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# A review of circular industrialised construction for sustainable and affordable housing: Towards a process-driven framework

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## ABSTRACT

Circular Industrialised Housing, underpinned by the systematic design of building components for future disassembly and reuse, offers valuable opportunities to deliver sustainable and affordable homes at scale. However, research interlinking these approaches remains thin, and critical socio-economic dimensions are often overlooked. This paper addresses these gaps through a systematic review of 65 publications spanning Europe, Asia, the Americas, Africa, and Oceania. Six key factors inductively emerged: cultural, governance, financial, site and logistics, construction system, and building information. Building on these findings, a four-step circular process framework is proposed—(re)planning, (re)designing, (re)manufacturing, and (dis)assembly—capturing the full housing lifecycle. Fifteen themes and 36 sub-themes were identified. Mapping barriers and enablers reveals a disproportionate emphasis on the (re)designing process (55%), with significantly less attention to (re)manufacturing (20%), (re)planning (13%), and (dis)assembly (12%). The strongest relationship identified was between the construction system and (re)designing, with sub-theme ‘theoretical design’ dominating the literature. Most literature gaps pertained to governance, particularly in relation to (dis)assembly. Few studies investigated social and affordable housing. Only six studies included interviews or surveys with practitioners. Overall, this review contributes a holistic perspective on Circular Industrialised Housing, offering a structured, process-driven lens to inform interdisciplinary research, policy design, and industry adoption. By illuminating how and where key factors intersect across the housing lifecycle, the framework serves as a roadmap for systematically advancing the field towards resource-efficient, regenerative and equitable housing outcomes. Future research can apply the framework to specific case studies to develop and refine its practical relevance.

## 1. Introduction

Providing environmentally sustainable and affordable housing for future generations requires urgent, profound changes within the built environment to respond to escalating climate and housing challenges. New construction is desperately needed to provide decent, affordable urban housing for the predicted global population of 9.8 billion people by 2050, 70% of whom will likely be city dwellers (UN 2022, 2021). Unfortunately, the construction of new housing using existing practices will significantly harm the environment. The construction industry is both the largest emitter of CO<sub>2</sub> emissions (IEA 2019) and greatest consumer of materials; using roughly half of all natural resources (World Economic Forum 2016), often via energy-intensive methods (Röck et al., 2020). Within the EU, for example, most resources are consumed by the housing sector (Circle Economy 2022), while close to 40% of all ‘waste’

is generated from construction and demolition, often ending up land-filled, backfilled, or incinerated (Eurostat 2023). It is therefore paramount to limit the negative impacts of construction within planetary boundaries and the Paris Agreement commitments, while providing adequate and affordable housing (United Nations 2015, IPCC 2023).

Recent research, along with policy and industry recommendations, identifies the transition to a Circular Economy (CE), or ‘circularity’, as a promising approach to limit the harmful environmental impacts of housing construction whilst improving affordability (Housing Europe 2023, ARUP 2016, Smith & Quale, 2017). CE is a broad term relating to both design and business strategies, denoting a systems orientated approach to production and consumption. It rejects the existing ‘Take-Make-Waste’ model of production and instead supports one that is ‘restorative or regenerative by intention and design’ (EMF 2013). Circular principles aim to close, slow, narrow, and regenerate resource

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loops within technological and biological cycles, with building components ideally upcycled or reused, rather than downgraded through recycling (EMF 2013, Pearce & Turner, 1990, Potting et al., 2017, Bocken et al., 2016). Circular business models shift the focus from selling products to services and emphasise retaining materials at their highest value (Tukker, 2015). In Europe, several political instruments under the European Green Deal promote the circular transition in housing, most notably the Circular Economy Action Plan (European Commission 2020) and the Waste Framework Directive (European Commission 2008), while in Asia, China has notably pursued strong CE policies for over two decades (Bleichwitz et al., 2022).

Scholars have pointed to two emerging trends in construction that may help to integrate CE principles in housing. The first is Industrialised Construction (IC). IC encompasses the systematic and controlled production of buildings, taking place both off- and on-site, to facilitate continuous improvement over time (Andersson & Lessing, 2017). IC is associated with modernising and innovating construction using the latest technology, taking a product- rather than project-based approach (Qi et al., 2021, Bertram et al., 2019) with production often carried out in factories, akin to the automobile industry (Agren & Wing, 2014). Industrialised strategies historically focus on off-site manufacture and assembly to lower housing costs through economies of scale, shorten construction time, improve worker safety, limit weather exposure, improve quality, and enhance seismic performance (Lessing, 2006).

A second concept, which is increasingly associated with IC, is an approach called Design for Disassembly (DfD), which extends resource-efficiency considerations beyond the initial assembly to include building maintenance, adaptability, and End-of-Life (EoL) scenarios. Within the construction sector, DfD is the design and planning of the future disassembly of building parts, enabling non-destructive component separation and reuse (Cruz Rios & Grau, 2019, Kibert et al., 2000, ISO 20887 2020), limiting reliance on virgin materials and extending the overall building lifespan. DfD is based on principles such as dry construction, and using standardised, interchangeable components and connections (Guy & Ciarimboli, 2008, Crowther, 2005, Morgan & Stevenson, 2005).

While quantitative lifecycle research is increasingly used to examine the environmental, economic, and social dimensions, few studies integrate these analyses to compare IC with DfD against conventional linear construction. IC is often assumed to provide environmental benefits but recent research by O'Hegarty et al. (2025) demonstrates that compared to traditional methods, IC alone does not reduce environmental impacts such as embodied carbon, as it typically involves higher material consumption and global supply chains. Conversely, DfD explicitly prioritises EoL material recovery. Comparative analysis across all three dimensions is essential to holistically demonstrate the true potential of Circular Industrialised Housing (CIH) and avoid misleading assumptions.

The importance of integrating the IC and DfD concepts is reflected by the latest EU construction guidelines for practitioners (Commission, 2020, J. R. C. European Commission 2024), and international standards, namely, ISO 20887 (2020). Design for Disassembly and Adaptability. Outside of Europe, the USA, Canada, Australia, and Asian countries such as China, Singapore and Japan, place greater policy emphasis on scaling IC (Alhawamdeh & Lee, 2025, Al-Aidrous et al., 2022), rather than embedding circularity through disassembly and reuse.

While policies encourage IC and DfD, translating these into practice remains challenging. Recent demonstration projects exemplify CIH solutions, primarily through industry-academia collaborations and EU funding. Notable projects include CIRCUIIT (2023) urban mining pilots across multiple cities, GTB Lab's (2025) modular prototypes with reversible connections for social housing, Houseful's (2023) integrated circular systems for housing retrofit, and the modular renovation approaches evaluated by Van Oorschot et al. (2022).

While the latest policy and industry guidelines widely regard the integration of IC and DfD as essential for supporting the CE transition and achieving improved housing affordability and sustainability, the transition remains in the early stages, and academic literature

connecting these concepts is limited and scattered. Early academic literature investigates the use of prefabricated, demountable, and reusable building systems for housing (Kibert et al., 2000, Durmisevic, 2006, Kieran & Timberlake, 2008). Recent studies look at digitalisation, such as reverse Building Information Modelling (BIM) (Durmisevic et al., 2021, Akanbi et al., 2019), Material Passports (Munaro et al., 2019), Product Platforms, Life Cycle Assessment (LCA), and Material Flow Analysis (Kibert et al., 2000, Durmisevic, 2006, Kieran & Timberlake, 2008, Eberhardt et al., 2019, O'Grady et al., 2021, De Wolf et al., 2020). Other emerging areas within circular construction research investigate Circular Hubs (also known as Material Depots) to improve supply chain efficiency, in addition to theoretical frameworks (Çetin et al., 2021, Dams et al., 2021, Hossain et al., 2020). Several authors have explored the barriers and enablers of buildings designed for disassembly and reuse (Tingley & Davison, 2011, Kanters, 2020, Rios et al., 2015), however, these focus on technical aspects and are not housing specific. Systematic reviews by Benachio et al. (2020) and Munaro et al. (2020) connect IC and DfD concepts to CE, although they are not applied to housing. De Silva et al.'s (2023) study emphasised that future research should incorporate holistic factors to ensure the viability of circular renovation. A growing body of research explores how circular practices can reduce housing inequalities and contribute to a just transition, particularly for vulnerable, low-income, and younger middle-income groups. In this context, social housing and cooperatives are increasingly recognised as vehicles for advancing the CE transition through resident engagement, social innovation, and supportive policy frameworks (Marchesi & Tweed, 2021, Lee et al., 2024, Van Opstal et al., 2025).

### 1.1. Study aims and outline

This study synthesises the challenges and opportunities for CIH through the lens of both affordability and sustainability, with a primary contribution being the development of a novel process-driven framework. While other studies touch upon these concepts, this framework is used to systematically map barriers and enablers influencing circularity in industrialised housing across the entire building lifecycle. In doing so, it applies a unique circular and flexible approach to understanding how IC can be leveraged to deliver long-term urban housing solutions.

This paper aims to support researchers and professionals in advancing knowledge and research on affordable and sustainable CIH and is guided by the following key questions:

- Which **processes** encompass all building lifecycle activities and support a circular approach?
- Which key holistic **themes** influence CIH, and how do they relate to lifecycle processes?
- What are the crucial **barriers, enablers, gaps, and future lines of research**?

To address these questions, the authors conducted a systematic literature review employing an in-depth qualitative approach, comprising both descriptive and thematic analyses of literature at the intersection of affordable housing, Industrialised Construction (IC), and Design for Disassembly (DfD). The study offers three key contributions: a synthesis of research on CIH, considering affordability; a comprehensive overview of current IC and DfD practices; and the identification of trends and key research gaps. It concludes with a novel, process-driven framework to support interdisciplinary decision-making and promote sustainable and affordable housing practices across the building lifecycle.

The paper proceeds as follows. In Chapter 2, the methodology for the systematic literature review is described. Chapter 3 describes the results of the review. Chapter 4 discusses these results and future relevant research directions, and Chapter 5 concludes the paper.

## 2. Methodology

A systematic literature review was considered appropriate, given the limited availability of academic material on the topic. The review follows a qualitative and descriptive approach using the PRISMA method (Cochrane 2019), establishing a rigorous search and screening process with unbiased inclusion/exclusion criteria. The method is divided into five iterative stages (Fig. 1), detailed below.

### 2.1. Defining Search Terms

The search was defined by three concepts: (1) Industrialised Construction, (2) Design for Disassembly, and (3) housing. ‘Reuse’ was included under the DfD umbrella term to capture the reintegration of building materials into the supply chain. Extensive synonymous terms for IC and DfD were used to broaden the search, considering variations based on geography and time. The term *hous\** was used to capture various housing types (affordable-, social-, public-, municipal-, government-, council-, subsidised-, and mass- housing). Given the scarcity of studies connecting IC, DfD, and affordable or social housing, this broader term inevitably retrieved general housing studies, whose transferable insights were included in the analysis.

In total, 56 terms were used (Appendix A). A search string connected umbrella terms using the Boolean operator “AND”, synonymous terms using “OR”, and alternative spelling and phrasing through wildcard tokens “?” and “\*”.

### 2.2. Database search

Prominent scholarly databases, Scopus and Web of Science (WoS), relevant to the Architecture, Engineering and Construction (AEC) industry, were searched. Searches were limited to titles, abstracts, and keywords to enhance result relevance. No time-period restrictions were

applied. The final search on 6 April 2025 yielded 443 results: 273 from Scopus and 170 from WoS. After removing 110 duplicates, 333 unique results remained.

### 2.3. Literature screening

Publications were independently screened by the authors using predefined inclusion and exclusion criteria. Included studies focussed on the AEC industry, resource-efficiency, housing in urban or suburban contexts, building-scale applications, and both new-build and existing buildings. Excluded were works on temporary or emergency housing, solely master-planning scale application, poor-quality text, non-English sources, and publications by the first author. Eligible publication types included journal articles, conference papers, and book chapters. Initial screening of titles, keywords, and abstracts yielded 84 publications. The second screening round of full texts, where duplicates and non-eligible studies were removed, resulted in 65 publications selected for analysis.

### 2.4. Analysis

#### 2.4.1. Part 1: Identifying barriers and enablers to circular industrialised housing

Barriers and enablers to CIH were categorised using grounded theory and inductive reasoning (Wolfswinkel et al., 2013). An inductive approach was chosen to ensure a comprehensive understanding of themes emerging from the literature without biases. Thematic analysis involved a three-step process: identifying broad factors, grouped into common themes, and refining sub-themes, which were revised iteratively amongst the authors until saturation was reached.

A summary of key characteristics at the beginning of the results (Chapter 3) provides a high-level literature overview through text and charts. Publication trends by year are shown in a bar chart, geographical context in a pie chart, and article characteristics in a second bar chart

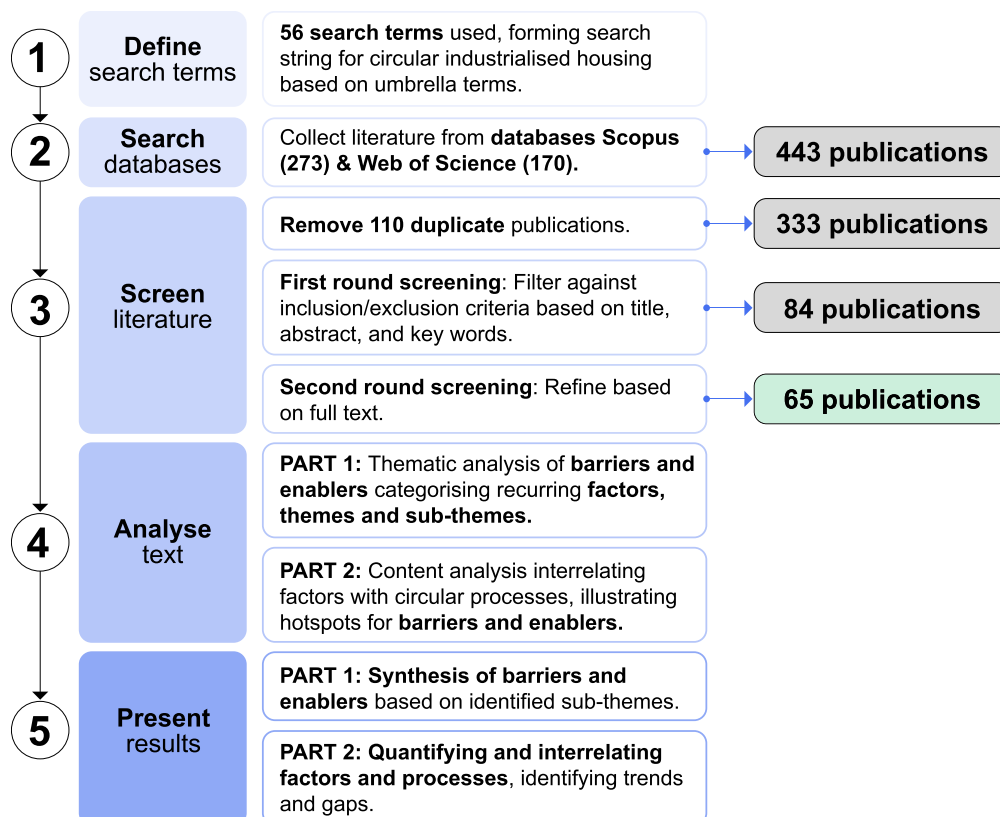


Fig. 1. Methodology overview and PRISMA method.

covering: article focus (IC and/or DfD/reuse), housing type (social/affordable/general), building typology, structural material, project scope (whole/partial building), strategy (new-build/existing building), and case study type (built/unbuilt/survey). Detailed information about the 65 publications, including the overview data and sub-themes mentioned by each publication is provided in the supplementary information.

