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RESEARCH ARTICLE

Understanding Success Factors and Challenges to Circular Industrialised Housing: An Interdisciplinary, Process-Driven Approach

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Abstract

The integration of Circular Economy principles with Industrialised Construction presents a crucial pathway for addressing the housing and climate crises. Industrialised Construction encompasses a controlled manufacturing approach, including prefabrication, off-site manufacturing, and on-site fabrication methods such as 3D printing, to produce repeatable products and reconfigurable systems that increasingly integrate digitalisation and Industry 4.0 technologies. However, scholarship on practical implementation across different national contexts remains limited, whilst existing frameworks are entrenched in linear approaches. This interdisciplinary study integrates practitioner knowledge across four distinct fields categorised as policymakers and disseminators, housing providers, designers, and off-site contractors to refine a process-driven lifecycle framework developed by the authors. The framework is structured around four key circular process types, rather than linear project stages: (re)planning, (re)designing, (re)manufacturing, and (dis)assembly. Drawing on interviews and survey analysis with 31 participants working at the forefront of applied circular and industrialised housing across the United Kingdom, the Netherlands, and Spain, success factors and challenges are identified and compared. The findings highlight the critical influence of the (re)planning process, cultural and governance factors, and identify new sub-themes for the lifecycle framework. The study provides best practice insights, supporting the transfer of Circular Industrialised Housing innovations across contexts with varying maturity, particularly within social and affordable housing.

Keywords Circular Economy · Industrialised Construction · Social Housing · Affordable Housing

1. Introduction

Countries worldwide continue to face a dual housing and climate crisis, demanding urgent action. Governments are tasked with balancing sustainability goals with the unavoidable negative environmental impacts arising both from constructing new build homes and carrying out the necessary upgrades of existing housing stock. Meanwhile, housing is increasingly unaffordable in many European countries. Homeownership is slipping further out of reach, particularly for middle-income and younger populations, whilst social housing is more often found in poor condition and in insufficient supply (Hochstenbach, 2025; Housing Europe, 2021). The Circular Economy (CE) and Industrialised Construction (IC) are widely regarded as instrumental in tackling these challenges in both industry and political spheres (Bertram et al., 2019; European Commission, 2025), as reflected in the national and local policy initiatives across the three countries examined in this study (Chapter 2).

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1.1. Circular Economy in Housing

The term Circular Economy (CE) relates to both design and business strategies, denoting a systems orientated approach to production and consumption that is "restorative or regenerative by intention and design" (EMF, 2013; Pearce & Turner R.K., 1990; Potting et al., 2017). Circular principles aim to close, slow, narrow, and regenerate resource loops within technical and biological material cycles, with building components ideally upcycled or reused, rather than downgraded through recycling (Bocken et al., 2016; EMF, 2015). The CE in housing has evolved beyond environmental concerns to a holistic approach, considering financial aspects and social value across building lifecycles (Marchesi & Tweed, 2021; Van Opstal et al., 2025). This broader understanding has enhanced the attractiveness of housing circularity to asset owners whilst maintaining focus on improving resource efficiency, regenerative systems and limiting pollution (EMF, 2013). Recent CE research in construction centres around digitalisation and material passports (De Wolf et al., 2024; Veliz Reyes et al., 2025). Government initiatives worldwide reflect this momentum, including the European Commission's Circular Economy Action Plan (2020), London's Circular Economy Statements (GLA, 2020), Canada's Circular Cities and Regions Initiative (CCRI) launched in 2021, and China's 14th Five-Year Plan that incorporates the CE (2021-2025).

1.2. Industrialised Construction in Housing

Industrialised Construction (IC) encompasses the systematic and controlled production of buildings, taking place both off- and on-site, incorporating prefabrication alongside aspects such as logistics and manufacturing processes amongst others (Andersson & Lessing, 2017). IC is associated with modernisation, technology and a modular approach to construction, with production often carried out in factories, similar to the automobile industry (McKinsey, 2020). The IC concept has evolved from mass production to mass customisation, automation, robotics, and integrating Industry 4.0 technologies, with recent research exploring Product Platforms, Artificial Intelligence (AI) and Digital Twins (Hedayati et al., 2026; Popovic et al., 2022; Qi et al., 2021). These advancements help to implement a 'product approach' as opposed to developing one-off projects and 'continuous learning' to improve building systems across multiple lifecycles, capable of producing housing of superior efficiency and quality, compared to traditional construction. The benefits of industrialising housing are evident in Scandinavia, and Sweden in particular, where over 90% of single-family housing and 20% of multi-storey housing utilises IC (Lessing, 2025). However, in most countries, the industrialised housing sector remains niche, and particularly limited in Southern European countries, and more broadly in developing economies (Kedir et al., 2020).

