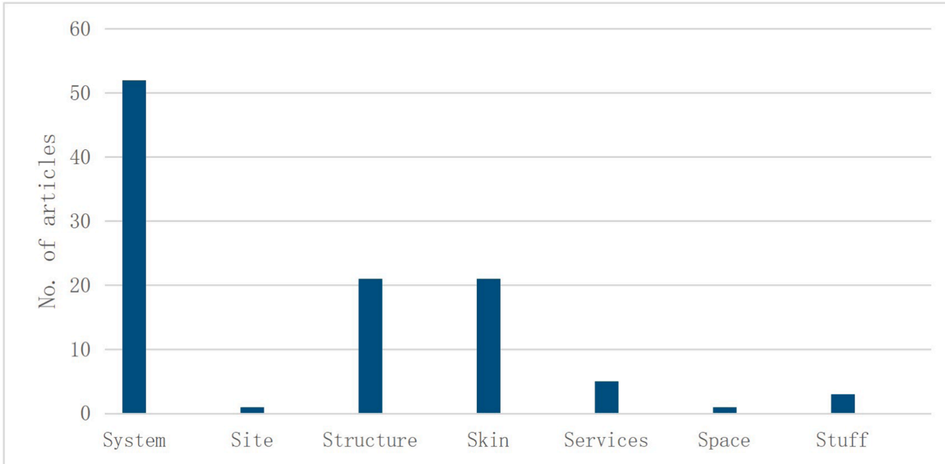

Fig. 5. Article distribution among seven building layers.

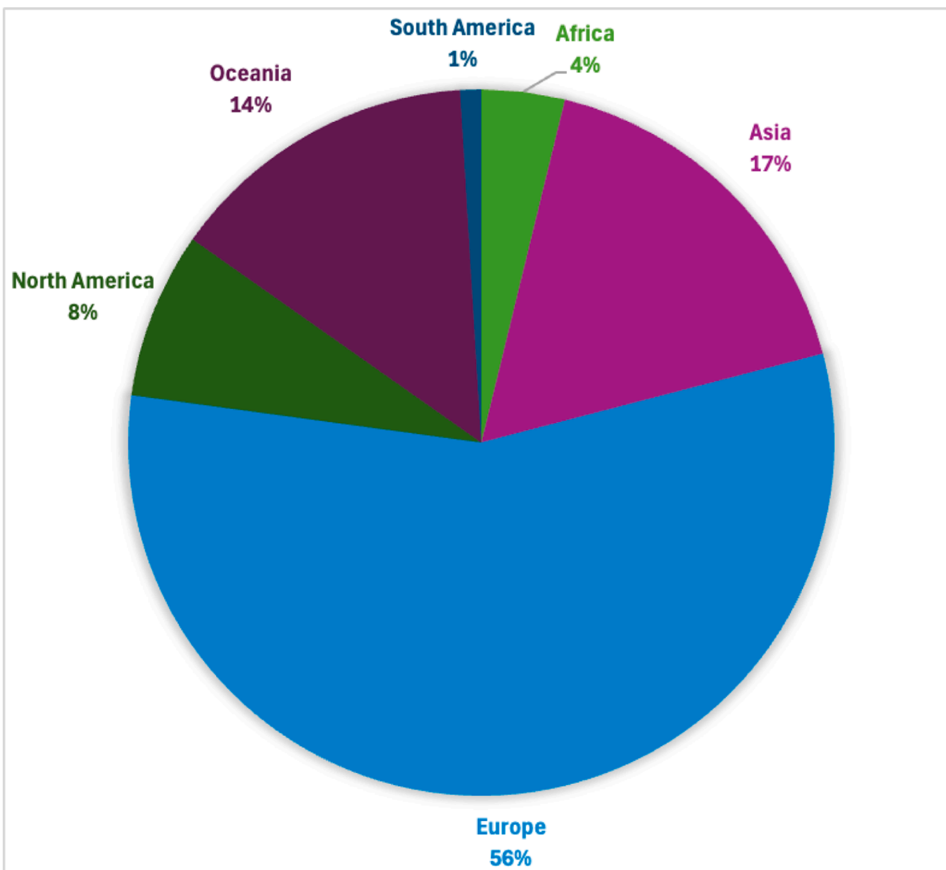

Fig. 6. Geographic distribution of publications.

non-residential cases.

Energy efficiency is categorised under the "Optimizing System Performance" tactic, with the highest representation in the literature, totalling 22 studies. These energy efficiency interventions span four building layers: system, structure, skin, and stuff.

Building energy consumption includes two main types: embodied energy, which relates to the materials' extraction and construction processes, and operational energy, consumed during the building's service life and impacting its heating and cooling requirements [46]. The primary strategies discussed in the literature to reduce operational energy are achieving net-zero carbon performance and implementing passive designs. To achieve net-zero carbon performance, energy consumption must be minimised, renewable energy sources must be integrated, and any remaining GHG emissions must be compensated for or offset [69].

Even with a fully decarbonised energy grid, buildings continue to produce unavoidable emissions, necessitating carbon sequestration measures, such as afforestation or vegetation growth, to offset their impact [53]. Among the various factors influencing passive standards, a well-considered design [56], mechanical system, occupancy rate, and lighting and appliances play vital roles [57]. Further, human behaviour and the type of energy source heavily impact the efficiency of Passive

Table 2
Content evaluation for Regenerate.