2.4.2. Part 2: Relating identified sub-themes to circular processes

The identification of recurrent themes is important. However, there is a need to relate these sub-themes to specific actions required for circular housing, here referred to as circular processes. Four circular processes were identified that encompass all activities during the lifecycle, which could re-occur at any stage. These are: (re)planning, (re)designing, (re)manufacturing, and (dis)assembly.

Following Part 1 analysis, content analysis quantified the frequency of barriers and enablers within each article based on predefined processes and emergent factors. This approach revealed factor-process relationships, showing the depth of information provided for each sub-theme, identifying when critical barriers and enablers occur, and highlighting trends and knowledge gaps. Coding analysis was conducted using Atlas.ti software (version 23.1.1). Each excerpt received four codes: process, factor, sub-theme, and classification as barrier and/or enabler.

Results appear in Part 2 of Chapter 3, visualised through a Sankey diagram and bar chart. The intersection of lifecycle processes with emergent factors forms a framework, presented in Chapter 4, that is enriched with sub-theme information to provide visual hot-spotting of the interrelated barriers, enablers and gaps within the studied literature.

3. Findings

The final set of 65 publications comprised 39 journal articles, 21

conference proceedings, and five book chapters, spanning from 2007 to April 2025, as documented in the supplementary information. The volume of relevant literature has increased over time, with a marked rise in 2025, which produced the highest number of publications to date (9), as shown in Fig. 2. This number is likely to grow as the year progresses. The quality of output has also improved, as reflected by the increasing prevalence of journal articles over conference papers.

The reviewed literature spans eight distinct regions (Fig. 3), over half of which are from Europe (55%). Per country, China contributed the most studies, followed by Canada, Spain, and Germany. The UK, Italy, and Australia also feature prominently. Recent South-East Asian contributions emerged from Indonesia and Thailand, whilst studies from Africa, South America and South Asia remain limited. No studies were identified from the Middle East or Central Asia.

Most studies focussed primarily on IC, with overall less attention to DfD and reuse (Fig. 4). The majority examined general housing in the private market rather than social or affordable housing.

In terms of typology, mid- and low-rise buildings and single-family dwellings were most considered. Tall and highrise residential buildings, defined as over 9 and 18 storeys respectively (Michalak & Michalak, 2024), were rarely considered. Concrete was the most frequently studied structural material, followed by timber and steel, although numerous studies compared different materials and hybrid systems. Brick masonry appeared occasionally, typically in relation to retrofit. Most studies considered whole building systems rather than individual components. Although the focus was largely on new-build, as opposed to existing buildings, many of these were prototype design projects. An increasing number of studies explored DfD and reuse through built examples that were dismantled or relocated, though these were detached from real-world contexts or constraints. Only six studies included interviews or surveys with designers or contractors, overall providing limited-yet valuable-empirical insights from industry.

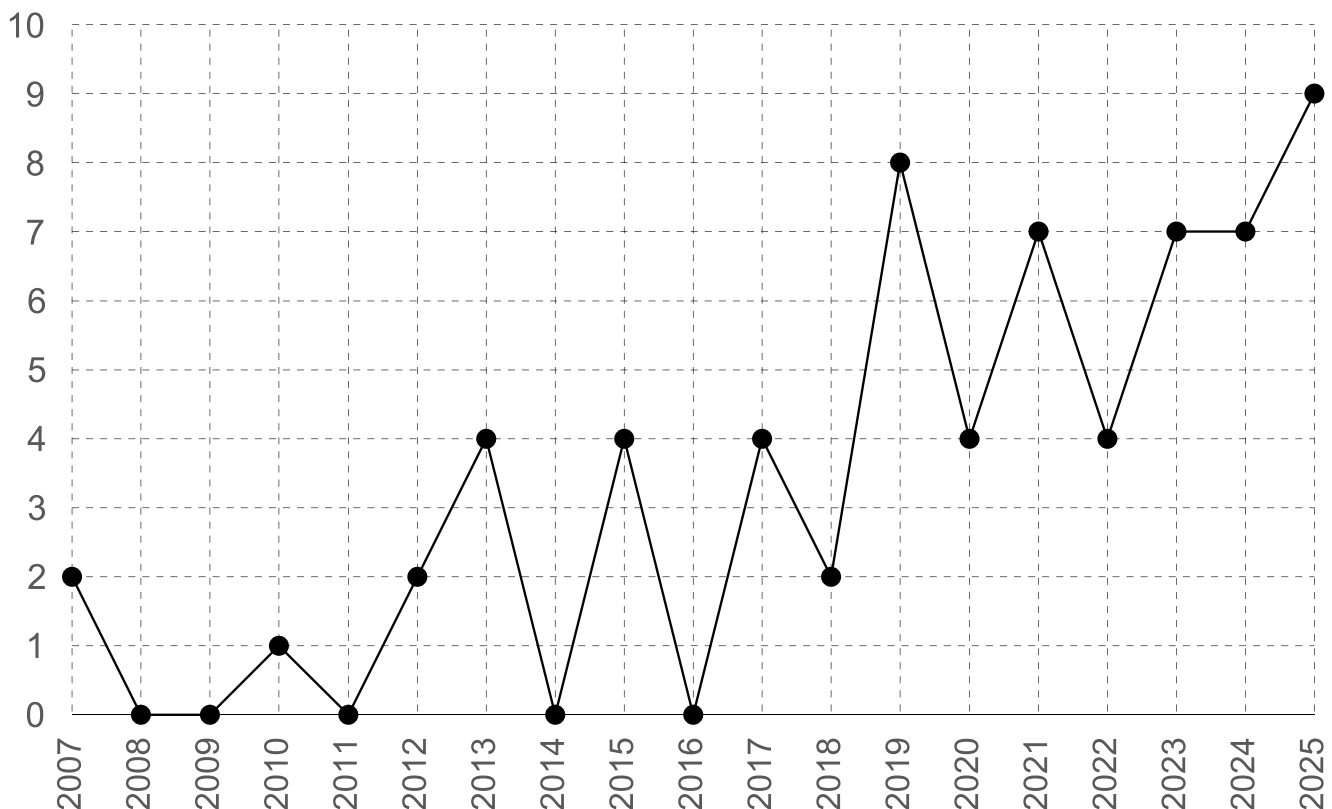


Fig. 2. Distribution of 65 publications across 2007 to April 2025.

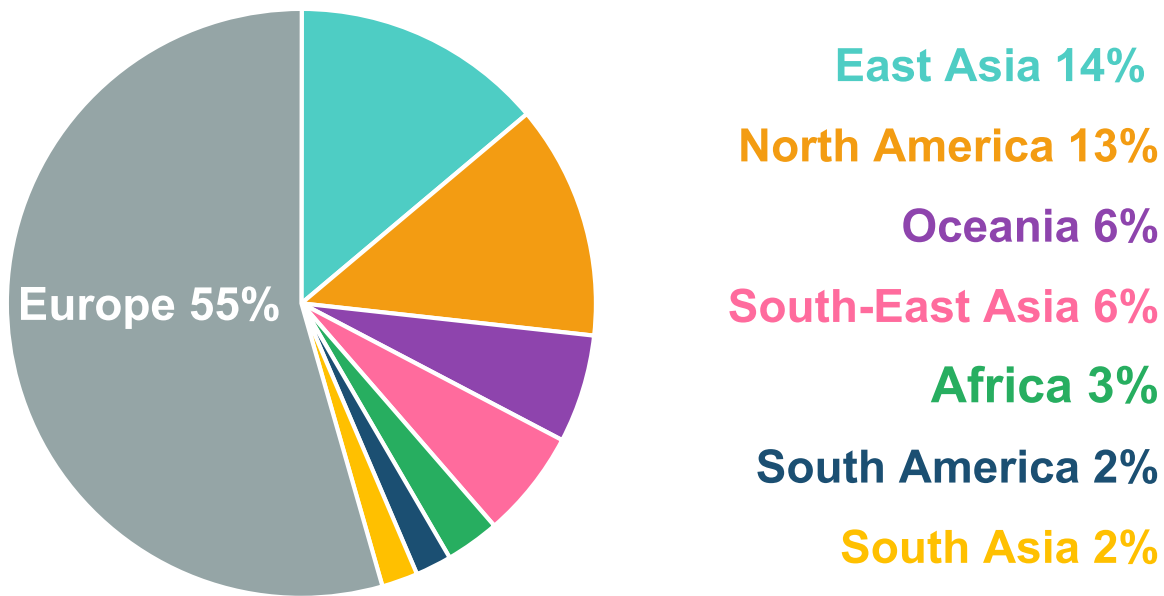


Fig. 3. Overview of geographical context within the 65 analysed publications.

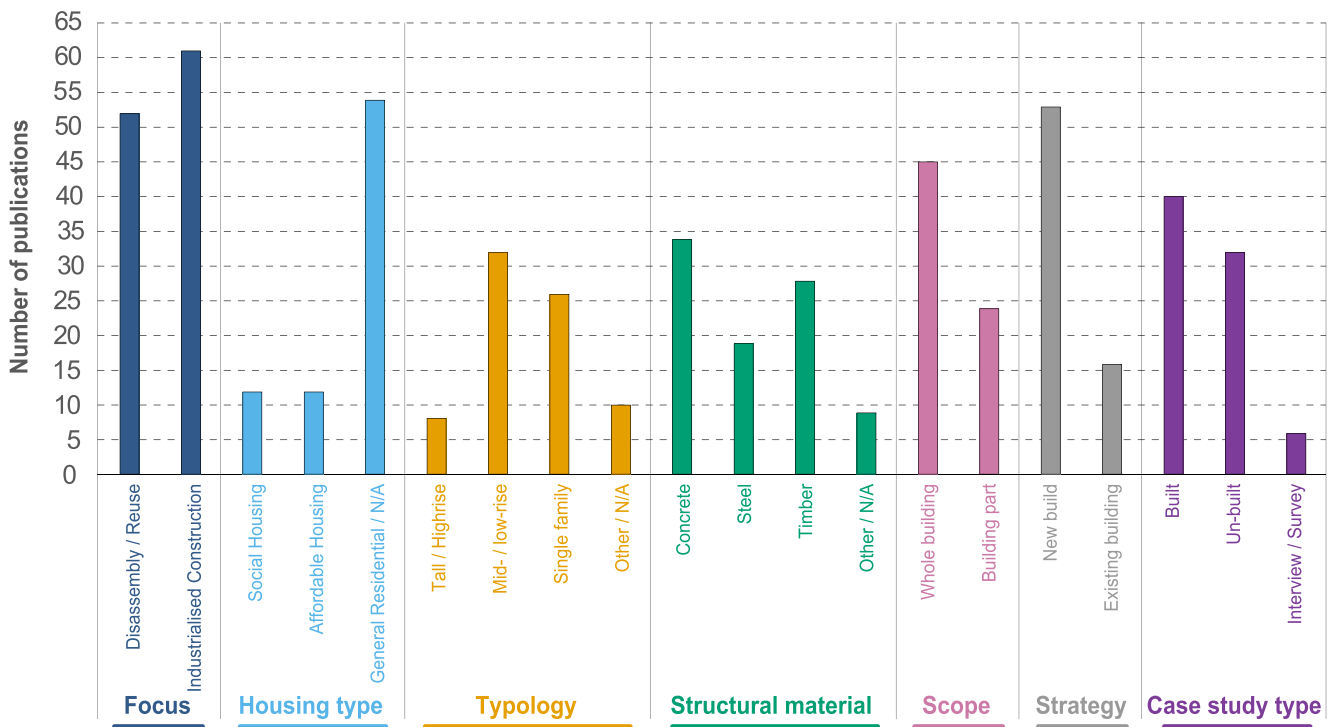


Fig. 4. Overview of content within the 65 analysed publications.

3.1. Part 1: Thematic analysis synthesis

Thematic analysis of the selected literature identified six broad factors: (1) cultural, (2) governance, (3) financial, (4) site and logistics, (5) construction system, and (6) building information. Cultural, governance, and financial factors represent ‘non-technical’, intangible dimensions influencing CIH, while site and logistics, the construction system, and building information are considered ‘technical’. These factors organise 15 recurring themes and 36 emergent sub-themes, listed in Table 1. This is followed by synthesis of each sub-theme; readers may use this information to delve deeper into areas of interest and gain a

comprehensive understanding of the analysed literature before Part 2 of the results. Supplementary inventory information lists which publication addressed each theme and sub-theme.

3.1.1. Cultural

Refers to behavioural and value-based aspects shaping how housing is designed, constructed, inhabited, and deconstructed. These are influenced by information and awareness, as well as socially accepted norms or practices amongst stakeholders and residents.