1.3. Circular Industrialised Housing

Developments in the CE and IC over the last decade have converged to create unprecedented opportunities for Circular Industrialised Housing (CIH) (Kedir & Hall, 2021; Van Oorschot et al., 2022). CIH offers a holistic lifecycle approach capable of systematically delivering sustainable, affordable homes at scale, integrating housing affordability with environmental and social sustainability. This integration is particularly relevant for social housing models, where long-term ownership and asset management aligns with circular principles (Çetin, Gruis, et al., 2021). However, despite policy support and technological advancements, practical implementation of CIH remains limited, with little insight into real-world application within social and affordable housing (Davis, Audí, et al., 2025).

Both the CE and IC have broadened in scope to address whole lifecycle thinking and the efficient production of buildings and components. This convergence, and complexity of housing and sustainability issues inherently require interdisciplinary collaboration amongst diverse stakeholders. This should include architects, engineers, manufacturers, demolition and deconstruction contractors, policymakers, and asset owners and managers amongst others, to collectively problem-solve and optimise solutions as part of an integrated system, rather than siloed or narrowly multidisciplinary approaches that risk blind spots and potentially lack big picture thinking (Bocken et al., 2021; Choi & Pak, 2006; Murphy, 2013). This is particularly relevant at larger scales, where harnessing industrial symbiosis across supply chains and sectors demands coordinated action beyond any single discipline (Cecchin et al., 2020). Circularity can be further enhanced through IC's controlled manufacturing environment, standardisation, and digital technologies, which together support Design for

Disassembly (DfD) and reuse, minimise resource and energy consumption, and enable the tracking and retention of materials and products across supply chains and building lifecycles (Kedir & Hall, 2021).

1.4. Literature Gaps

Three key gaps emerge from existing relevant research. First, limited studies investigate CE-IC integration, with empirical research on industrialised housing giving minimal attention to circularity (Xie et al., 2023). Second, whilst interdisciplinary studies bridging CE theory with built environment practice has grown over the past decade, as called for previously by Pomponi and Moncaster (2017), relevant studies that do engage a range of stakeholder perspectives tend to focus on a single country or context (Jaillon & Poon, 2010; Knoth et al., 2022; Leising et al., 2018), rather than adopting a comparative approach that can highlight opportunities to 'cross-pollinate' knowledge across national contexts. Kaewunruen et al. (2024) compare challenges and opportunities across five European countries but do not consider IC, while Kedir et al. (2023) engage CIH practitioners in three African countries but the national contexts studied lack CE-IC maturity. To the best of the authors' knowledge, no cross-national interdisciplinary studies engage experts at the forefront of CIH specifically. Third, while holistic, whole lifecycle approaches to encompass housing affordability alongside environmental and social sustainability are considered valuable (Sparrevik et al., 2021), existing studies narrowly focus analysis on environmental metrics and specifically reducing embodied and operational carbon (De Wolf et al., 2017; Sotorrío Ortega et al., 2024).

An overarching limitation is a lack of frameworks that explicitly accommodate circular and lifecycle thinking within the academic scholarship. Proposed frameworks continue to reflect a linear approach to housing circularity and typically adopt prominent frameworks such as the RIBA Plan of Work (2020) and the international standard framework for lifecycle assessment (EN 15978, 2011), which remain entrenched in problematic linear stages.

1.5. Research Problem and Contribution

Despite promising policies and innovation, the practical implementation of CIH remains limited across Europe and globally, particularly in the social and affordable housing sectors. Furthermore, there is limited understanding of local-level implementation and knowledge sharing across disciplines and international contexts, with missed opportunities to gain insights from experience. Furthermore, current guidance frameworks remain entrenched in a linear 'stages' or 'phases' approach, rather than embracing dynamic lifecycle thinking aligned with circular paradigms.

This study addresses these gaps by investigating three European countries with varying maturity levels in CIH, using a process-driven framework (Figure 1), which was developed by the authors with two previous studies (Davis, Audí, et al., 2025; Davis, Bortel, et al., 2025). Each category pairs a circular process and its inverse, such as assembly and disassembly, which interlink the categories to enhance lifecycle thinking across multiple reuse pathways. For example, disassembly back to replanning, redesigning, or remanufacturing.