CE Intervention	Source / Article	Building layer	Description
Regenerating and restoring natural capital	Dotelli, Moletti [45], WorldGBC [46]	Structure	The potential benefits of hempcrete and hemp materials in the construction sector
	Majumder, Canale [47], Belhous, Boumhaout [48], Saeli, Batra [49], Geldermans, Tenpierik [50]	Skin	Thermo-insulating renewable natural building materials such as date palm, spent coffee grounds, renewable natural fibre composites
Safeguarding, restoring and increasing the resilience of ecosystems	Dühr, Berry [17]	Site	Prioritising brownfield over greenfield development

Table 3
Content evaluation for Share.

CE Intervention	Source / Article	Building layer	Description
Maximising asset utilisation	GBCA [51]	Stuff	Sharing cars and exchange of information on materials
Pooling the usage of assets	Keena, Friedman [52]	Skin	

House designs. Maintaining energy efficiency becomes more challenging when reliance on non-renewable energy sources increases [59].

Regarding embodied energy, construction elements such as concrete structures, slabs, and walls represent the highest levels of embodied energy in residential buildings [55], contributing significantly to energy consumption at the building's end-of-life phase [60]. It is important to carefully choose construction materials and technical systems for an energy-efficient building [67] as energy-intensive materials contribute to high embodied energy and carbon. Timber buildings could significantly reduce emissions [61], achieving a 48 $kgCO_2$-e/m^2 reduction in mean embodied carbon at the end of life compared to post-tensioned concrete buildings in Australia [8]. In mass timber construction, various types, such as cross-laminated timber, nail-laminated timber, and dowel-laminated timber, are used. Among these, dowel-laminated timber has been identified as having the lowest environmental impact [63,79]. Passive wooden houses are characterised by lower energy consumption, lighter materials, less waste generation and reduced transportation, water and energy consumption during construction [58].

An Australian case study at Daramu House, Barangaroo, demonstrates the successful integration of a photovoltaic system with a green roof [51]. This biosolar roof reduced surface temperatures by up to 20 °C, removed 8.1 tonnes of CO_2-equivalent emissions, improved solar panel efficiency, boosted biodiversity, and reduced stormwater runoff [51]. Compared to a similar building without a green roof, Daramu House shows that such integrated systems can effectively enhance sustainability outcomes, proving the viability of circular economy interventions in the residential sector.

The Skin layer represents the building's exterior components, including façades, windows, and roof covers, characterised by high embodied energy and shorter lifespans [37]. Addressing design options for envelope construction [55] and implementing selective deconstruction for reuse can significantly reduce the overall environmental footprint of residential buildings [54]. A practical approach in some European countries as part of an EU project involves a modular façade system that acts as a second skin to existing façades. This system reduces energy consumption, enhances aesthetics, and allows continuous building use during installation due to its prefabricated design and

Table 4
Source evaluation for Optimise.

CE Intervention	Source / Article	Building layer	Description
Optimising system performance	Dicko, Roux [53], Keena, Rondinel-Oviedo [54], Monteiro and Soares [55], Allacker and De Troyer [56], Kildsgaard, Jarnehammar [57], Lewandowska, Noskowiak [58], Was, Radon [59],Chau, Xu [60]	System	Achieving net-zero carbon performance, maintaining passive strategies, and improving user behaviour to enhance energy efficiency
	Robati and Oldfield [8], Oladazimi, Mansour [61], Kröhnert, Itten [62], Balasbaneh and Sher [63]	Structure	Energy efficiency in timber structured buildings
	Aldawi, Alam [64], Dannapfel, Osterhage [65], Mercader-Moyano, Anaya-Duran [66], Motuziene, Rogoža [67]	Skin	Thermal energy efficiency from double glazed windows and different façade material
	GBCA [51], Built [68], Kwan and Guan [69], Zsiborács, Vincze [70], Milousi and Souliotis [71]	Service	Product-as-a-Service models and improving product efficiency for energy savings
	Sevindik and Spataru [72]	Stuff	Energy and environmental efficiency by fixing air source heat pump
	Pauliuk, Heeren [73], Maury-Ramírez and De Belie [74] Malabi Eberhardt, Rønholt [75], Kempton, Boehme [76]	System	Reducing resource use and emissions through material efficiency and urban mining offers a significant opportunity for resource recovery.
	Morales-Beltran, Engür [77], Li and Densley Tingley [78], Oh, Park [79], Arehart, Pomponi [80]	Structure	
	Mayer [81], Talpur, Liuzzi [82], Zandonella Callegher, Grazieschi [83], Illankoon, Vithanage [84], Pomponi and D'Amico [85]	Skin	
	WorldGBC [46], Akinade, Oyedele [86], Hossain and Ng [87]	System	Assessing waste materials at different stages, optimising design to use minimal structural materials, and planning for deconstruction
	Shooshtarian, Maqsood [88]	Skin	
	Yang, Lyu [89], Ghani, Egilmez [90], Soonsawad, Martinez [91]	System	Decarbonise the construction value chain should focus on the production and supply of most polluting building materials and energy
Prolonging an asset's life	Attaianese, Illario [92], Geldermans [93], Hamida, Remøy [94], Zairul [95], Cinquepalmi, Paris [96]	System	Extending an asset's lifespan through designing for longevity
Decreasing resource usage -	Pan and Zhang [97], Antwi-Afari, Ng [98], van Stijn and Gruis [99],	System	Offsite production of modular houses or components such as

(continued on next page)

Table 4 (*continued*)

CE Intervention	Source / Article	Building layer	Description
Modularity and offsite construction	Shahi, Wozniczka [100], Kyrö, Jylhä [101], Petcu, Barbu-Mocănescu [102]		slab, bathroom, and kitchen
	Oorschot and Asselbergs [103], Antonov, Molodtsov [104],	Structure Zhang, Xu [106]	
Skin	Tavares, Soares [105]		
Implementing reverse logistics	WorldGBC [46]	System	Reverse logistics enhances supply chain efficiency Extended Producer Responsibility (EPR). Reverse logistics, which enhances supply chain efficiency

shortened assembly time [65]. The thermal performance of house wall systems with double-glazed windows saves around 20 % more energy compared to single-glazed windows in Australia [64].