3.1.1.1. (1A) Knowledge & Skills. Limited industry understanding of

**Table 1**  
Categorised recurring factors, themes, and sub-themes with descriptions.

Factor	Theme	Sub-theme	Description
Cultural	(1A) Knowledge	Theoretical Concepts	Knowledge of broad concepts
		Knowledge Sharing	Collaboration and knowledge exchange
	(1B) Values	Cultural Norms	Currently accepted practices
Priorities		Conflicting aims and trade-offs	
Governance	(2A) Regulation	Product Regulation	Regulation at the product level
		Building Regulation	Regulation at the build level
		Land Regulation	Restrictions and requirements for land use
	(2B) Policy	Policy Initiatives	Policies promoting certain practices
		Subsidies	Government-funded incentives
		Taxes	Government-enforced disincentives
(2C) Legal	Ownership	Building and product owners	
	Procurement	Acquiring construction services and materials	
Financial	(3A) Costs	Material Costs	Building materials costs
		Labour Costs	Design and construction labour costs
		Factory Costs	Factory set-up and production costs
	(3B) Financial Strategies	Business Models	Whole lifecycle approach to financing
		Housing Models	Structure determining access and tenure types
Site & Logistics	(4A) Logistics	Transport	Restrictions caused by vehicle types and infrastructure
		Supply Chains	Delivery of materials and building parts
	(4B) Site Conditions	Storage	Material storage either on- or off-site
		Ground Conditions	Coordination between site and construction system
		Weather	Impacting weather conditions
Construction System	(5A) Design	Theoretical Design	Design concepts informing spatial design
		Technical Design	Technical design and construction information
		Materiality	Types of building materials used
	(5B) Production	Connections	Connections at the product level
		Supporting Equipment	Specialist machinery used off- and on-site
		Industrialised Approach	Building in parts from components to 3D modules
(5C) Building Performance & Energy	Testing & Quality Control	Previous testing of assembly performance	
Building Information	(6A) Data Collection	Energy Strategies	Passive and low in-use demand for energy
		Auditing	First-hand building information
	(6B) Data Storage	Archived Data	Second-hand building information
		Digitalisation	Digitalisation of building information

**Table 1 (continued)**

Factor	Theme	Sub-theme	Description
		Information Type	Detailed material and building information
	(6C) Data Analysis	Assessments & Simulations	Quantified environmental and financial impacts
		Strategic Delivery	Strategic dismantling and logistics planning

key **theoretical concepts** such as 'disassembly' and 'sustainability', presents a major challenge in advancing CIH (Atta et al., 2021, Wadel & Cuchí, 2007). Earlier academic research often conflated 'recycling' (downcycling) with 'reuse' (Asam, 2007, Spisakova & Kozlovská, 2013). Earlier concepts and foundational frameworks such as 'Green Building', the '3Rs', 'Cradle-to-Cradle', redefining 'waste' as 'mis-allocated resources', and the 'Waste Hierarchy' paved the way for CIH today (Kuri & Leardini, 2022, Buehler et al., 2025, Lehmann, 2013), although continued use of the term 'waste' is problematic. A growing body of academic literature has since expanded to consider embodied carbon and resource-efficiency, with the 'R-Ladder', '9 Planetary Boundaries', 'Doughnut Economics' and a 'Lifecycle Approach' as prevalent theory driving circularity in industrialised housing (Buehler et al., 2025, Lehmann, 2013, Keena & Friedman, 2023, Arisya & Suryantini, 2021). However, stakeholder awareness of circularity, remains limited (Xie et al., 2023), partly due to insufficient lifecycle guidance (Atta et al., 2021) and is only beginning to gain traction in retrofit practices (Nigumann et al., 2024). Progress is hindered by limited interdisciplinary research, particularly in DfD for adaptable housing (Kuri & Leardini, 2022), and skills gaps, particularly in digitalisation (Kirschke & Sietko, 2021).

**Knowledge sharing** remains a key challenge due to unclear stakeholder roles and poor cross-field communication (Kedir et al., 2023, Pan et al., 2020). Responsibility for coordinating circular industrialised processes is debated between government bodies, housing developers (Xie et al., 2023), and off-site contractors (Hei et al., 2024). Early, sustained collaboration between designers and off-site manufacturers is deemed essential (Jaillon & Poon, 2010, Young et al., 2015), supporting continuous learning and a product approach. Digitalisation increasingly facilitates knowledge sharing (Atta et al., 2021, Ullah et al., 2024), but raises confidentiality concerns (Xie et al., 2023, Yildirim, 2013). Misconceptions around natural materials such as timber further hinder knowledge exchange (Lehmann, 2013). Historically, knowledge sharing was often also limited by publications in local languages and was largely confined to designers and contractors (Jaillon & Poon, 2010, Huuhka et al., 2015). Contrastingly, current research is more international and interdisciplinary, involving actors across the building lifecycle (Hei et al., 2024, Pichlmeier & Lindner, 2024). Contemporary studies provide greater attention to knowledge sharing during (dis)assembly (Pichlmeier & Lindner, 2024, Hei et al., 2024), with built pilot projects testing disassembly and reuse or relocation further promoting CIH and gaining post-occupancy data (Buehler et al., 2025, Lehmann, 2013, Bras et al., 2020, Padilla-Rivera et al., 2018). Recent projects involve residents, providing manuals to adjust or partially disassemble layouts, extending learning beyond assembly (Djukanovic et al., 2025, Dubina et al., 2025). Previous studies recommend design seminars to share findings (Asam, 2007), whereas recent publications call for wider changes to professional training (Hei et al., 2024).

**3.1.1.2. (1B) Values.** Several authors contend housing providers consider sustainability a low **priority** compared to short-term financial gains, with demolition sometimes used to control social mix (Jaillon & Poon, 2010, Huuhka et al., 2015, Huuhka et al., 2019). Commitment from asset owners is widely regarded as essential to advancing circular practices in housing, and particularly in social housing (Hei et al., 2024,

Huuhka et al., 2019, Kuusk et al., 2021). Disassembly is often considered by practitioners as the “least important” aspect of IC (Jaillon & Poon, 2010), while academia has traditionally focussed on monumental buildings, often overlooking the value of ‘ordinary buildings’ such as housing (Sung-Hwa & Beisi, 2012). Despite growing awareness of sustainability issues, business models remain consumer-centric, prioritising profit and speed (Nigumann et al., 2024). This can have detrimental effects, as demonstrated in Finland, where overuse of the BES system resulted in poor-quality, monotonous dwellings (Huuhka et al., 2019). Alternative frameworks incorporating social value are suggested to prioritise holistic practices (Archila et al., 2023). Material reuse is dependent upon DfD being an early-stage priority; case studies demonstrate that outcomes vary according to the clarity of initial developer objectives and care taken by demolition contractors (Pichlmeier & Lindner, 2024). IC is proven to help prioritise residents by minimising disturbance during retrofit and reducing energy and building maintenance costs (Gubert et al., 2023). These co-benefits can help unlock the wider adoption of CIH.

**Cultural norms** often conflict with disassembly, IC and circular approaches in housing generally. Negative perceptions of ‘disassemble-able’ housing persist (Kedir et al., 2023), particularly in private and affordable markets, alongside limited end-user involvement in new and existing buildings (Djukanovic et al., 2025, Scuderi, 2019). Rising demand for larger homes and increased reliance on air-conditioning, driven in part by global warming, intensifies the need for circular solutions (Keena & Friedman, 2023). Lingering associations with poor-quality post-war prefab housing in Europe and aversion to timber construction in regions including Australia and the USA further hinder acceptance (Lehmann, 2013, Kirschke & Sietko, 2021, Tavares et al., 2025). Despite the proven environmental and social benefits of holistic lifecycle thinking, the construction industry’s conservative, risk-averse nature challenges the integration of low-carbon materials and digitalisation (Atta et al., 2021, Buehler et al., 2025, Kedir et al., 2023, Day et al., 2019), while ‘knock-down-rebuild’ remains standard practice (Kuiri & Leardini, 2022, Vega, 2015, Whittaker et al., 2021). Nevertheless, industrialised processes, including digitalisation, have been reshaping traditional stakeholder roles and responsible decision-making (Hei et al., 2024, Jaillon and Poon, 2010, Ullah et al., 2024). Middle- to higher-income homeowners could be attracted by mass-customisation options, pushing adoption of disassembly and adaptability (Djukanovic et al., 2025). Deconstruction remains challenging in practice where demolition is the norm, often resulting in material damage (Hei et al., 2024). Cultural change can be facilitated through tools such as ‘serious games’ (Archila et al., 2023), public education (Lehmann, 2013), and long-term planning approaches (Scuderi, 2019). Xie et al. (2023) suggest that norms may naturally shift towards circular, industrialised approaches as existing technologies prove inadequate.

### 3.1.2. Governance

Encompasses policies, regulations, legal considerations and institutional frameworks guiding housing lifecycle decision-making. This involves governmental and regulatory bodies from the international to national, regional and local levels.

**3.1.2.1. (2A) Regulation. Product regulations** supporting resource-efficiency through reuse, such as the EU Construction Products Regulation, continues to have limited impact (Nigumann et al., 2024). International standards supporting recycling—notably a downcycling route—are also restricted in some cases. For example, recycled material content is capped at certain percentages in structural elements (Huuhka et al., 2015, Kuusk et al., 2021). Whittaker et al. (2021) highlight these limits may cause significant waste when downcycled materials are oversupplied. Extended Producer Responsibility schemes are identified as a key enabler for housing circularity at the product level, yet remain underapplied (Lehmann, 2013). The RE4 project addressed these

challenges by classifying Construction and Demolition Waste (CDW) to facilitate inclusion in structural design norms and building codes (Grigoriadis et al., 2019). Studies utilise lifespan assumptions based on ISO standards and where applicable, public housing bodies provide national regulation for component lifespans, such as the German Federal Housing Ministry, aiding designers with LCA and EoL considerations (Pichlmeier & Lindner, 2024).

**Building regulations** currently fail to adequately support circular and IC practices, particularly regarding material reuse (Xie et al., 2023). Legal classification of entire buildings as ‘waste’ under demolition permits often prohibits reuse (Asam, 2007, Huuhka et al., 2019). Building parts from CDW must comply with various national and European codes, adding complexity (Whittaker et al., 2021). Safety regulations favour demolition over disassembly due to increased worker risks, especially in Germany (Asam, 2007). Technical barriers arise when salvaged elements must meet new building standards in acoustic, thermal and structural performance (Huuhka et al., 2015, Pichlmeier & Lindner, 2024, Huuhka et al., 2019). For example, Huuhka et al. (2015) found in 90 % of cases, use of 265 mm hollow-core floors was prohibited in apartment buildings but allowed in terraced housing, limiting reuse potential in typical social housing typologies. Emerging technologies face further barriers due to inflexible or outdated regulations (Tavares et al., 2025, Rennen et al., 2021), while current codes inadequately address holistic lifecycle impacts (Bras et al., 2020). Enablers include adaptable, performance-based codes (Kedir et al., 2023), standardised codes such as European Norms (Lehmann, 2013, Yildirim, 2013, Vega, 2015), wider permission for CLT in highrise buildings as in Singapore (Day et al., 2019), and improved standardisation of industrialised systems within regulations, with Denmark as an exemplar (Liu & Zhang, 2017).

**Land regulation** presents challenges and opportunities for sustainable urban development in addressing ‘waste’ and promoting circular housing, though it receives limited attention in the literature. Urban spatial constraints can encourage CIH and infill site development (Lehmann, 2013, Jaillon & Poon, 2010). Land regulation can boost the IC market share among housing providers, as demonstrated in Chongqing, China, where the local government designated land specifically for industrialised housing (Xie et al., 2023). Temporary land holdings in Spain and North America support disassemble-able industrialised systems, providing affordable city-centre housing (Wadel & Cuchí, 2007, Albright et al., 2021). Wider land-use constraints in forestry heavily impact timber use and establishing local supply chains (Tienthavorn, 2024).

**3.1.2.2. (2B) Policy.** Global **policy initiatives** play a critical role in advancing CIH, particularly in developing regions. While initiatives such as the UN’s Agenda 2030 and the Paris Agreement provide broad direction (Kedir et al., 2023, Archila et al., 2023), they remain largely aspirational unless enforced through building regulations and context-specific frameworks, which are either lacking or under development (Larasati et al., 2023). The EU Green Deal, which aims to be CO<sub>2</sub> neutral by 2050, drives various European initiatives (Gubert et al., 2023), notably the Waste Hierarchy and a 70 % recovery target for CDW (Atta et al., 2021, Asam, 2007, Kedir et al., 2023, Whittaker et al., 2021, Androsevic et al., 2019). This benchmark inspired numerous projects within the last decade (Huuhka et al., 2015, Kuusk et al., 2021, Whittaker et al., 2021, Grigoriadis et al., 2019, Klinge et al., 2019). Energy-efficiency policies increasingly consider lifecycle impacts, supporting a growing trend in material reuse and industrialised (deep) retrofit projects, namely, the revised Energy Performance of Buildings Directive (EPBD) and the Renovation Wave strategy (Nigumann et al., 2024, Gubert et al., 2023). Some scholars warn energy-efficiency policies may undermine embodied carbon considerations and increase demolition of underperforming housing (Nigumann et al., 2024, Huuhka et al., 2019, Kuusk et al., 2021). National initiatives in Asia, such as in

China, Malaysia and Indonesia, continue to focus on boosting industrialised housing through mandates and quotas, rather than disassembly and reuse (Xie et al., 2023, Larasati et al., 2023, Balasbaneh & Ramli, 2020). Government-initiated architectural competitions, and the New European Bauhaus, are increasingly considered essential for advancing circular industrialised multi-family housing (Kirschke & Sietko, 2021, Djukanovic et al., 2025). Scholars consistently emphasise the need for policy prioritising lifecycle carbon impacts (Lehmann, 2013), which is increasingly adopted into national policy frameworks through carbon benchmarking and LCA (Keena & Friedman, 2023).

**Subsidies** are mentioned as a key enabler for IC and housing circularity, helping overcome housing providers' reluctance towards unfamiliar methods (Asam, 2007, Kedir et al., 2023, Jaillon & Poon, 2010, Huuhka et al., 2019), but were not explored in depth. Subsidies should support local companies producing carbon-sequestering materials to reduce embodied emissions (Kedir et al., 2023). Loan interest discounts for companies, developers, and homeowners adopting IC are also recommended (Xie et al., 2023, Kirschke & Sietko, 2021). Notably, subsidy discontinuation has harmed pioneering reuse projects (Huuhka et al., 2019), and despite existing subsidies, traditional construction still dominates (Xie et al., 2023). This indicates that continued, targeted financial support is critical for wider CIH adoption.

**Taxes** show promise as an enabler, though under-explored in the literature. Government influence through taxation could exempt IC housing developments, or impose demolition charges (Jaillon & Poon, 2010, Wen et al., 2024). Klinge et al. (2019) suggest increasing disposal, transport, and raw materials costs to address the prioritisation of profit over environmental impacts. However, taxes alone have generally proven ineffective in deterring conventional construction practices in favour of industrialised methods (Xie et al., 2023).

**3.1.2.3. (2C) Legal.** Housing ownership presented a significant barrier to affordability. In Huuhka et al.'s (2019) comparison case study, public land and materials were sold to private developers to enable disassembly and reuse, yet measures to ensure affordability for existing residents and avoid demolition were lacking. Similarly, poorly designed and maintained municipal housing can lead to tenant loss and reduced council income, as evidenced in Raahe, Finland (Huuhka et al., 2019). Current ownership models frequently conflict with circular principles. Theoretically, manufacturers should retain ownership to ensure responsible maintenance of housing assets. Wadel & Cuchí (2007) attempted to apply this ownership model in student housing, but the client rejected the proposal. Whilst there is no guarantee that CIH will remain affordable or be sustainably maintained, this challenge is particularly complex where multiple or individual ownership structures exist (Silva et al., 2020).