The literature also highlights key factors, such as the product-as-a-service model and improved product efficiency for energy savings. One practical example can be found in Australia, where light is provided as a service. The service provider supplies the light and manages the maintenance [68]. CE principles for residential solar thermal systems can enhance product efficiency, such as by integrating heat pumps for domestic electric water heating and photovoltaic systems [70].

Although material efficiency in the residential sector is widely discussed in the literature as a key circularity strategy for reducing resource use and emissions, [73] this review has not identified any practical interventions for its implementation. Maximising the reuse of existing buildings, components, and materials, reducing reliance on energy-intensive and short-lived materials, and ensuring future potential for reuse, recycling, or energy recovery [75]. Using recycled materials such as fly ash and blast furnace slag in eco-concretes improves resource efficiency and reduces environmental impacts [74]. Kempton, Boehme [76] highlight several data gaps in housing construction in Australia. Using locally sourced materials and enhancing material circularity are key strategies to minimise the embodied carbon in Australian construction [84].

Studies have emphasised the need for various strategies to minimise waste, such as assessing waste materials at different stages, optimising design to use minimal structural materials, and planning for deconstruction [85,86,107]. As an example, the brick industry relies on virgin raw materials, and efforts are being made to implement more initiatives, such as recycling waste from clay brick production, utilising half-brick production processes, and repurposing other waste materials such as charcoal, wheat dust, and oak sticks for production [78]. Additionally, numerous design strategies and opportunities for reducing and recycling materials are being explored at various stages, including design, transport, construction, demolition, and end-of-life phases [88].

Extending the lifespan of assets by designing them for longevity enhances their durability and can significantly reduce the need for materials throughout the life cycle of housing assets [75]. Adaptive reuse and Design-for-Adaptability are highly effective strategies for enhancing resource efficiency and prolonging the usability of built environments [93–96].

Off-site construction and modular construction reduce resource consumption by enabling the reuse and repurposing of materials, thereby decreasing the need for primary materials [46]. Further, modular construction enhances productivity, reduces waste and emissions, lowers energy use, and extends the lifespan of building components through refurbishment [97,101,104].

Modularity is applied in the residential sector as a whole house and a component. Examples of the whole house are a biobased flexible house called "Uuthuuske" in The Netherlands and Nidus houses in Romania [103]. The literature features numerous comparative studies identifying optimal materials for modular construction components. These studies examine various materials, including steel slabs [98] steel-framed modules [97], wood frames [105], and prefabricated envelope cladding [108].

A circular housing retrofit strategy can effectively incorporate modularity, as exemplified by the "Circular Kitchen" [99]. This approach uses modular components that come with a take-back guarantee after their use, allowing them to be returned, refurbished, remanufactured, or recycled. Reverse logistics is important to streamline material and product flow within the supply chain as promoted in Extended Producer Responsibility [109], which improves material movement and management (focusing on product returns, reuse, recycling or proper disposal) and contributes to a sustainable supply chain system [46].

5.2.4. Loop

The "loop" is a common CE intervention that involves keeping products and materials in cycles, prioritising inner loops, focusing on strategies such as reuse, designing buildings for easy disassembly, enhancing material circularity, and employing material passports. Among the 30 identified interventions, six are practical and span four building layers (Table 5).

Timber building components have a high potential for reuse across multiple cycles due to their ease of deconstruction [110,111]. In contrast, some studies suggest that reusing steel components in multiple

Table 5
Source evaluation for Loop.

CE Intervention	Source / Article	Building layer	Description
Keeping products and materials in cycles, prioritising inner loops	Pronk, Brancart [110], Psilovikos [111]	Structure	Reusing material, components and space in different building layers
	Rios, Grau [112]	Skin	
	Ollár, Granath [113]	Space	
	Cottafava and Ritzen [114], Zaman, Arnott [115]	System	Facilitate reuse by Design for Disassembly (DfD)
	Braakman, Graaf [116], Cristescu, Honfi [117]	Structure	
	Stijn, Eberhardt [118]	Stuff	
	Kedir, Hall [119], Honic, Kovacic [120], Atta, Bakhoum [121], Poolsawad, Chom-in [122], Malmqvist, Moncaster [123], Arora, Raspall [124]	System	Information on materials circularity
	Malabi Eberhardt, van Stijn [125]	Structure	
Recycling materials	Ritzen, Oorschot [126], Shooshtarian, Maqsood [127], Mostert, Weber [128], van Oorschot, Sprecher [129], Papadaki, Nikolaou [130], Volk, Steins [131], Leising, Quist [132], Sudarsan and Gavali [133]	System	Analyse the recycling potential for resource recovery
	Su, Huan [134], Tanthanawiwat, Gheewala [135]	Structure	
	Braakman, Bhochhibhoya [34], Shooshtarian, Maqsood [88], Finch, Marriage [136]	Skin	
	WorldGBC [46]	Site	

lifecycles can help offset the embodied environmental impacts associated with their manufacturing phase [112]. Ollár, Granath [113] emphasises the use of adaptive reuse in the space layer when designing the spatial configuration of the kitchen to allow for flexible use of spaces.