**Procurement** has only recently emerged within the reviewed literature, with contributions appearing in the past two years, despite being critical in real-world construction and demolition practices. Short-term or temporary contracts have been shown to cause compounding delays, particularly when specialised teams are required for tasks such as disassembly (Hei et al., 2024). Public procurement is increasingly recognised for improving transparency, particularly in material pricing, facilitating design decisions, EoL scenarios, and reducing reliance on assumptions (Gubert et al., 2023).

### 3.1.3. Financial

Financial aspects relate to housing affordability and the economic side of the CE. These encompass costs and financial strategies, which consider circular business models and structures for housing tenure.

**3.1.3.1. (3A) Costs.** Material cost implications for CIH show contradictory findings. Material costs decreased in small-scale projects using harvested materials from donor buildings rather than demolition and new construction (Asam, 2007, Huuhka et al., 2015, Huuhka et al.,

2019). Huuhka et al. (2019) report that deconstructed panels in Gothenburg were in fact "as good as new ones, but only one-third of their price". Conversely, remanufactured and bio-based materials are often more expensive than virgin and high embodied-carbon alternatives, perpetuating demolition and concrete use (Wadel & Cuchí, 2007, Archila et al., 2023, Tienthavorn, 2024, Li et al., 2023). Cost calculations are complex when considering transport and EoL options; lightweight materials with higher upfront costs, such as steel, may prove more cost-effective in the long-term compared to concrete (Balasbaneh & Ramli, 2020). While circular IC offers promising cost savings (Li et al., 2023), conventional products continue to dominate the market, as novel designs incorporating IC and DfD create cost uncertainties (Kedir et al., 2023). Materials costs are optimised during design and manufacturing by integrating affordable standard sized products (Panzini & Quadrato, 2022) and proprietary products (Kirschke & Sietko, 2021, Huuhka et al., 2015). Long-term savings through materials can emerge when circular strategies stipulating component removability and durability are embedded from (re)planning onwards (Jaillon & Poon, 2010). Material considerations also include transport costs, which are particularly high for 3D modular elements (Gubert et al., 2023).

High labour costs significantly increase CIH expenses, mainly due to disassembly (Huuhka et al., 2015), despite potential material recovery savings and reduced on-site labour (Kuiiri & Leardini, 2022, Pan et al., 2020, Djukanovic et al., 2025, Kern et al., 2018). Although BIM shows promise for reducing design, manufacturing, and disassembly labour in the future (Kirschke & Sietko, 2021, Hei et al., 2024), unconventional methods currently increase design labour, while disassembly remains particularly labour-intensive (Nigumann et al., 2024, Jaillon & Poon, 2010, Gubert et al., 2023). Early research advocates for high-quality design to incentivise material salvaging and preservation, as with heritage buildings (Asam, 2007). While IC could reduce manufacturing labour costs, this depends on contractors' experience and equipment (Jaillon & Poon, 2010). Similarly, housing developers remain reluctant to engage with comparatively expensive off-site contractors (Kedir et al., 2023). Recent research explores incorporating robotics to address skilled labour shortages, improve production quality, safety, and wages for low- to semi-skilled workers (Xie et al., 2023, Kedir et al., 2023, Pan et al., 2020). Further reductions are achievable through local, specialised manufacturing labour (Sung-Hwa & Beisi, 2012) and parallel assembly/disassembly methods (Silva et al., 2020). Recent studies highlight the growing potential for large-scale disassembly and reuse to overcome high labour costs and compete with virgin material use (Nigumann et al., 2024, Li et al., 2023).

High factory costs present a significant barrier for manufacturers. Despite potential cost savings, IC requires high capital investment (Djukanovic et al., 2025, Gubert et al., 2023), though costs could be limited by integrating a BIM methodology (Ullah et al., 2024). Recent studies assume 70 % of factory costs are determined during design, affecting the viability of (re)manufacturing and disassembly (Xie et al., 2023, Pan et al., 2020). The degree of industrialisation influences production costs, with Kedir et al. (2023) finding partially industrialised systems more expensive than conventional ones, reducing their attractiveness to off-site housing companies. Upfront investment in equipment is financially risky and only viable when economies of scale can be achieved (Jaillon & Poon, 2010, Young et al., 2015, Archila et al., 2023, Day et al., 2019). Hence, despite the benefits of robotics and factory reconfiguration to accommodate local and low-embodied materials, many companies avoid such high-cost investments (Bras et al., 2020, Silva et al., 2020, Vujović et al., 2017, Navarro-Rubio et al., 2019). The 'Modern Flying Factory' model offers flexible temporary off-site production but faces reconfiguration challenges (Young et al., 2015). Huuhka et al. (2015) note comparable production costs between social and private sector housing, potentially encouraging manufacturers to target larger social housing contracts or smaller high-end projects, though bespoke designs increase costs (Jaillon and Poon, 2010).

3.1.3.2. (3B) *Financial strategies.* CIH **business models** face return on investment challenges. There are mixed findings as to whether IC is cheaper compared to traditional construction; however, whole lifecycle assessments demonstrate circular IC can provide financial benefits if effectively implemented (Gubert et al., 2023, Tavares et al., 2025). Competition between component manufacturers and main contractors presents further barriers (Xie et al., 2023). Improved cost prediction through standardised systems under controlled factory conditions, coupled with a Life Cycle Cost (LCC) approach, can make CIH particularly attractive to social and affordable housing developers in new and existing buildings (Atta et al., 2021, Nigumann et al., 2024, Larasati et al., 2023). LCC supports both off-site contractors and housing providers to balance upfront cost against future investment gains (Gubert et al., 2023, Balasbaneh & Ramli, 2020, Navarro-Rubio et al., 2019). Enabling strategies include expanding mature Scandinavian IC housing companies to other EU countries (Kirschke & Sietko, 2021) and developing eco-industrial parks to harness resource streams (Wadel & Cuchi, 2007). Product-as-a-Service models, Take-Back schemes, Sharing Economy models, and revenue gained from selling building parts are suggested as viable solutions supporting reuse of either components or whole units but are not tested within the literature (Wadel & Cuchi, 2007, Keena & Friedman, 2023, Pichlmeier & Lindner, 2024, Gubert et al., 2023, Klinge et al., 2019, Li et al., 2023). Encouragingly, recent research finds housing renovation consistently more cost-effective compared to demolition and new-build (Huuhka et al., 2019, Panzini & Quadrato, 2022).

CIH is suitable for various **housing models**, with greater affordability and sustainability potential in social and affordable housing (Kirschke & Sietko, 2021). Despite this, the literature remains heavily focussed on private market or general housing. In the social housing sector, IC faces challenges due to limited sales revenue to offset costs (Xie et al., 2023). Standardised prefabricated extensions present cost-effective solutions for upgrading existing dense highrise social housing with ample green space, as demonstrated by Lacaton & Vassal's *Grand Ensembles* project, improving lower-income residents' quality of life (Panzini & Quadrato, 2022), although such approaches can overlook future disassembly and reuse. IC and DfD underpin a growing trend in 'incremental housing' aimed at low- and middle-income households particularly in developing countries, designed to facilitate affordable, gradual extensions (Kuri & Leardini, 2022, Djukanovic et al., 2025, Viriezky et al., 2025, Friedman, 2025). Similarly, scholars explore IC's role within the tiny homes' movement to "gain a balance in housing price-to-household earnings ratio" (Keena & Friedman, 2023, Tienthavorn, 2024), as private market house prices continue to rise. Huuhka et al. (2019) highlight how deconstruction and reuse projects have affected housing models differently, causing gentrification. In Germany, former social housing sold to private owners caused displacement, while other projects increased rents beyond the original residents' means. The authors note difficulties implementing disassembly and reuse in depopulating cities despite available social housing donor buildings due to insufficient rental income (Huuhka et al., 2019). This underexplored issue may pose greater risks in developed countries with aging populations.

#### 3.1.4. Site and logistics

Refer to the conditions and activities outside of the construction system itself, such as management and transport of materials, equipment, and labour between extraction, manufacturing, assembly, and storage sites. Site conditions include constraints or features, such as ground and weather considerations.

3.1.4.1. (4A) *Logistics.* **Transport** constraints influence design and environmental impacts, limiting dimensions and weight. Jaillon & Poon (2010) and Whittaker et al. (2021) emphasise dimensioning to standard lorry sizes to avoid increased time and costs associated with transporting

larger 3D volumetric elements. Asam (2007) highlights strategically cutting elements that were not designed for disassembly to sizes that avoid the need for oversized vehicles, which require additional licencing. Dense urban contexts further complicate prefabrication, with narrow sites limiting vehicle size and access (Jaillon & Poon, 2010, Li et al., 2023). These challenges are especially relevant to social and affordable housing, which are typically located in compact sites and historic neighbourhoods (Kirschke & Sietko, 2021). Scholars discuss transport damage prevention, such as vertical stacking strategies and vibration considerations, although these are not the focus of research (Asam, 2007, Huuhka et al., 2019, Bui et al., 2022).

Streamlining **supply chain** ecosystems is critical for CIH, receiving greater attention within the last three years. Currently, logistics mismanagement and fragmented supply chains cause unnecessary costs, delays, and material loss (Atta et al., 2021, Kedir et al., 2023). Insufficient timber supply chains present barriers to using carbon-sequestering materials across various countries, including Australia (Lehmann, 2013). However, scholars increasingly consider supply chain impacts, cautioning against overreliance on imported 'sustainable' products, citing higher transport emissions and reduced local investment (Keena & Friedman, 2023, Kedir et al., 2023). Recent discourse emphasises ethical and responsible production management, particularly in the forestry sector (Michalak & Michalak, 2024, Tienthavorn, 2024). Xie et al. (2023) suggest government intervention to address these challenges. Social housing particularly benefits from circular supply chains using materials from donor buildings and second-hand markets (Asam, 2007), though these remain underdeveloped, lack standardisation, storage facilities, and market acceptance (Klinge et al., 2019). Scholars reflect on how IC and DfD have supported resource-efficiency and alleviated material shortages throughout history, particularly during periods of war (Sung-Hwa & Beisi, 2012), with improved efficiency through Just-In-Time (JIT) production (Asam, 2007, Lehmann, 2013, Pan et al., 2020, Hei et al., 2024, Jaillon & Poon, 2010). While disassembly creates new opportunities for second-hand material markets (Hei et al., 2024), unpredictable availability of second-life materials creates new challenges. For example, design compromises arose in the KREIS-Haus project when the windows arrived late (Buehler et al., 2025).

3.1.4.2. (4B) *Site Conditions.* **Storage** during disassembly is vital for EoL planning within housing (Andreosevic et al., 2019), receiving greater attention in recent literature. On-site storage is often limited yet essential for JIT delivery during disassembly (Hei et al., 2024). Buildings under deconstruction can serve as temporary storage, though this is constrained by safe dead-load limits (Atta et al., 2021). Post-disassembly, materials require controlled storage conditions for preservation before remanufacturing (Spisakova & Kozlovskaya, 2013), ideally located close to the main (dis)assembly site to minimise transport impacts (Wen et al., 2024). While IC can offer advantages for space-constrained sites, limited storage capacity for reclaimed materials poses a significant challenge as reuse markets develop (Lehmann, 2013, Klinge et al., 2019). Imbalances between supply and demand, alongside disassembly complexity, create knock-on storage challenges during (re) manufacturing (Young et al., 2015). One solution is repurposing components into temporary buildings for interim use, providing functional storage solutions for materials recovered from deconstructed structures (Pichlmeier & Lindner, 2024).

**Ground conditions**, often overlooked, prove integral to IC design and delivery, with additional structural advantages in seismic zones (Djukanovic et al., 2025, Dubina et al., 2025, Albright et al., 2021, Viriezky et al., 2025, Zhong, 2013). Localised studies and customisation are required to optimise site-specific opportunities whilst adapting to soil conditions, topography, and existing structures (Jaillon and Poon, 2010, Whittaker et al., 2021, Silva et al., 2020). In Bergsjön, Sweden, prefabricated housing designed for flat sites created detrimental access issues when placed on a sloped site, demonstrating the importance of

early ground-condition assessments during (re)planning (Huuhka et al., 2019). Additional challenges emerge when designing for atypical sites, such as non-parallel street plots (Kirschke & Sietko, 2021). While temporary factories offer certain benefits, they require suitable secondary sites in near proximity to the assembly site to maximise controlled off-site construction benefits (Young et al., 2015). No studies explored reuse of excavated or site-clearing materials from the construction terrain itself.

Industrialised housing provides significant advantages in avoiding adverse **weather** conditions, with construction typically taking place within factory settings. Climate variations limit the suitability of standardised circular industrialised systems across weather regions (Dubina et al., 2025). Reusing existing housing highlights the importance of designing for durability to enhance reuse potential and prevent humidity-related degradation (Jaillon & Poon, 2010, Huuhka et al., 2015). Hence, exterior elements such as outer walls and balconies require particular design attention to enhance longevity (Asam, 2007). Additionally, caution is advised against prefabricated reinforced concrete, which is prone to structural degradation from air and moisture exposure through carbonation and corrosion (Huuhka et al., 2015).

### 3.1.5. Construction system

Constitutes the physical building system and all its constituent parts, referring to its design, production, and building performance. The type of construction system is crucial for housing circularity, facilitating the systematic disassembly and reuse of materials.

**3.1.5.1. (5A) Design.** The studied literature overwhelmingly focusses on **theoretical design** approaches as opposed to all other sub-themes, centring on standardisation to leverage mass production and economies of scale (Wadel & Cuchí, 2007, Jaillon & Poon, 2010). Post-war social housing illustrates this potential but often compromised design quality (Jaillon & Poon, 2010, Huuhka et al., 2019, Whittaker et al., 2021, Silva et al., 2020). Modern rules-based design enhances affordability whilst accommodating customisation (Kirschke & Sietko, 2021, Djukanovic et al., 2025). However, studies reveal tensions between standardisation and flexibility, particularly in the private sector, where customisation is favoured and prefabrication is generally unpopular (Kirschke & Sietko, 2021, Jaillon & Poon, 2010, Young et al., 2015). IC and DfD have long supported adaptable housing, particularly in Asia, where the standardised Japanese 'Tatami' mat and Korean 'Kan' unit optimised (re)manufacturing (Kuiiri & Leardini, 2022, Arisya & Suryantini, 2021). 'Lean Construction' remains integral, improving resource-efficiency using a product-based approach (Pan et al., 2020, Hei et al., 2024). Studies advocate for 'Kit-of-Parts' (Pan et al., 2020) and layered approaches, drawing on Brand's 'Shearing Layers' and Habraken's 'Open Building', which continue to guide industry practice (Asam, 2007, Kuiiri & Leardini, 2022, Buehler et al., 2025, Lehmann, 2013, Pan et al., 2020, Jaillon & Poon, 2010, Androsevic et al., 2019, Friedman, 2025, Bertolazzi et al., 2023). Typologies help identify opportunities, such as horizontal or vertical extensions and urban infill solutions (Huuhka et al., 2019, Li et al., 2023, Panzini & Quadrato, 2022). Recent literature expands resource-efficiency design concepts to include 'Material Banks' and 'mining' existing materials (Kuiiri & Leardini, 2022, Pichlmeier & Lindner, 2024, Silva et al., 2020, Friedman, 2025, Al-Najjar et al., 2025). Designing with predetermined component lifespans, explored by Whittaker et al. (2021), remains compelling but difficult to validate long-term.