Incorporating design strategies for disassembly and deconstruction early in the planning phase is essential for maximising the recovery of resources at the end-of-life stage. Compared to other CE interventions, the DfD has relatively high practical interventions. Effective DfD involves evaluating the types of connections, ensuring accessibility to these connections and evaluating building circularity for efficient material recovery and reuse [114]. Zaman, Arnott [115] demonstrated that systematic deconstruction of an entire house can effectively contribute to resource conservation and environmental protection by promoting inner loops and recycling of materials.

In the transition towards a CE, residential construction often lacks sufficient data regarding the environmental impacts and embodied carbon of various materials, which are essential for determining effective building design and construction strategies. Indicators for material circularity play a vital role in giving this information to identify the potential for reuse, recycling or material recovery [75,122]. A materials passport is a key tool for circular information flow in construction, providing guidance on material handling during construction and outlining recovery potential at the end-of-life [120]. It supports sustainable practices by promoting reuse, recycling, and material recovery. Integration with the Building Information Modelling (BIM) enhances collaboration across the supply chain, making the approach more practical and effective for the CE goals [121].

Recycling is a widely promoted option, as it helps recover resources and minimise waste. The literature assesses the recycling potential for various components of an entire timber house [135], building elements such as the envelope [136], and different construction materials [130] such as concrete, bricks [88], timber [134], and autoclaved aerated concrete [131]. Shooshtarian, Maqsood [137] highlight the potential for stakeholders to improve waste management by using recycled materials to reduce landfill waste and lessen the use of virgin resources.

5.2.5. *Virtualise*

Digital technologies are essential for enabling CE in the construction sector. They offer virtual platforms that substitute for physical marketplaces, facilitate the exchange of goods and services, and decrease users' costs and time [138]. Additionally, enhanced digital services permit real-time maintenance and other tasks that previously demanded physical interventions [35] (Table 6).

The review found no documented practical interventions, and none of the articles reviewed were Australian-based. All four identified articles focused on "replacing physical products and services with virtual services." There was no evidence of other virtual interventions, such as replacing physical locations with virtual locations or remote service delivery using remote sensors and smart monitoring devices.

The articles demonstrate that BIM-based tools can estimate the salvage potential of structural components [139], label reusable elements, and plan for deconstruction [141]. These tools also use a digital platform to assess carbon emissions and potential savings by integrating building stock data with energy modelling to evaluate life-cycle carbon emissions and identify carbon reduction opportunities [140].

Table 6
Source evaluation for Virtualise.

CE Intervention	Source / Article	Building layer	Description
Replacing physical products and services with virtual services	Çetin, De Wolf [138], Akanbi, Oyedele [139], Heisel, McGranahan [140], van den Berg, Voordijk [141]	System	Estimate salvage potential and plan for the deconstruction with BIM [142] and internet of things (IoT)

5.2.6. *Exchange*

"Exchange" modernises processes by integrating new technologies, such as renewable energy and alternative materials, to replace traditional solutions and improve efficiency [35] (Table 7).

The identified sources are scarce, emphasising the use of alternative materials in construction, with only three sources noted, two of which have been practically applied. The articles discuss the use of upcycled materials, such as plastic bottles for building construction [144], repurposing shipping containers [145], and employing recycled materials to create bricks and 3D-printed buildings [143].

6. Discussion

This paper examines global and Australian CE interventions, highlighting their integration potential in the residential sector. This section examines relevant barriers and challenges to understand why practical CE interventions are limited and assess theoretical interventions' impracticalities. Identifying opportunities within the literature review delineates how specific interventions have been practically applied. The discussion is structured into descriptive and content analyses to evaluate these interventions.

6.1. *Descriptive analysis*

The descriptive analysis was based on classifying studies based on the fragmented nature of the ReSOLVE strategies, whether theoretical or practical, and their geographical distribution. In addition, article distribution was examined across the seven building layers to contextualise the application of CE interventions.

The fragmented nature of the ReSOLVE strategies

This study observed an uneven distribution of publications across the ReSOLVE framework elements, reflecting prevailing trends in CE research and practice within the residential sector. The elements "Optimise" and "Loop" emerged most frequently, with strong representation of energy efficiency, recycling, modular construction, and material efficiency strategies. In contrast, "Share", "Virtualise", and "Exchange" strategies were less prominent, suggesting gaps in practical implementation or scholarly attention. It is also possible that some relevant interventions, particularly those aligned with "Virtualise", were not captured due to the limitations of the keyword selection, as such practices may not always explicitly reference CE terminology. Nonetheless, the insights drawn from these underrepresented categories remain valuable and contribute to a more comprehensive understanding of CE application. While this distribution presents a limitation, it does not compromise the overall validity of the findings but instead highlights important areas for future exploration.

Notably, the fragmented nature of CE interventions across different components of the house and life cycle stages may hinder a holistic understanding of the benefits, making it difficult to support decision-making for effective implementation. Despite various policy initiatives promoting CE practices, such as Victoria's 'Recycling Victoria' plan [19], there remains a significant gap in the CE implementation within Australia's residential construction sector [146,147]. The absence of practical studies restricts the comprehension of the obstacles and opportunities of integrating CE principles, hindering precise evaluation of benefits such as resource conservation and waste reduction. This gap

Table 7
Source evaluation for Exchange.

CE Intervention	Source / Article	Building layer	Description
Using alternative material inputs	Mazur [143] Adefila, Abuzeinab [144], Bertolini and Guardigli [145]	System Skin	Upcycling of different materials for residential construction

makes it difficult to assess policy effectiveness, identify barriers, and develop evidence-based guidelines for stakeholders, leading to fragmented approaches in sustainable building. Therefore, it is paramount to address this research gap to bridge the gap between policy objectives and practical implementation. To foster CE integration in this sector, a more robust practical understanding is needed to underpin more effective, industry-specific policies and guidelines.

Classification of studies as theoretical or practical

Among the limited practical interventions identified, most focused on recycling, regenerative materials, energy efficiency, and design for deconstruction. Several of these were identified in Australian contexts through the narrative literature review, demonstrating that such strategies are technically and operationally viable within the residential construction sector. The limited number of practical studies highlights the need for more practical research to validate the effectiveness of CE interventions and the way forward to implementation.

Studies' geographical distribution

Many articles reflect Europe's proactive stance on sustainability and CE initiatives, supported by robust policy frameworks such as the European Green Deal and the CE Action Plan [55]. These policies have spurred a significant amount of research and publication in the region [49,113], highlighting Europe's commitment to integrating CE principles into various sectors, particularly the residential construction sector. Furthermore, several European countries, such as France and The Netherlands, have advanced CE implementation through targeted EPR schemes that mandate producer responsibility for recycling construction materials like gypsum, PVC, and float glass [148].

6.2. Content Analysis

To address the research question and objectives, it is essential to identify the barriers and enablers influencing the implementation of circular economy strategies in the Australian residential sector. To provide a systematic overview, discussion on the content analysis highlights key barriers and challenges for practical CE implementation, along with opportunities and recommendations within the relevant ReSOLVE strategies.

AlJaber, Martinez-Vazquez [149] conducted a systematic review identifying key barriers to CE adoption in the building sector, categorising them into six areas: awareness, technical, economic and market, implementation, support/promotion, and social. Similarly, Hart, Adams [150] classified CE barriers and enablers into four broad categories: cultural, regulatory, financial, and sectoral. Building on these foundations, the present study adopts a broader categorisation based on the frameworks proposed by AlJaber, Martinez-Vazquez [149] and Hart, Adams [150], as presented in Table 8. Furthermore, specific barriers and enablers aligned to each ReSOLVE strategy within the Australian residential sector are discussed in the following sections.

Table 8
Summary of key barriers and challenges.

Barrier Category	Key Barriers/ Challenges
Policy /Regulatory barriers	**Lack of consistent regulatory framework** [150] • To facilitate the supply and use of regenerative materials [151] • For promoting low-carbon buildings focused on reducing embodied carbon [152] • Lack of CE policy and insufficient regulatory frameworks for C&D waste management [88] • Lack of flexibility in building codes and regulations • Limited market-based policy tools such as EPR schemes and reverse logistics [148] **Obstructing laws and regulations** [150] • Dual key homes face challenges due to varying local planning laws [153] (DOH) **Lack of incentives for CE** [150] • Lack of promotion of Design for Disassembly (DfD) in buildings [19]
Economic/ Financial barriers	**Mismatch between cost of supply and reused materials** [149] • Low virgin material costs compared to reuse/recycle costs [149] **Cost of removing contaminated materials** [149]**High initial costs for adopting certain CE technologies and materials** [149,150] • 3D printing, digital twins **Lack of integrated technology-service-finance support** [150] • Challenges in implementing case studies and living labs
Technical/ Sectoral barriers	**Lack of government support** [149] • Limited regeneration of brownfield projects in the residential sector **Insufficient use or lack of CE designs, tools, information, and metrics** [149,150] • Limited data and information across the full life cycle • Inadequate evaluation of environmental impacts for end-of-life scenarios • Technological challenges in designing for disassembly and recycling • Lack of material reuse practices in the residential sector and insufficient data on material reuse potential **Building complexity** [150]**Lack of market mechanisms for recovery and storage facilities** [149] • Lack of an established recycling market for timber • Underdeveloped secondary materials market
Social/ Cultural barriers	**Operating within a linear economy** [150] • Resistance to behavioural change **Lack of stakeholder collaboration** [149,150]**Lack of interest, knowledge, or skills** [149,150]

6.2.1. Regenerate

Regenerate materials: In Australia, hempcrete is used for construction and insulation, but tamped hemp floors and insulation under concrete slabs are uncommon compared to Europe [154]. Industrial hemp cultivation requires a state-issued licence, and Victoria's climate is ideal for developing a successful hemp industry [151]. Government support is essential to facilitate the supply and use of regenerative materials. The potential of regenerative agricultural residue as a building material can be concentrated in the agricultural regions of the country. However, some regenerative building materials, such as date palm fibres, are not available in commercial quantities in Australia. The Australian date palm industry is a niche sector in horticulture, encompassing an area of approximately 100 hectares [155].

Renewable energy: Rooftop solar systems contribute directly to circular economy goals by reducing reliance on fossil fuels and optimising resource use throughout the building lifecycle. Within the ReSOLVE framework, solar technologies align with both "Optimise" and "Regenerate".

Regeneration land: The detoxification and regeneration of brownfield land is a government-driven initiative in Australia. While there are successful examples, most projects focus on neighbourhood-level developments such as Nightingale Village. There is an opportunity to expand these efforts to residential projects [17].

Key Barriers/ Challenges: Lack of policy incentives and government support to facilitate Australia's supply and use of regenerative materials and renewable energy. Industrial hemp cultivation requires a state-issued licence, and rooftop solar is not mandatory in Australia; however, rooftop solar uptake is strongly incentivised through schemes like the Small-Scale Renewable Energy Scheme (SRES), reinforcing its role as a practical CE intervention in residential housing [156]. One technical barrier is the lack of regeneration of brownfield projects in the residential sector, as government support is necessary for land developers.