**Technical design** demands highly resolved detailing for manufacturing (Huuhka et al., 2019, Day et al., 2019). Downsizing and reusing existing buildings has been tested, particularly with post-war concrete prefabricated housing, though expertise to scientifically assess reuse potential is lacking (Asam, 2007, Huuhka et al., 2019). As reuse in existing buildings gains priority, technical issues persist (Nigumann et al., 2024, Scuderi, 2019). Load-bearing elements are more

difficult to disassemble and damage can render them unusable (Spisakova & Kozlovská, 2013, Huuhka et al., 2015, Lupíšek et al., 2015), while building parts with specific technical requirements are difficult to reuse (Arisya & Suryantini, 2021). Errors in (re) manufacturing, such as miscalculated thicknesses, are difficult to correct (Young et al., 2015), and even minor tolerance variations can create disassembly issues (Youssef et al., 2019). Crucially, changes in upstream design and manufacturing processes exacerbate future downstream inefficiencies (Day et al., 2019). Strategies explored to enhance disassembly, reuse and adaptability include separating services (Pan et al., 2020, Silva et al., 2020), column-based layouts (Djukanovic et al., 2025, Klinge et al., 2019), double-height spaces, floating floors (Youssef et al., 2019), converting components for alternative uses (e.g. floor slabs into walls or roofs), and improving durability (Asam, 2007, Huuhka et al., 2015, Klinge et al., 2019, Navarro-Rubio et al., 2019). Cleaning and sandblasting offer simple, effective methods for remanufacturing (Nigumann et al., 2024). Structural elements, such as load-bearing walls, floor slabs, external walls, stairways, and landings prove particularly suitable for reuse (Spisakova & Kozlovská, 2013, Wen et al., 2024).

**Materiality** is crucial for minimising environmental impacts. Studies compare structural materials including prefabricated concrete, steel, and timber, although hybrid systems are common in practice. Despite numerous downsides to concrete, much of the IC advancements are attributed to prefabricated reinforced concrete (Kirschke & Sietko, 2021), which continues to dominate the literature, followed by timber and steel. The concrete industry has historically prioritised downcycling (Asam, 2007) and is generally more challenging to disassemble and reuse compared to timber or steel (Pan et al., 2020, Wen et al., 2024). Recent research explores strategies to reduce concrete's environmental impact (Kirschke and Sietko, 2021, Bras et al., 2020, Djukanovic et al., 2025, Bui et al., 2022). Steel on the other hand, offers both high reuse (and recyclability when necessary) and is suitable across building types, including highrise structures (Kedir et al., 2023, Yildirim, 2013, Balasbaneh & Ramli, 2020, Wen et al., 2024). Steel reuse through the upcycling of shipping containers has been explored in housing across early and recent studies (Wadel and Cuchí, 2007, Tavares et al., 2025). Timber, valued for its renewability, carbon sequestration and lightweight properties (Kuiiri & Leardini, 2022, Lehmann, 2013, Keena & Friedman, 2023, Li et al., 2023) is increasingly used in highrise construction using engineered products such as CLT and GLT (Michalak & Michalak, 2024). Studies explore the advantages of mature, salvaged timber though metal impurities complicate processing (Michalak & Michalak, 2024, Klinge et al., 2019, Li et al., 2023). The literature explores hybrid structures, commonly concrete with steel, while timber is often combined with concrete or steel to meet performance requirements (Dubina et al., 2025). The latest studies based in northern and western Europe, North America, and Australia prioritise timber in CIH, while prefabricated concrete continues to dominate in southern Europe, such as Portugal (Djukanovic et al., 2025), and developing regions. Overall, timber and steel surpass concrete in reducing environmental impacts (Wadel and Cuchí, 2007, Whittaker et al., 2021, Aye et al., 2012), while reusing concrete from existing building stock remains vital for circularity (Asam, 2007, Huuhka et al., 2015, Huuhka et al., 2019, Bertolazzi et al., 2023).

Reversible, dry **connections** are essential for future disassembly and reuse, which must support both the initial assembly and future component replacement or adaptations (Rennen et al., 2021, Albright et al., 2021). Disassembly often leads to material loss, particularly with cement joints (Asam, 2007, Huuhka et al., 2015), and may require cutting to specific lengths (Klinge et al., 2019). In-situ concrete connections should therefore be avoided (Kedir et al., 2023, Jaillon and Poon, 2010, Pichlmeier and Lindner, 2024). Although standardised connections exist in systems such as the Swedish Ingeböck or Finnish BES, they remain under-explored in housing. Even so, disassembly and reuse are still possible when connections were not originally designed

for deconstruction, which is especially relevant for existing stock (Huuhka et al., 2019). Steel-based mechanical connections dominate the literature due to their climatic adaptability and compatibility with timber and concrete (Lehmann, 2013, Yildirim, 2013, Navarro-Rubio et al., 2019). Certain steel connection types, such as bolted and hooked joints, prove advantageous for disassembly (Huuhka et al., 2019, Silva et al., 2020), whereas welded joints typically fail during disassembly (Asam, 2007). Traditional timber carpenter joints promote mono-materiality and reuse across multiple lifecycles (Sung-Hwa and Beisi, 2012, Albright et al., 2021, Tienthavorn, 2024, Klinge et al., 2019), although using nails remain common in timber balloon frame construction (Torres et al., 2025). Emerging solutions include 3D-printed joints, threaded rods, click systems, and Velcro (Pan et al., 2020, Youssef et al., 2019). Recent studies distinguish intra-component, inter-component, and foundation-module connection types (Li et al., 2023, Torres et al., 2025).

**3.1.5.2. (5B) Production.** Modern **supporting equipment** enhances production efficiency, worker safety, and precision, particularly during (re)manufacturing (Xie et al., 2023). While factory-based IC often uses heavy-duty equipment in industry, CNC machines offer an accessible form of precision manufacturing, widely used in academic research (Lehmann, 2013, Rennen et al., 2021, Albright et al., 2021). During on-site assembly, IC typically requires less on-site equipment compared to traditional methods, using working platforms or cranes and minimal scaffolding (Gubert et al., 2023). Robotics show promise in automating (re)manufacturing and (dis)assembly tasks through 3D printing and robotic arms (Pan et al., 2020, Vujović et al., 2017). However, various barriers persist, including difficulties in automating material separation, costly installation for assembly equipment onto existing buildings, and challenges lifting heavy elements (Pan et al., 2020, Rennen et al., 2021, Klinge et al., 2019). Bespoke lifting and remanufacturing tools, as used in the RE4 project, can increase material reuse rates (Grigoriadis et al., 2019, Wen et al., 2024), although such technologies, particularly for 3D printing or timber processing, are often unavailable in developing regions (Tienthavorn, 2024, Viriezky et al., 2025). Regardless of context, disassembly remains predominantly manual, frequently involving basic hand-held tools (Pichlmeier & Lindner, 2024). Scholars such as Day et al. (2019) highlight positive early robotics advancements in Japan and promise for industry ventures, however, the subsequent 2021 bankruptcy of prominent startup Kattera suggests caution regarding technology maturation for CIH.

The **industrialised approach** to manufacturing encompasses framing systems, 2D panels, and 3D volumetric elements. Some authors distinguish between levels of prefabrication, categorising systems as ‘full IC’ or ‘partial IC’, though conclusions on the sustainability of partial IC vary (Kedir et al., 2023, Padilla-Rivera et al., 2018, Navarro-Rubio et al., 2019, Viriezky et al., 2025). Truly ‘full IC’ remains limited, as interior finishes typically require in-situ construction (Bui et al., 2022). 3D volumetric systems aid (dis)assembly although few built examples within the literature demonstrate their disassembly and reuse, unlike 2D panelled or hybrid systems (Huuhka et al., 2019, Viriezky et al., 2025). Furthermore, volumetric construction may counter resource-efficiency goals due to additional materials required for doubling of the structure (Albright et al., 2021). Hybrid systems, typically combining 2D and volumetric elements, are common and increase reuse potential, although they may add to disassembly complexity (Arisya and Suryantini, 2021, Wen et al., 2024). Industrialised approaches extend to on-site 3D printing, however, in Rennen et al.’s (2021) study, 3D printed concrete was prefabricated off-site, resulting in significant weight-related transport emissions.

**3.1.5.3. (5C) Building performance & energy. Testing and quality control** can advance both IC and reuse to ensure compliance with regulations, supported by factory settings to enhance quality assurance for

systems using new and second-life materials. Full-scale mock-ups are valuable for evaluating options before large-scale production, particularly for customised housing, though these remain uncommon (Jaillon & Poon, 2010, Bras et al., 2020). Testing is crucial to detect contaminants and meet structural integrity requirements during remanufacturing, yet current methods are inefficient, resulting in unnecessary material loss sent to landfill (Spisakova & Kozlovska, 2013, Huuhka et al., 2019, Whittaker et al., 2021, Klinge et al., 2019). Invasive tests cause damage, and inspections require additional time for laboratory analysis (Kuusk et al., 2021, Klinge et al., 2019). Clear routes for integrating testing into early (re)planning processes or addressing re-warranting as standard practice and governance frameworks were absent in the literature.

**Energy strategies** are an increasingly important consideration within CIH, complementing resource-efficiency to reduce overall energy consumption, predominantly during production and use. Numerous trade-offs are discussed. For example, sourcing cleaner fuels for manufacturing and transport is encouraged alongside reuse (Buehler et al., 2025, Padilla-Rivera et al., 2018), however, long-distance material relocation increases emissions (Hei et al., 2024). Similarly, precision manufacturing can improve energy-efficiency through passive design (Lupšek et al., 2015), contributing to nearly Zero-Energy Buildings while reducing energy costs for residents (Lehmann, 2013, Nigumann et al., 2024, Kirschke & Sietko, 2021), yet such strategies require more materials for thicker envelopes and shading devices (Pichlmeier & Lindner, 2024, Bras et al., 2020) and older buildings typically require additional materials and technical upgrades (Nigumann et al., 2024, Pichlmeier and Lindner, 2024). As Wen et al. (2024) note, improvements in energy-efficiency continue to shift greater focus towards limiting embodied emissions. Nonetheless, balancing these trade-offs remains challenging, particularly as embodied carbon is still largely unregulated compared to operational energy.

### 3.1.6. Building information

Refers to data collection, storage, and analysis. The information captures material quantities, properties, geometry, and sustainability impacts. It is increasingly digitalised and utilises ‘smart’ technologies.

**3.1.6.1. (6A) Data Collection. Auditing** is essential for maximising reuse and reducing material loss, particularly in the absence of material passports. However, limited empirical research restricts understanding of auditing practices. Pre-demolition audits identify materials and construction systems necessary for strategic deconstruction, involving coding and physically marking components and materials (Pichlmeier & Lindner, 2024, Klinge et al., 2019). Recent studies highlight technologies such as laser scanning to extract physical and geometric data from existing buildings (Atta et al., 2021, Pan et al., 2020). Auditing methods within the literature focus on identifying common components, such as wall panels and floor slabs, to improve reuse likelihood (Huuhka et al., 2015). Nonetheless, specialist auditing equipment and on-site inspections remain necessary for assessing hygrothermal performance, humidity, and thermal bridging, especially for timber, though these processes are time-consuming and require expertise (Nigumann et al., 2024, Huuhka et al., 2015, Kuusk et al., 2021, Whittaker et al., 2021), hindering widespread adoption in industry. Maintaining current, accurate building information remains challenging due to undocumented alterations and the absence of mandatory auditing protocols (Bras et al., 2020).

**Archived data** serves as a valuable secondary information resource for existing buildings. In Finland, Huuhka et al. (2015) utilised architectural drawings and photographs to evaluate reuse potential, with similar approaches reported internationally. In Poland, archival records supported research on IC technologies within state-led affordable housing initiatives while in Germany, federal housing projects also drew on archival sources (Kirschke and Sietko, 2021). In Italy, the Nested Building project used archived data to establish standardised building

typologies (Bertolazzi et al., 2023). In the USA, detailed archival documentation enabled analysis of experimental projects incorporating IC and DfD, including the Loblolly House and Cellophane House by Kieran and Timberlake (Arisya & Suryantini, 2021). Despite these examples, archived data remains limited, is not consistently digitalised, and must be complemented by physical inspections for comprehensive building audits (Pichlmeier & Lindner, 2024, Tienthavorn, 2024).

**3.1.6.2. (6B) Data Storage.** Within the last decade, **digitalisation** has been widely recognised as a powerful enabler for advancements in circular and industrialised construction, with BIM, and more recently, material passports, capturing technical properties and supporting reuse evaluations (Atta et al., 2021, Lehmann, 2013, Ullah et al., 2024, Archila et al., 2023). Integration with gaming software and smart tools can enhance decision-making processes (Archila et al., 2023), while QR codes offer a promising, accessible method for optimising (dis)assembly, enabling on-site access via smartphones (Buehler et al., 2025, Hei et al., 2024). Digital predictive tools, Artificial Intelligence, parametric modelling, augmented reality, and automated LCA offer opportunities to reduce embodied impacts and improve lifecycle processes (Ullah et al., 2024, Archila et al., 2023, Day et al., 2019, Androsevic et al., 2019, Navarro-Rubio et al., 2019). Barriers include discrepancies between 'Digital Twins' and physical construction systems (Rennen et al., 2021), functional features of digital tools require better integration with IC methods, and new concerns are raised over cybersecurity (Ullah et al., 2024). Despite widespread recognition of digital tools, their integration into IC remains fragmented, with low maturity even in advanced contexts such as Scandinavia (Hei et al., 2024).

**Information type** plays a critical role in developing material passports and maturing second-hand markets, yet often neglects explicit indicators for disassembly and reuse potential (Atta et al., 2021). Collecting comprehensive data remains challenging, with recent studies recommending inclusion of socio-economic factors and visual 3D information (Balasbaneh and Ramli, 2020, Navarro-Rubio et al., 2019). Data sources include Environmental Product Declarations (EPDs) from suppliers (Archila et al., 2023, Androsevic et al., 2019) and exact Bills of Materials (BoM) from contractors (Hei et al., 2024, Wen et al., 2024). However, accurate, up-to-date data remains scarce, with EPDs for second-life products rarely available and contractor BoMs often inaccessible, forcing researchers to use generic datasets such asecoinvent (Pichlmeier and Lindner, 2024, Padilla-Rivera et al., 2018, Gubert et al., 2023, Wen et al., 2024). EoL predictions, site logistics, and cost calculations often rely on assumptions due to limited real-world data (Nigumann et al., 2024, Wen et al., 2024). While in-use data from CIH prototypes is particularly scarce, 'living labs' offer potential to provide improve long-term insights (Buehler et al., 2025).

**3.1.6.3. (6C) Data analysis. Assessments and simulations,** particularly LCA, are widely used to quantitatively compare options such as industrialised versus traditional construction, material choices, and multiple use cycles (Kedir et al., 2023, Pan et al., 2020, Ullah et al., 2024, Aye et al., 2012). However, conventional LCA methods often lack compatibility with disassembly and circularity (Atta et al., 2021). Studies typically adopt a standard, limited reference period of 50 years (Gubert et al., 2023) and rarely consider reuse potential (Hei et al., 2024), partially due to challenges in carbon accounting (Wen et al., 2024). Despite LCA's growing industry influence (Androsevic et al., 2019), integration with LCC and policy support remains limited (Balasbaneh and Ramli, 2020). Recent studies attempt to assess disassembly processes and transformation capacity (Hei et al., 2024). In practice, sustainability assessments and simulations integrate IC and DfD to varying degrees over the years, though generally with little effectiveness. In Hong Kong, (non-mandatory) housing authority assessments recommended integrating DfD with IC two decades ago but implementation was minimal (Jaillon & Poon, 2010). Circular

construction and EoL considerations remain limited in mainstream certifications such as LEED and BREEAM (Androsevic et al., 2019). Notably, recent industry-adopted indices focussing on DfD and reuse, such as the Dutch Alba Concepts Building Circularity Index, are being applied in academic research (Nigumann et al., 2024).

**Strategic delivery** requires integrating deconstruction plans early in (re)planning and (re)designing processes to enable controlled, demolition-free disassembly (Asam, 2007, Spisakova & Kozlovskaja, 2013, Hei et al., 2024, Klinge et al., 2019). 'Reverse delivery' strategies can improve safety, efficiency, and labour upskilling during disassembly, however, stakeholders often lack tools to support reverse logistics and EoL options (Atta et al., 2021). Computational algorithms help optimise disassembly sequences, though these must be tailored to specific construction systems and contexts (Spisakova & Kozlovskaja, 2013, Ullah et al., 2024, Zhong, 2013). Storage constraints during (re) manufacturing and (dis)assembly also highlight the value of predictive sequencing (Young et al., 2015). Selective deconstruction strategies yield the highest recovery rates (Navarro-Rubio et al., 2019) but standardising dismantling remains difficult due to varied construction systems (Klinge et al., 2019). Few studies document real-world disassembly, and the common assumption that disassembly mirrors assembly remains untested within the studied literature (Pichlmeier & Lindner, 2024, Wen et al., 2024).

### 3.2. Part 2: Quantifying and interrelating factors with processes

Part 1 synthesises the barriers and enablers to CIH, which were presented as emergent sub-themes, categorised into six holistic factors: cultural, governance, financial, site and logistics, construction system, and building information.

Part 2 of the study uses a quantitative approach to investigate the frequency with which these factors and associated sub-themes occurred within the 65 analysed publications, and reveal their interrelationship with four predefined circular processes. These are: (re)planning, (re) designing, (re)manufacturing, and (dis)assembly (Fig. 5).

Results of the coding exercise and frequency analysis, illustrated in Fig. 6, reveal the interrelationship between factors (left) with circular processes (right). Barriers and enablers were most frequently related to the (re)designing process (55 %), followed by (re)manufacturing (20 %), and (re)planning (13 %), while (dis)assembly processes received the least attention (12 %). This suggests insufficient application of a circular lifecycle approach to industrialised housing, which requires a long-term vision and application of disassembly and reuse. This correlates with the lack of disassembly literature highlighted in Chapter 1.

Approximately half of the literature reviewed focussed on the construction system, followed by building information, financial, cultural, and governance factors, with the least attention given to site and logistics. The strongest interrelationship identified was between the construction system and the (re)designing process, while the weakest was between governance and (dis)assembly. Multiple mentions were included in the analysis, reflecting the depth of discussion for each factor and sub-theme across the 65 publications.

Fig. 7 presents a breakdown of the four processes by factor, along with the number of associated barriers and enablers. This highlights the clear emphasis on the construction system and (re)designing process, with a disproportionate focus on enablers. Such an imbalance suggests a predominantly theoretical approach to CIH within the academic discourse, where barriers are insufficiently identified and explored. Detailed results are included in the supplementary information.

Delving deeper into the analysis, Fig. 8 presents the framework developed through this systematic analysis, integrating four lifecycle processes with six emergent factors and 36 sub-themes. It provides a granular breakdown of how frequently the identified barriers and enablers occur across the 65 analysed publications, indicating their connection as 'exceptionally strong', 'strong', 'moderate', 'weak', or 'data gaps' within each process. The full analysis breakdown is included

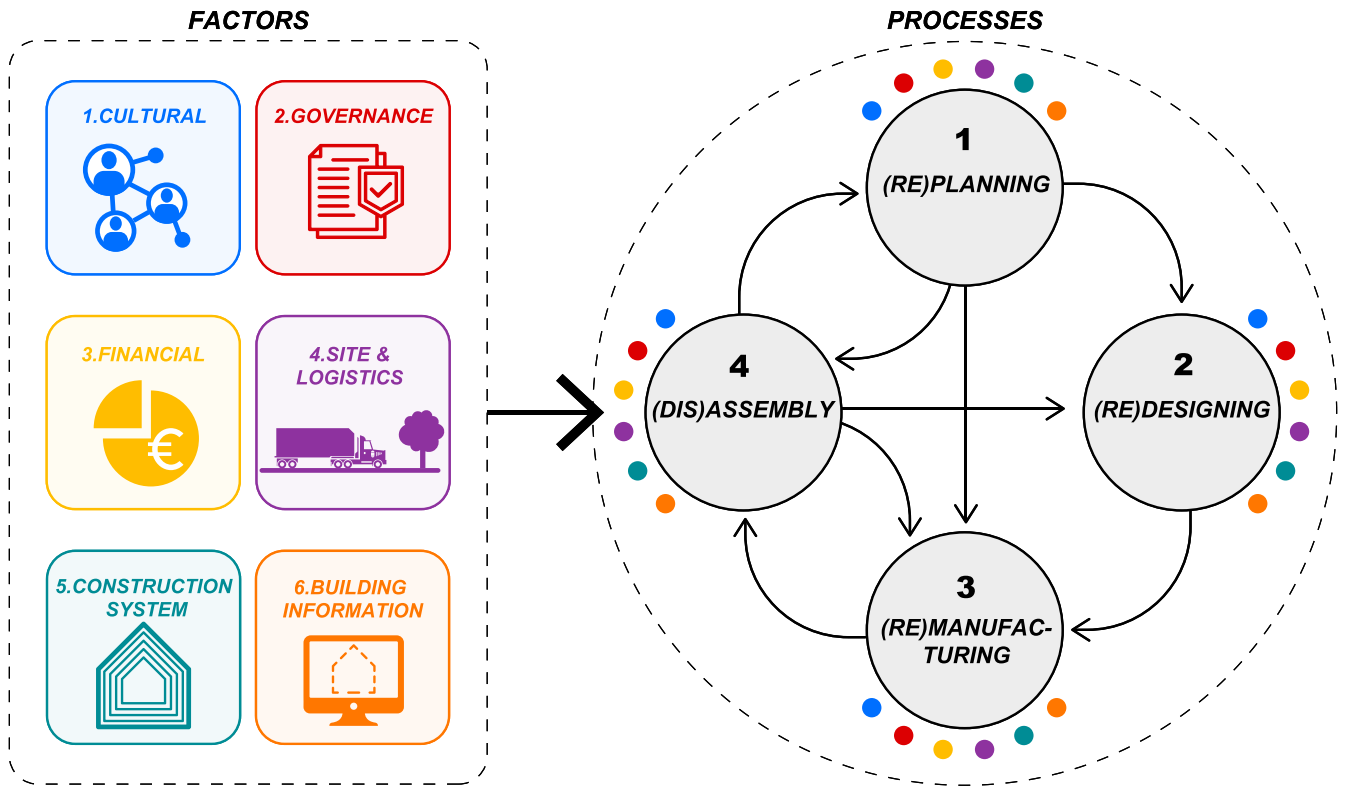


Fig. 5. Framework relates six emergent factors with four lifecycle processes.

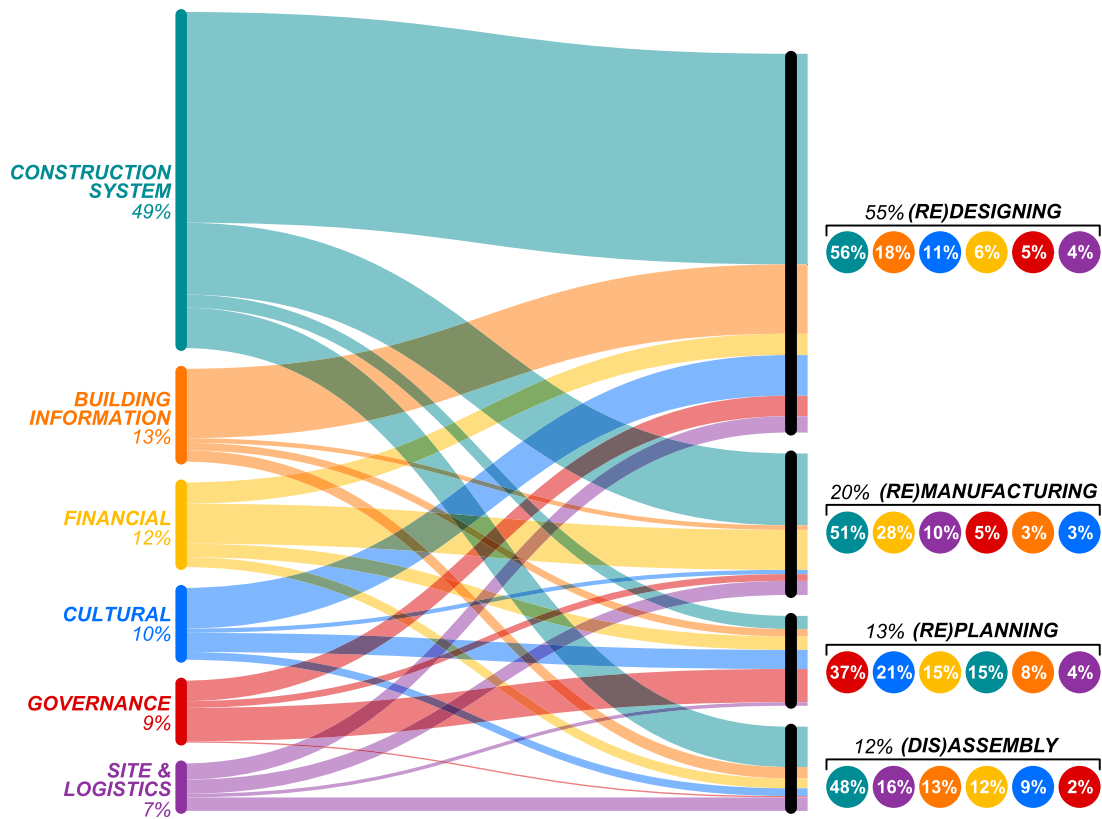


Fig. 6. Relationship between circular processes and recurring factors.

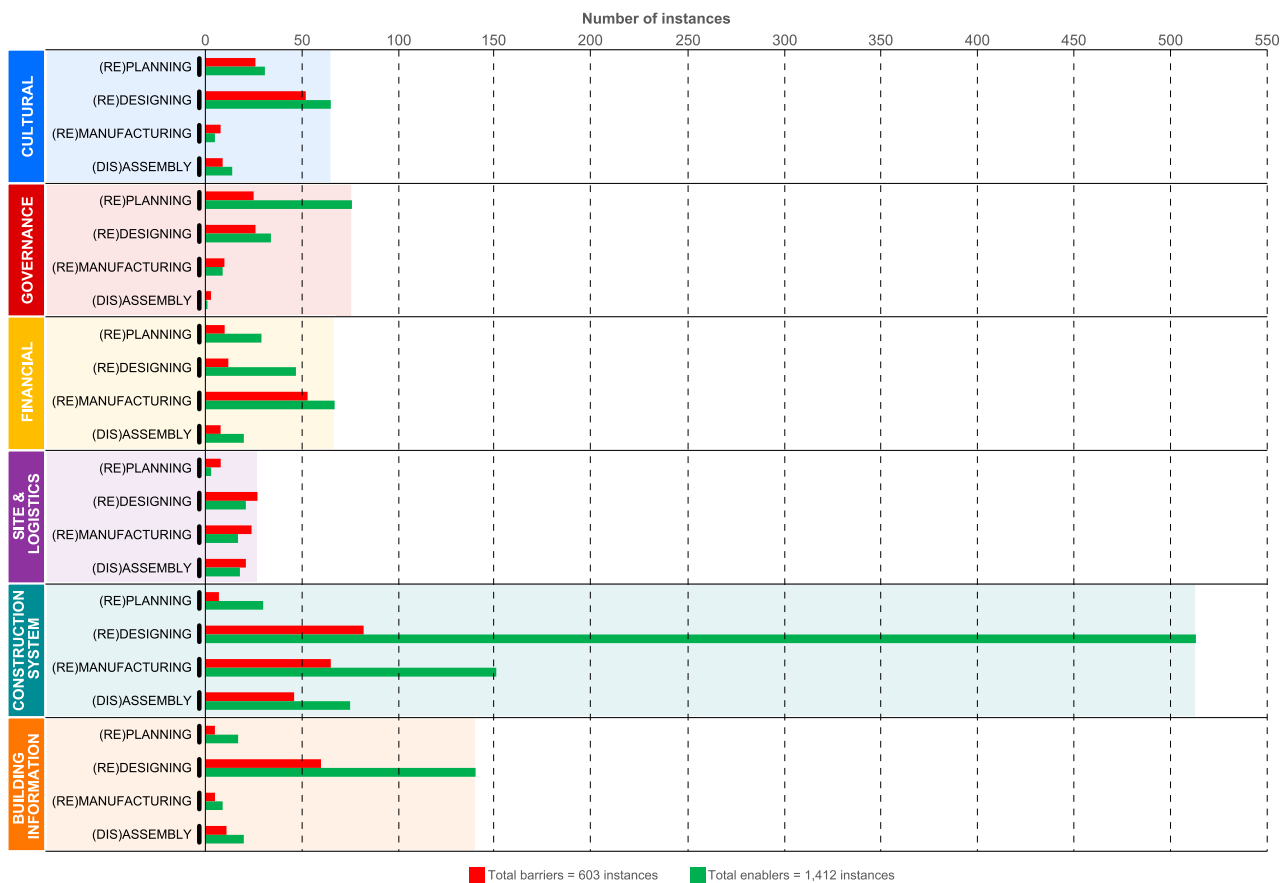


Fig. 7. Results bar-chart-breakdown of barriers and enablers across processes and factors.

in the supplementary information.