6.2.2. Share

Sharing assets: In residential construction, sharing can be implemented through housing more people within a smaller footprint, renting, infrastructure sharing (such as parking, green spaces, and water tanks), shared appliances, and co-housing [157] which are needed top-down approaches and must be incorporated with design. Practical implementations exist, such as Nightingale Village's practice of residents sharing laundry and gardens and the emerging concept of dual-key (dual occupancy) houses in Australia, where a single property is divided into two separate units in a standard home [153]; they necessitate additional resources for expansion.

Sharing information: Open-source design platforms also encourage sharing by pooling asset usage. However, the standardised exchange of information remains a significant challenge in residential buildings. Some aspects discussed in the other ReSOLVE actions are interrelated with the Share concept, such as supplying excess solar energy to the grid, reusing structural elements, DfD, and such types of uses. Leveraging online platforms, especially open-source ones, to share real-time data, enabling user customisation and supporting modular construction, DfD, and sustainable materials use [35]. Reusing materials in residential construction is rare, but building partnerships across the supply chain is key to scaling CE practices.

Key Barriers/Challenges: There are policy and regulatory barriers, as dual-key homes face challenges due to varying local planning laws that require permits and town planning advice [153]. Obstructing laws and regulations hindered the Nightingale project, as the plan to eliminate onsite car parking was overturned after an objection, forcing the inclusion of parking spaces and causing a 12-month delay despite its sustainability goals [158].

6.2.3. Optimise

Optimising system performance: Most studies have focused on reducing operational energy, but the environmental impact of materials used in production, transportation, and construction processes is often overlooked. The choice of materials during construction heavily influences a building's embodied energy content, carbon emissions, and life cycle impacts due to the large volumes of materials that account for more than half of its embodied energy.

The main building layers, the Structure, Skin, and Space Plan, contribute 58 %, 23 %, and 18 %, respectively, to the total embodied carbon [159]. However, the study highlights a lack of attention to the "Space layer," indicating that this aspect has been underrepresented in research. Establishing a correlation between embodied energy and CE strategies concerning the mentioned phenomena is imperative.

In Australia, more than half of the nation's electricity is used for building construction, operation, and maintenance, contributing to about a quarter of its GHG [160]. Horne, Dorignon [146] contend that existing strategies must be improved to tackle climate change and the housing affordability crisis within housing systems and practices. Some practical interventions are not extensively published, even in grey literature, as they often involve individual actions. For instance, AVJennings, a volume home builder, developed a prefabricated energy-efficient housing model, demonstrating the feasibility of modular housing [161]. While it addresses cost-effectiveness, energy efficiency, reduced labour, and faster construction, there is uncertainty about embodied energy due to overseas prefabrication. Therefore, a systematic method should be established to gather and assess information on the actual efficiency of these isolated practical interventions, ensuring that they effectively and practically promote circularity.

The Netherlands and Germany have implemented regulations requiring complete life cycle assessments to account for operational and embodied impacts in buildings [152]. To foster low-carbon buildings, strategies should include material approaches that consider the entire building lifecycle, offer financial and legislative incentives to extend building lifespans and use Life Cycle Analysis to address embodied and operational carbon through more innovative design and greater stakeholder involvement with correct data [162]. In Australia, under the National Greenhouse and Energy Reporting Scheme, companies and organisations must report their Scope 1 and 2 emissions, while reporting Scope 3 emissions remains voluntary [152]. Recognising the significant role of embodied emissions in the built environment's overall carbon footprint is important [152].

A notable advancement in energy efficiency is the use of passive design strategies. While incorporating passive house strategies and building Passive Houses can effectively reduce operational energy, the application of additional CE strategies to these houses remains largely unexplored.

The literature showed that more studies on material selection for building optimisation, including building envelopes, walls, windows, insulation materials, wall panels, ceiling facades, etc., have been conducted in a fragmented manner. Reflecting the global context, Australia must enhance material efficiency and shift towards a CE as it has one of the highest per capita material footprints among developed nations [76]. Scholars suggested that buildings will serve as significant temporary material stocks, providing resources for the future. However, insufficient data collection on construction methods and limited detailed information on materials lead to generalised data, inconsistent waste recording practices, and a lack of comprehensive data on material reuse, which hinders effective CE strategies. Enhancing data collection and dissemination through digital technologies is key for the practical implementation of CE strategies.

Timber is suggested as a low-carbon construction material in residential buildings, and it is essential to consider structural and design parameters, responsible sourcing of timber, the service life of the materials, and end-of-life scenarios [163]. Timber's capacity to sequester carbon results in a negative carbon footprint, which can help counterbalance any remaining emissions and contribute to a reduced overall emission profile [163]. Dalton, Dorignon [24] highlighted the availability of the recycling market for concrete and steel materials, but timber faces market potential limitations due to the associated costs of nail removal and quality concerns. The design principles for disassembly and deconstruction must be considered, and prefabricated and modular elements must be designed during the design stage.

Modularity and off-site construction: Waste minimisation in the construction sector can be achieved throughout the entire life cycle by implementing CE interventions such as reuse, recycling, design for deconstruction, promoting longevity, off-site construction, and modularity. It is essential to analyse, quantify and improve secondary markets for materials and components to address unavoidable waste. Additionally, updating waste-related regulatory policies is important to facilitate participation from all stakeholders.

Implementing reverse logistics: Reverse logistics enhance supply chain efficiency, and implementing EPR is one of the most effective ways to promote CE practices. EPR, a market-based policy tool, aids waste prevention and material circulation. Developing EPR policies in Australia is essential to translating theoretical CE strategies into practical applications. Limited research exists on behavioural changes in the context of CE strategies, and this is a key area to focus on for effective CE practice.