### 3.2.1. (Re)planning

(Re)planning refers to the early, non-spatial stages that define the project brief and business case, typically before the design team is appointed. This process was most influenced by governance and cultural factors. Policy support for disassembly and reuse was the strongest enabler, while prevailing cultural norms such as demolition acceptance and residents' resistance to disassembly acted as key barriers. These attitudes are beginning to shift as awareness of CIH grows, particularly among asset owners and support through local or national policy. Although housing and business models were discussed, there was limited expertise and few financial strategies aligning affordability with environmental goals or to prevent gentrification. Building information and site and logistics factors were rarely addressed, despite the importance of considering data collection and site conditions in the business case. The numerous gaps in site and logistics and governance are considered critical during (re)planning.

### 3.2.2. (Re)designing

(Re)designing involves developing conceptual and technical information to produce geometry and material specifications, significantly influencing other circular processes. Greatest attention is given to construction system enablers, particularly the technical design, materials, connections, and overwhelmingly on theoretical design. Building information was also a major focus, with studies highlighting the benefits of digitalisation, particularly BIM, and assessments such as LCA. Although limited, pilot projects involving both new and existing buildings demonstrated the technical feasibility of CIH, including opportunities to redesign post-war prefabricated concrete housing. Cultural factors pointed to industry resistance to IC and DfD, although there are

improvements to knowledge sharing. Governance, such as building regulations, and financial factors were often poorly aligned. Industrialised and circular design was commonly viewed as expensive and risky for housing developers, with demolition remaining a more attractive option. The largest gaps were found in governance and notably, procurement.

### 3.2.3. (Re)manufacturing

(Re)manufacturing encompasses material and component processing, primarily under off-site factory conditions in CIH. This aims to restore materials to sufficient quality for reintroduction into the supply chain, while meeting legal and performance requirements. The analysis reveals supporting equipment, testing and quality control, and materiality in particular, were hotspots for research. While several studies explored remanufacturing reclaimed materials and components, investigation remained detached from industry. Constraints such as scalability issues, regulatory challenges (e.g. re-warranting), and high remanufacturing costs were not sufficiently addressed. Building information and cultural factors overall showed weak relationships with (re) manufacturing, while governance factors were largely neglected.

### 3.2.4. (Dis)assembly

(Dis)assembly involves the removal and transportation of elements for remanufacturing to enable replacement, adaptations, or full dismantling at EoL. Disassembled parts can be reassembled to provide new or adapted housing, as demonstrated by several case studies. The analysis reveals underdeveloped disassembly processes and limited documentation of practical applications in social, affordable, and private market housing. Most barriers and enablers relate to the construction system, with supporting equipment being the most notable enabler. However, research on robotics and automation for reverse

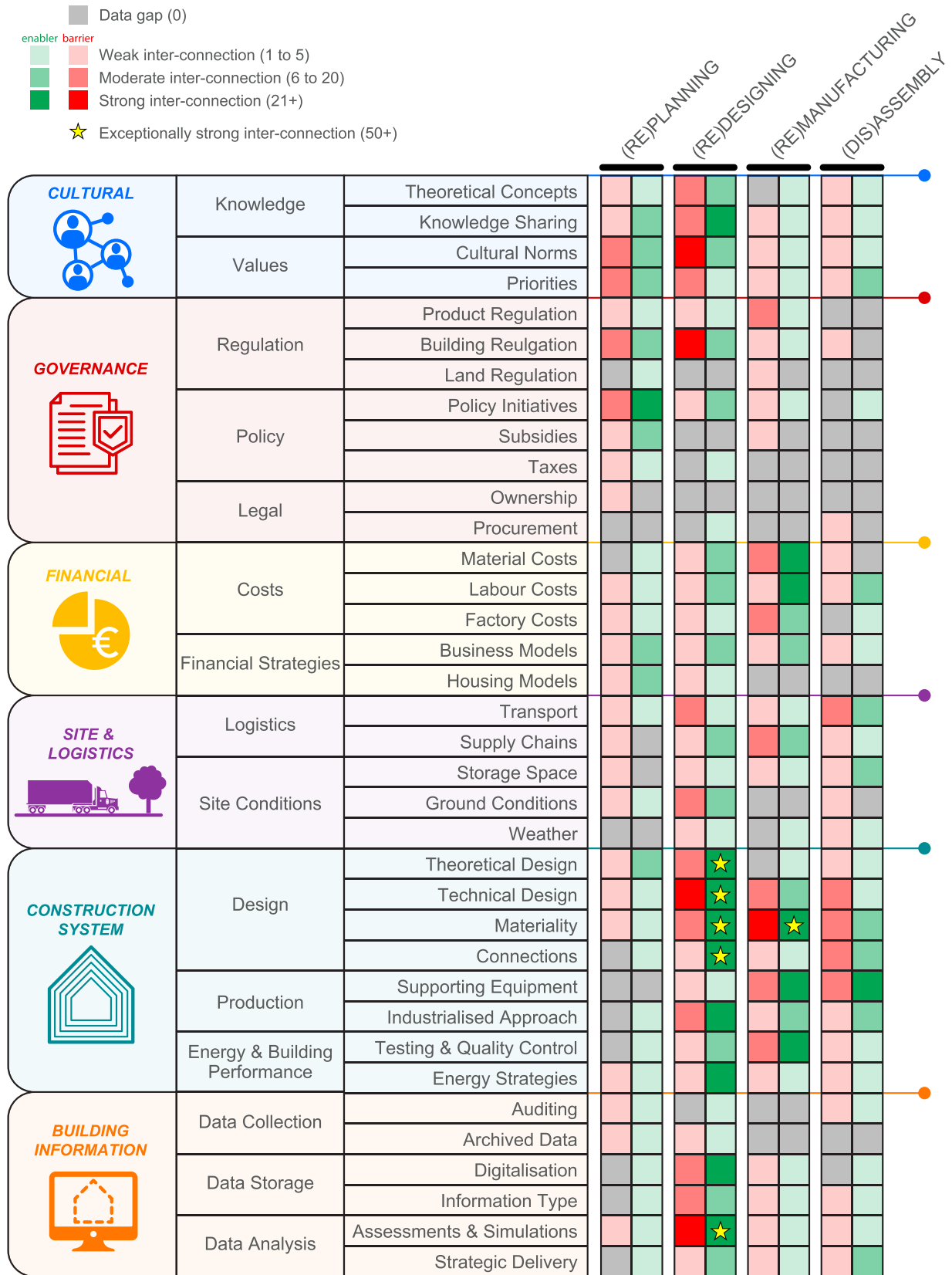


Fig. 8. Emergent circular process framework-gaps and barriers/enablers hotspots.

construction remains scarce. All other factors are largely neglected, with significant gaps across the governance factor. Key challenges include labour intensity, high costs, and material damage when disassembly is performed on buildings not originally designed for disassembly.

#### 4. Discussion

There is a pressing need for today’s housing to be designed with disassembly and adaptability in mind to mitigate premature obsolescence. This risk is reflected in the [European Commission’s \(2020\)](#) latest circular design guidelines, which stress the need to utilise industrialised methods for both new-build and existing building developments through two strategies: (1) building systems with virgin ‘pre-use’ materials, designed for future disassembly and reuse (2) actively reusing existing materials for multiple cycles ([Fig. 9](#)).

While significant developments have occurred in the CIH, reflected in the recent uptick in literature connecting IC and DfD, their integration presents a major challenge, particularly in housing, while shifting from ‘upstream’ to ‘downstream’ activities, ensuring reclaimed materials are systematically reintegrated. Currently, the CE transition remains in its infancy globally, with limited development in Strategy 2, and housing demolition remains common practice. Notably, IC is not currently geared-up for remanufacturing processes, although there is significant potential, as reused materials inherently need to return to factory settings, making the theoretical integration of DfD, remanufacturing, and IC in housing particularly promising.

Cultural perceptions of IC and use of locally sourced, natural materials vary significantly across regions, particularly influencing adoption in developing economies where traditional building practices may conflict with CIH approaches. This review reveals a euro-centric bias in the literature, with developing nations underrepresented despite their growing application of circular industrialised approaches to improve housing affordability and sustainability ([Moghayedi & Awuzie, 2023](#), [de B. Gomide et al., 2024](#)). Limited representation from Central and South America, Africa, and parts of Asia constrains our understanding of routes for global implementation. Sharing information and lessons learned from international advancements is essential to translate identified opportunities into policy and practice elsewhere, and to help emerging construction industries leapfrog towards more sustainable circular housing models.

Compared to other review studies, this study provided granular insights through detailed sub-themes and developed a novel process-driven conceptual framework, whilst others continue to follow more widely adopted linear framework structures ([Kedir and Hall, 2021](#), [Hernández, 2025](#)).

#### 4.1. Issues highlighted by the studied literature

##### 4.1.1. Need for new analytical framework

This study derived four core lifecycle processes: (re)planning, (re)designing, (re)manufacturing, and (dis)assembly, which are based on processes drawn from two comprehensive and widely used frameworks in academic research and practice: the international standard for LCA and [European Norm 15978 \(2011\)](#) and the Royal Institute of British Architects *Plan of Work* ([The RIBA 2020](#)), which serves as a comprehensive architectural framework that is used throughout the construction sector in the UK and internationally.

These linear frameworks, though well established, proved inadequate for CE analysis due to their inability to accommodate material reuse cycles. EN 15978 creates classification problems. For example, repurposed components from decommissioned buildings could be categorised as either Module C3 ‘Waste processing for reuse, recovery, or recycling’ or Module A1 ‘Raw material supply’, creating methodological inconsistencies. Furthermore, planning (pre-design) and design processes are not included, while the RIBA Plan of Work fails to account for EoL reuse opportunities after the use phase.

[Fig. 10](#) shows an analytical framework that adapts the above frameworks, overcoming their limitations for circular applications. These processes can (re)occur in various sequences, indicated by connecting arrows, covering all activities that result in significant physical building changes. The framework is therefore designed to enhance the understanding of disassembly and reuse in conjunction with industrialised methods across both new construction and existing buildings in construction and housing. It can be used to break down the processes involved with component replacements during the use phase, building adaptations, or in rare instances, relocation.

By interrelating the four processes with factors such as those identified in this study, the framework offers a clear and flexible structure that supports sector-specific guidelines alongside knowledge sharing and collaboration. Populated with relevant themes and sub-themes, it can organise process-specific steps, measured impacts, checklists, case studies, and lessons learned, aiding designers, housing providers, local authorities, and manufacturers.

Holistic KPIs assigned to each sub-theme across lifecycle processes could enhance social value and cost-benefit outcomes for residents alongside minimising environmental impacts. For example, in a social housing retrofit, this could include minimum auditing during (re)planning; meeting reused material and social value benchmarks during (re)designing; material savings and local employment targets during (re)manufacturing; disassembly rates and recovery of undamaged components during (dis)assembly. The framework complements established linear models and can be adapted to incorporate alternative sub-themes. Integration with assessment tools such as LEED and BREEAM could embed these metrics into relevant categories, while pilot projects would refine indicators, guide procurement, and support gathering input from

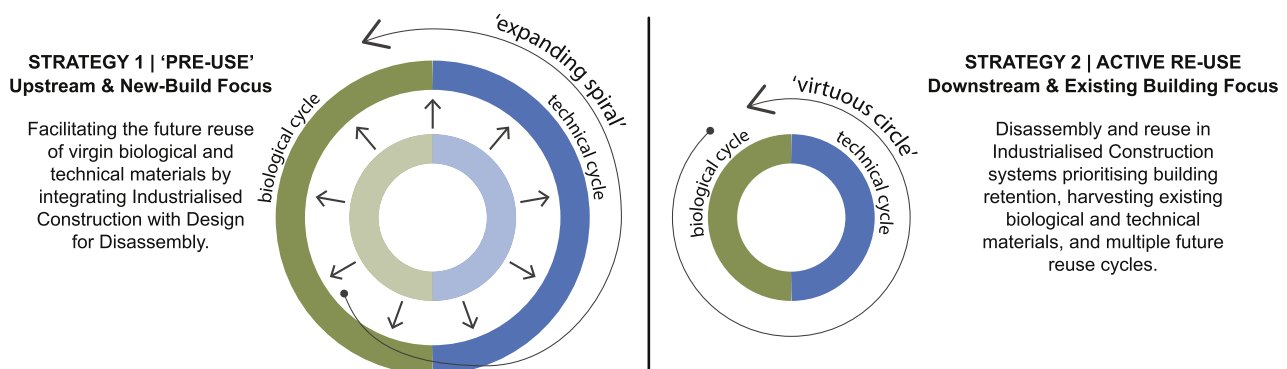


Fig. 9. Two circular design strategies—partially based on EMF’s Butterfly diagram.