The literature review provides limited evidence regarding the optimisation of transport links between built assets. However, optimising transport is vital to assessing transport emissions and identifying reduction strategies.

Key Barriers/Challenges: Under policy and regulatory barriers, the absence of a comprehensive regulatory framework remains a critical challenge in Australia. In particular, there is a lack of regulations focused on promoting low-carbon buildings and reducing embodied carbon, with Scope 3 emissions reporting still voluntary despite mandatory reporting for Scope 1 and 2 emissions [152]. Furthermore, although major changes have occurred in Australia's regulatory landscape following the China Waste Ban to strengthen local waste infrastructure, there remains a need for stronger frameworks supporting C&D waste management to encourage inner-loop recycling [19]. Given Australia's diverse climatic conditions, with eight distinct climate zones, developing sustainable, climate-responsive sectoral policies for CE in housing is particularly important [164].

Soonsawad, Marcos-Martinez [165] highlights the importance of long-term urban planning and the development of policies at different spatial scales, from suburbs to national levels, to address the challenges posed by varying population dynamics and evolving construction technologies, especially as approximately 86 % of Australia's population resides in urban areas.

Economic barriers remain significant; the lack of integrated technology, services, and financial support hampers the implementation of pilot projects and living labs that are essential for advancing CE initiatives [150].

Technical and sectoral barriers persist due to the insufficient use of CE designs, tools, information, and metrics [150,149]. Data availability across the full life cycle remains limited, and the evaluation of environmental impacts for end-of-life scenarios is inadequate. Capturing information on reused or salvaged materials would enable better quantification of circularity practices. In the long term, mandatory digitalisation measures, such as the introduction of material passports, could enhance tracking and stock management in the residential construction sector [76].

Social and cultural barriers continue to impede circular economy adoption, primarily due to entrenched linear economy practices and resistance to behavioural change [150]. A lack of stakeholder collaboration and limited interest, knowledge, and skills among stakeholders further restrict progress [150,149]. Additionally, business models and stakeholder attitudes remain aligned with traditional practices, limiting the shift towards more circular approaches [150].

6.2.4. Loop

Loop in the inner cycle: Looping the material in its inner cycles, particularly reusing, is a highly effective CE strategy for mitigating environmental impacts and reducing the demand for virgin resources. However, the research on the reuse of components is relatively scarce, both in theoretical and practical contexts. An underdeveloped secondary materials market within the construction value chain is a significant barrier to this. However, DfD and material passports are prominent and promote reuse. DfD requires comprehensive planning with proper documentation, creating accessible connections to simplify dismantling, separating materials to facilitate recycling, reuse, or disposal, standardising component sizes and dimensions, and designing with labour practices, productivity, and safety in mind [112].

During the construction phase, it is essential to consider how building components, such as bathroom fittings (e.g., washbasins, toilet bowls), window frames, and electric switches, will be dismantled. Improper installation, such as using white Portland cement or concrete at the base of these components, can cause damage and reduce their potential for reuse [124].

Recycling: This is prominently featured in theoretical and practical CE interventions, typically considered after reuse. Evaluating the environmental impacts, including embodied and operational carbon, of different CE strategies is essential to determine the most suitable options. For instance, while recycling is important, not all recycling methods are equally beneficial; upcycling should be prioritised over downcycling to maximise environmental benefits.

Key Barriers/Challenges: One key policy barrier is the insufficient emphasis on Design for Disassembly (DfD) in building practices, which impedes the sector's transition towards circularity. However, government interventions such as tax reliefs, financial incentives, and the implementation of sustainable construction appraisal systems could be essential enablers to support the adoption of circular practices [19].

Additionally, under obstructive laws and regulations, the limited presence of market-based policy tools, such as EPR schemes and reverse logistics, has been identified as a significant barrier to advancing circular economy practices in the residential sector [148].

A key technical barrier is that virgin materials are often cheaper than reused or recycled alternatives, discouraging the adoption of circular practices [149]. Strengthening material looping strategies and updating the National Construction Code could help address this challenge and support greater circularity in the Australian residential sector. High costs associated with removing contaminated materials further limit reuse opportunities. Promoting relevant DfD measures could help reduce material cleaning costs. Operating within a linear economy [150], outdated business models, and entrenched stakeholder behaviours and attitudes [150], limits the flow of information across the material supply chain, thereby hindering circularity. Value chain engagement, strengthened stakeholder relationships and partnerships, and adopting systems thinking are key enablers to overcome this barrier [150].

6.2.5. Virtualise

Virtual services: Integrating digital technologies and innovative design strategies is vital to achieving sustainability and affordability in the residential sector. Compared to other industries, the residential sector has been relatively slow to adopt digital transformation. While BIM, material passports, and digital platforms are more commonly utilised, the sector is less familiar with and adopts advanced technologies such as digital twins, blockchain, and robotic manufacturing.

Virtual technologies can support achieving other CE interventions outlined in the ReSOLVE framework, transitioning from theoretical strategies to practical applications. These technologies are essential for enhancing stakeholder collaboration, enabling efficient data and knowledge sharing, minimising raw material consumption through optimised design processes, and improving material tracking and tracing.

Key Barriers/Challenges: There are technical barriers to integrating advanced technologies such as additive manufacturing, big data, blockchain, digital twins, and 3D printing in Australia. While only a few of these are currently adopted in the Australian residential sector, BIM is an exception and is widely used in practice. A clear vision for CE in the built environment, coupled with greater sector standardisation, will facilitate the adoption of new technologies.

6.2.6. Exchange

Using alternative material inputs: Exchange in the construction sector focuses on carefully selecting resources and mechanisms to enhance sustainability over the current linear practices. Though the literature focuses on upcycling materials, replacing traditional solutions with advanced technology and replacing product-centric delivery models with new service-centric ones are included under share.

Some scholars argue that provider-driven integrated technology-service-finance solutions can unlock significant opportunities for natural resource conservation, cost reduction, and improved working and social environments [166]. The business model, often called the "as-a-service" model, is adaptable for building modifications that primarily target commercial and government buildings [166,167]. "As-a-service" models can be effectively applied in residential buildings to enhance the practical implementation of CE interventions [167].

Key Barriers/Challenges: A social barrier is also evident, as Australia is generally resistant to changing established construction practices. This behavioural inertia must be addressed to enable the adoption of more robust and circular technologies, moving away from conventional methods that often have significant environmental impacts.

6.3. Recommendations for future research

The limitations of this study include the potential that the literature review may not have captured all relevant studies, and that some practical research may remain unpublished or inaccessible through the reviewed sources. The research identified CE gaps in the current literature. Hence, future research should address the limited understanding of the reuse potential of components, which is vital for effective implementation and research on optimising transport links between built assets. Future research should investigate underrepresented ReSOLVE elements, such as Share, Exchange and Virtualise, to address existing gaps and broaden the applicability of CE strategies in residential construction. A more balanced exploration of all ReSOLVE categories could enhance the robustness and generalisability of future findings. Additionally, studies on policy interventions are needed to accelerate CE uptake in the residential sector. More research is recommended to fill the recurring gap, analysing behavioural dynamics in the housing context and developing sector-specific guidelines to support sustainable transitions.

Furthermore, future research should adopt more applied and longitudinal methodologies to validate and scale CE strategies in the residential sector. This includes conducting pilot studies to test CE interventions in real-world construction settings such as prefabricated modular housing or design-for-disassembly techniques and establishing Living Labs to support stakeholder co-creation and iterative testing of CE innovations. Empirical evidence generated through methods such as life-cycle assessment and material flow analysis could help quantify the contribution of CE strategies to environmental sustainability and support informed policy decisions. Additionally, longitudinal tracking of CE practices would offer valuable insights into their durability, economic feasibility, and behavioural acceptance over time. These approaches can help bridge the gap between theoretical concepts and sustained, real-world implementation. Further research should also explore the role of policy interventions in accelerating the adoption of CE practices across the residential sector.

7. Conclusion

Adopting a CE in the residential sector offers a promising shift toward sustainability and resource efficiency. However, theoretical and practical CE interventions remain fragmented, often focusing on limited aspects. There is a lack of comprehensive research comparing theoretical frameworks with their practical implementation. This article explored both theoretical and practical CE interventions in the residential sector, emphasising the critical need for practical research to support implementation.

The review of 105 articles from the SLR and NLR analysis identified CE interventions within the ReSOLVE framework and across seven building layers, exploring various approaches applicable to housing. The descriptive analysis revealed limited practical studies and only focused on energy efficiency and waste recycling, highlighting the need for a more holistic approach. Additionally, the limited availability of knowledge for selecting the most environmentally sustainable design choices for circular building components presents a significant challenge.

Although this study is based on global literature, the findings have been contextualised to the Australian residential sector through relevance filtering during content analysis, identification of local case studies from the narrative review, and alignment with national regulations such as the National Construction Code and state-based initiatives like Recycling Victoria. These steps ensured that the insights presented are applicable to Australian housing practices and policy environments. Practical examples from Australia were highlighted in the NLR. Gaps and barriers specific to the Australian policy and construction landscape are discussed.

The content analysis of the literature highlighted that energy-related interventions in the housing sector primarily target operational energy, with fewer interventions addressing embodied carbon, a mandatory consideration for a low-carbon future. Additionally, there is a lack of comprehensive approaches for achieving whole-life cycle carbon reduction, highlighting a significant research gap in effectively integrating CE principles into residential buildings. The interconnectedness of various CE interventions emphasises the need to convert theoretical concepts into practical applications. This integration can be seen in strategies such as design for deconstruction, material stock management, and virtual technologies to facilitate reuse practices. Aligning policy regulations and fostering stakeholder collaboration is essential to enhancing the effectiveness of these CE implementations. Moreover, this review recommends exploring new business models integrating multiple CE strategies to promote circular practices in the built environment.

This paper contributes valuable insights to understanding the research gaps in practical interventions and the fragmented nature of CE strategies across different building components. Another recurring research gap was a deeper analysis of behavioural changes within the context of CE in the housing sector. The findings of this paper explore opportunities to enhance the practical application of CE interventions, particularly relevant to policymakers crafting strategies for climate change and CE, academic researchers, and stakeholders in the construction sector, such as architects, product designers, builders, and companies involved in Construction and demolishing waste management. While the research primarily focuses on Australia, it offers globally applicable insights, addressing sustainability and CE challenges relevant to many countries.

The limitations of this paper include the possibility that the literature review may not capture all relevant studies and that some practical research might be either unpublished or not included in the accessible literature. Future research should focus on applied methods such as pilot studies, Living Labs, and longitudinal tracking to validate circular economy strategies in residential construction and support their practical implementation through empirical evidence. Additionally, further studies would benefit from policy interventions to catalyse the adoption of CE and promote the adoption of CE practices in the residential sector.

CRediT authorship contribution statement

Dona Iresha Gurusinghe: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Usha Iyer-Raniga:** Supervision. **Trivess Moore:** Supervision.

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.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.buildenv.2025.113279.

Data availability

No data was used for the research described in the article.

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