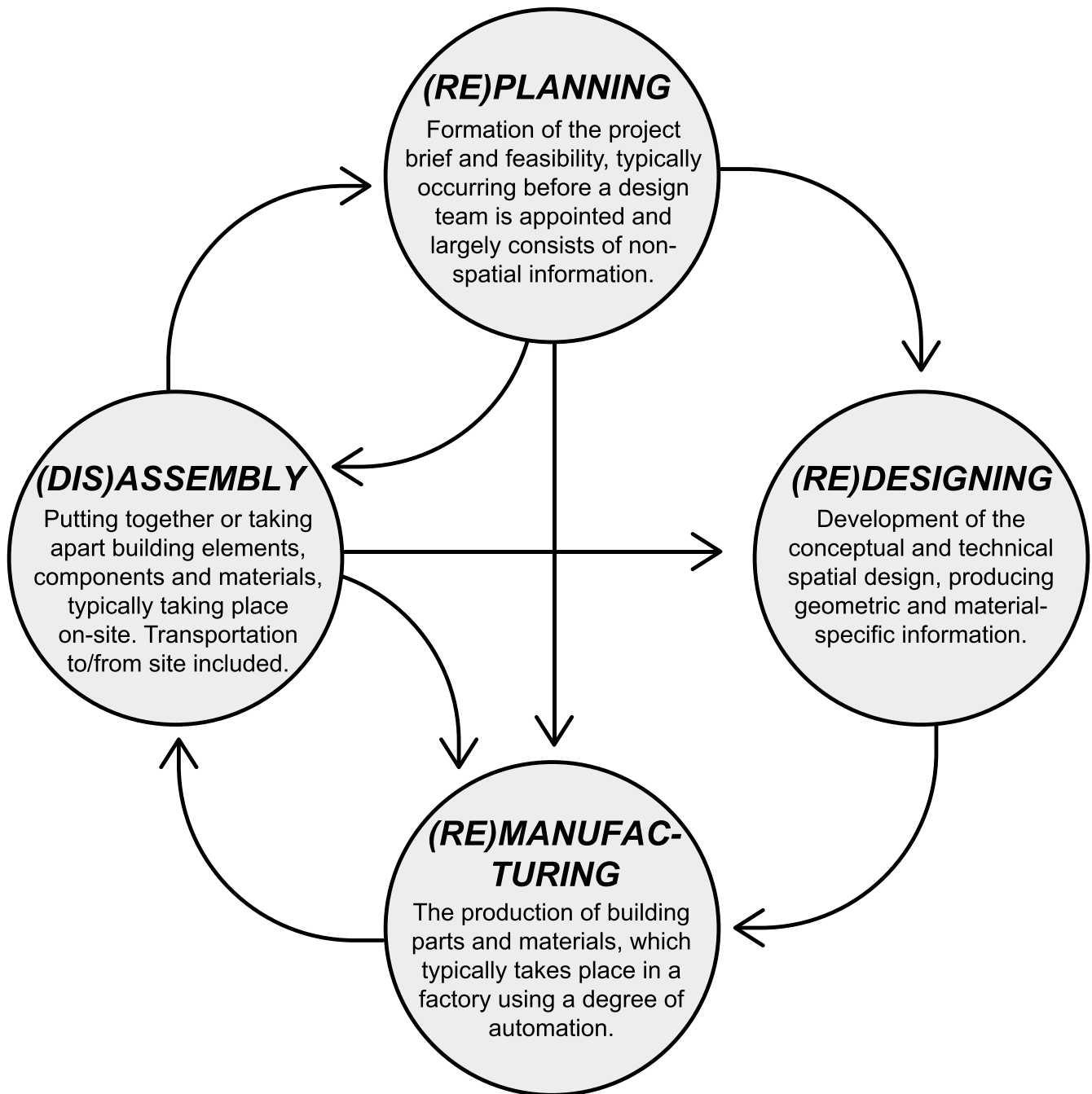


Fig. 10. Four circular processes used to interrelate with emerging themes over the lifecycle.

industry.

#### 4.1.2. Few applications for disassembly

Despite existing disassembly solutions in construction, the systematic literature review revealed a notable lack of application to permanent industrialised housing. Housing was often a case study rather than the main focus, with greater emphasis on IC and new-build over DfD or reuse in existing buildings, reflecting industry trends favouring demolition. This gap partly arises from legal and economic constraints, where material reuse depends largely on asset owners' goodwill. Although promising reuse pilot projects exist, discussions on reuse and DfD remain superficial. The literature mostly treats disassembly theoretically, with limited empirical evidence or real-world application. While both IC and DfD appear in publications, they are not well integrated. Content analysis shows disassembly is often discussed abstractly, with few tested

solutions beyond construction system aspects. Most studies assume disassembly is feasible but underexplore context-specific challenges and provide little practical insight on enablers or implementation experiences, though emerging research is beginning to address this.

#### 4.1.3. Lack of common vocabulary

The need for a common vocabulary is foundational to CIH. Language issues within the studied literature add further complication, for example, Silva et al. (2020) and Asam (2007) consistently refer to 'material recycling', although reuse methods were described. Furthermore, Spisakova & Kozlovska (2013) use the term material 'waste', similarly to the naming of the EU 'Waste' Framework Directive and Construction and Demolition 'Waste'; using such terms can inadvertently undermine the value of construction materials in existing buildings, as emphasised by the Cradle-to-Cradle concept. The term Circular

Economy or ‘circularity’ is relatively new, appearing in publications from 2017 onwards within the studied literature. Kirchherr et al. (2023) also highlight that the circular transition is hindered by the lack of a common global vocabulary, identifying 221 CE definitions.

4.1.4. Little consideration for affordability, inclusion and the role of social housing

Applying CE principles in housing encounters challenges due to extended time frames, entrenched perceptions of housing permanence, and unconventional ownership models. These hurdles vary across social, affordable, and private housing models. However, several critical areas remain underexplored across the studied literature. The role of financing for different housing models was not compared within the literature. Despite social housing’s suitability for enhancing circularity, attributed to greater standardisation, long-term institutional ownership models, and defined design standards (Çetin et al., 2021), few studies connected these concepts. Circular practices across the studied literature focussed heavily on environmental sustainability, neglecting opportunities to improve housing affordability and social considerations.

Since most of the literature focussed on general or private market housing, the unique implications for the affordable and social housing sectors remain underexplored. For instance, barriers such as high upfront costs and regulatory constraints may be particularly acute in social and affordable housing. Policy incentives and long-term tenure models could serve as strong enablers, although social housing tenure varies by country, affecting CE implementation.

Circularity in social housing could yield environmental and economic benefits including reduced waste, improved energy-efficiency and lifecycle cost savings, alongside notable social benefits such as better access to quality housing, greater adaptability, community empowerment and local job creation. However, the literature reveals a persistent fragility in connecting environmental goals with social justice, particularly in relation to accessibility for more vulnerable populations.

4.2. Policy recommendations

Governance is a critical yet underexplored factor in integrating circular and industrialised construction to meet housing needs, particularly during the (dis)assembly and (re)planning processes. Drawing on the regulatory frameworks, policies and legal instruments reviewed, this study recommends embedding IC, DfD and reuse principles into policies on urban renewal, building retrofits, renovations, adaptations and social housing in particular.

Government-led financial measures such as shifting taxation from labour to materials, increasing demolition costs over new-build, and providing targeted subsidies can incentivise circular, industrialised practices. Standardised, adaptable performance-based building codes are also essential to support innovation. Legal barriers such as the classification of entire buildings as waste upon demolition decisions should be reformed. These measures are especially pertinent for circular industrialised buildings, which often require more materials compared to conventional construction, yet lack legal protection against premature demolition.

Polymakers should balance mandatory measures, such as reuse targets, with softer instruments that stimulate market development. The optimal policy mix will depend on the maturity of IC and CE transitions within local contexts, in addition to national, regional and local constraints.

4.3. Future research

The field continues to advance rapidly. A follow-up search conducted on 8 August 2025 using the original search terms and databases yielded four additional highly relevant papers (Liu and Loo, 2025, Chen et al., 2025, Jeleniewicz et al., 2025, Gurusinge et al., 2025). Despite these recent contributions, research on Strategy 2 (Fig. 9) and deeper insights

into improving housing affordability and leveraging social housing opportunities remain limited.

Within this study, several gaps were found across the factors and processes in the framework, particularly concerning governance and the (dis)assembly and (re)planning processes (Fig. 8). This shows that while sub-themes describe barriers and enablers for CIH, their nature varies depending on the lifecycle stage, defined by the four key processes.

Future research should test and refine the framework through built projects that actively integrate IC, DfD and reuse, aligned to CE principles. Such studies could evaluate whether cultural factors posed equal barriers and enablers as the construction system or identify potential new emergent sub-themes.

Table 2, based on the reviewed literature, highlights critical sub-themes across processes for future investigation. These are shaped by the identified gaps and strongly related sub-themes needing further attention to advance CIH.

Future research should engage industry practitioners and policy-makers in different geographic contexts through interviews and reviews of grey literature to capture recent developments and real-world implications. Greater focus should be placed on (dis)assembly, (re)planning, and (re)manufacturing within the recommended research lines outlined in Table 2. Such studies could help refine and validate the proposed process-driven framework.

While assembly processes are relatively well understood, more empirical research on disassembly and reassembly through built projects is needed as scalability challenges persist, which is highlighted by the recent EU-funded industry-academia built pilot projects.

Future research could focus on sub-themes such as ‘storage space,’ ‘supporting equipment,’ and ‘strategic delivery.’ The analysis also revealed a significant gap in (re)planning, calling for further study of emerging ‘policy initiatives,’ ‘housing models,’ and ‘auditing’ methods in Europe and beyond. Research on (re)planning should clearly define key stakeholders and their roles across the identified processes and factors. Case studies on remanufacturing materials and components addressing challenges such as ‘ownership,’ ‘testing and quality control,’ and ‘supply chains’ would offer valuable insights. Finally, exploring the overlaps among sub-themes and transitions between processes could deepen understanding of cause-and-effect relationships.

Table 2 Sub-themes in connection to processes to be considered for future research.

Process	Factor	Sub-Theme	Research direction description
(Re)planning	2	Policy Initiatives	Explore new/successful circular IC housing policies
	3	Housing Models	Improving affordability, considering housing cooperatives
	6	Auditing	Exploration and standardisation of pre-demolition auditing
(Re)designing	2	Building Regulation	Integration of DfD/A standard in practice
	2	Procurement	Strategies for embedding circular IC
	6	Assessments & Simulations	Application of circular and IC theory using LCA
(Re)manufacturing	2	Ownership	Product agreements between manufacturers and asset owners
	5	Testing & Quality Control	Efficient testing supporting re-warranting of reused materials
	4	Supply Chains	Maturing of local second-hand building material markets
(Dis)assembly	4	Storage space	Connections to suitable circular hubs & infrastructure
	5	Supporting Equipment	Machinery/robotics automating disassembly on-site
	6	Strategic delivery	Reverse logistics and differences with (re)assembly

Numbers correspond to six factors: (1) Cultural, (2) Governance, (3) Financial, (4) Site and Logistics, (5) Construction System, (6) Building Information.

#### 4.4. Limitations

The barriers and enablers identified in this review are based on literature sourced from a limited number of databases and should be viewed as indicative of general trends rather than definitive conclusions. Due to the scarcity of targeted studies on social and affordable housing, most findings primarily apply to general housing or other building types. The categorisation of excerpts into processes, sub-themes, and barrier/enabler groups involved subjective interpretation, which may lead to different results if replicated by others. Therefore, the results serve to highlight general themes and trends rather than provide a definitive meta-analysis. Additionally, the discussion of literature gaps and future research lines reflect the authors' knowledge and are not exhaustive.

#### 5. Conclusions

The transition to Circular Industrialised Housing (CIH) requires a move away from linear frameworks in favour of process-driven approaches that recognise the dynamic and interconnected nature of life-cycle activities. This systematic review of 65 publications proposes a process-driven framework that highlights missed opportunities to balance housing needs with climate goals by integrating non-technical factors alongside technical innovations.

The construction industry is at a pivotal point where sustainability goals align with advancements in Industrialised Construction (IC) methods. IC offers significant potential to enhance resource-efficiency through circular principles, creating opportunities to improve housing affordability. However, integrating Design for Disassembly (DfD) and active reintroduction of used materials remain essential yet undervalued, as evidenced by the systematic neglect of (dis)assembly processes in current research and practice. Promisingly, a significant recent increase in literature connecting these concepts in 2025 illustrates the fast-growing academic interest in advancing CIH.

This review of literature drawing from a variety of global contexts, including new-build, retrofit, relocation and building adaptation studies, reveals a strong focus on (re)designing processes (55 %), whereas (dis)assembly (12 %) receives the least attention, closely followed by (re)planning (13 %). This points to a lack of true lifecycle thinking, while frameworks rooted in a linear approach remain prevalent. The proposed framework's four core processes of (re)planning, (re)designing, (re)manufacturing and (dis)assembly address these gaps by spanning the full lifecycle of housing assets to support flexible, interdisciplinary stakeholder collaboration and advance CIH.

Six key holistic factors emerged inductively: cultural, governance, financial, site and logistics, construction system and building information. These organise 15 themes and 36 sub-themes representing the challenges and opportunities that occur across lifecycle processes. However, construction system considerations dominate the (re)designing process, while the weakest relationship was identified between governance and (dis)assembly. Such imbalances may perpetuate

#### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.scs.2025.106837](https://doi.org/10.1016/j.scs.2025.106837).

#### Appendix A

Scopus and WoS database search string composed of 56 terms

linear thinking and the assumption that circular and industrialised transitions are mainly a technical and design issue.

The overwhelming focus on theoretical design enablers over practical implementation barriers reveals a body of research that struggles to effectively develop CIH and exposes a disconnect between research and practice. Few studies fully integrate IC with disassembly, reuse and housing affordability. Furthermore, social innovation and the role of social housing are largely neglected, despite their potential to accelerate the Circular Economy transition. Significant knowledge gaps exist in site conditions, data collection, housing models and across governance sub-themes.

These findings challenge the assumption that technological advancement will naturally drive the adoption of CIH. Instead, meaningful transformation requires targeted and collaborative input across institutional frameworks and contextual constraints. For cities facing housing affordability and sustainability challenges, this process-driven framework offers structured, flexible guidance for applying circular and industrialised principles within housing policy.

Future research should deepen collaborative, interdisciplinary practitioner engagement across diverse geographical contexts to test, refine and translate the framework into a practical and relevant tool that advances sustainable, affordable and socially equitable housing solutions.

#### CRediT authorship contribution statement

**Annette Davis:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Núria Martí Audí:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Daniel M. Hall:** Writing – review & editing, Supervision, Methodology.

#### Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Annette Davis reports financial support was provided by EU MSCA-ITN. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Industrialised Construction (AND) (OR)	Design for Disassembly (AND) (OR)	Housing (OR)
industriali?ed construction, industriali?ed building, system* building, modern methods of construction, modular building, modular construction, volumetric, prefab*, pre-assembly, sub-assembly, design for manufacturing and assembly, off-site construction, off-site manufactur*, off-site production, off-site fabrication, on-site fabrication, additive manufactur*, 3d print*, manufactured construction, manufactured hous*, industriali?ed hous* construction, industriali?ed house-building, industriali?ed hous*, prefabricated prefinished volumetric construction, industrial flexible and demountable, lean construction, lean manufacturing	design for disassembly, design for deconstruction, design for reuse and recycling, design for reuse, design for recycling, design for x, design for the environment, design for disassembly and adapt*, design for adaptability and deconstruction, deconstruct*, dismantl*, re-assembl*, disassembl*, reversib*, design for adaptability and disassembly, reversible building design, design for reversible building, recyclable architecture, reversible building, design and manufacture for deconstruction, design for adaptability, design for longevity, design for manufacture assembly disassembly and end-of-life processing, construction in reverse, reuse	hous*, home*, residential, apartment*
27 Total: 56 terms	25	4

## Data availability

This review is based on peer-reviewed publications identified through systematic database searches of Web of Science and Scopus

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