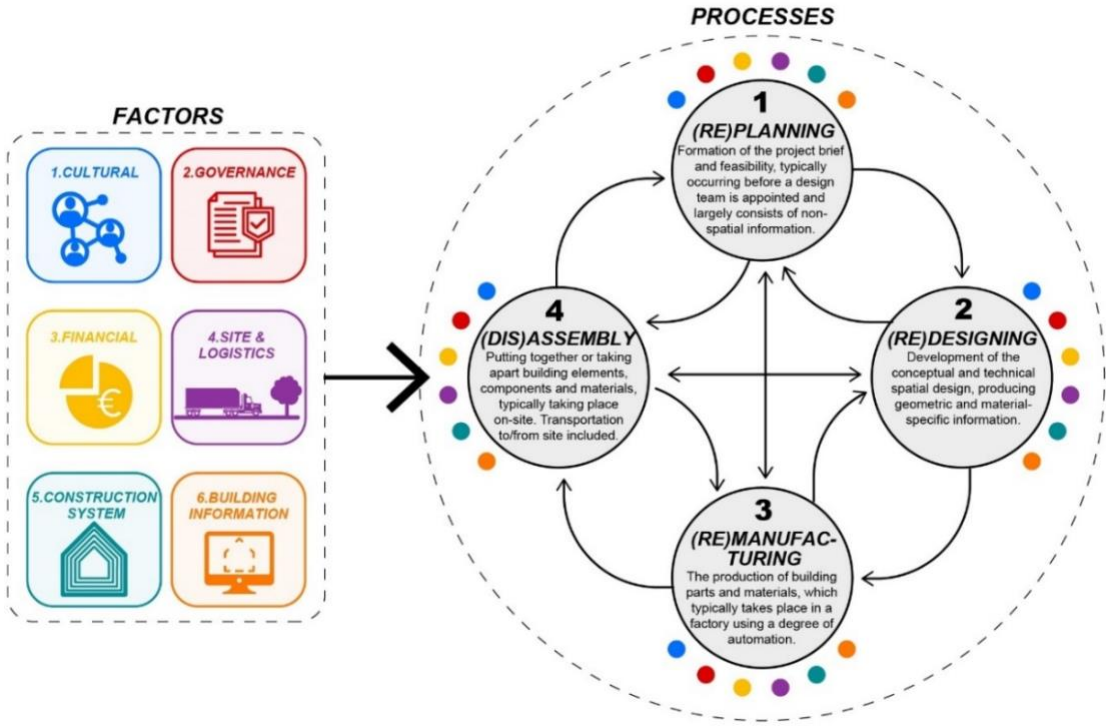


Figure 1. Framework and analysis method relates six holistic factors with four lifecycle processes (Davis, Audí, et al., 2025; Davis, Bortel, et al., 2025)

This framework is used to map practitioner insights and better understand the relationship between lifecycle processes and critical holistic factors. This intersecting process-factor lens is also used to provide insights into the varying maturity levels in CIH observed. While this study is developed within a housing context, the analytical framework's core processes and six broad holistic factors are building-use agnostic and transferable to other building and construction sectors. Researchers and practitioners with sustainability aims working across different building use types are encouraged to apply and adapt the framework, identifying and mapping relevant sub-themes accordingly.

1.6. Research Aim

Understanding of current challenges and success factors for local-level implementation based on practitioner insights is scarce, with missed opportunities for international knowledge exchange. This study includes three countries with a mix of high, medium and low maturity levels of circular and industrialised construction in social and affordable housing, to enhance understanding of failure and success factors across national contexts, and aims to achieve the following research objectives:

- Identify and compare barriers and enablers to CIH across the United Kingdom, Netherlands and Spain.
- Explore how these factors interrelate with lifecycle processes.
- Explore patterns within the findings to better understand the different maturity levels.

This research contributes: (1) rich primary data from practitioners and local policymakers at the forefront of CIH in application to social and affordable housing; (2) comparative analysis across countries with different CIH maturity levels; and (3) a refined framework incorporating industry and policy insights and feedback, supporting interdisciplinary decision-making across building lifecycles and informing future comparative studies.

The paper is structured as follows: Chapter 1 introduces background literature, the study scope and framework; Chapter 2 introduces the countries selected for analysis; Chapter 3 outlines the interview and survey methodology; Chapter 4 presents thematic and comparative analysis of each country, incorporating survey results, Chapter 5 discusses implications; Chapter 6 concludes the study and provides recommendations.

2. Comparative Contexts: The United Kingdom, Netherlands and Spain

This study examines CIH implementation across three European countries representing high, medium, and low ranges of social housing provision, IC and circularity (Figure 2). The Netherlands demonstrates both the highest social housing proportion (28%) and greatest IC uptake in housing (27%) (BouwTotaal, 2023; Housing Standardisation, 2023a). The United Kingdom (UK) occupies an intermediate position, with roughly half the social housing provision and industrialised housing as the Netherlands at 16% and 8% respectively (House of Lords, 2022; UK Parliament, 2024). Spain exhibits lowest levels in both areas, with current estimates at approximately 2% social housing, with limited industrialised house-building (2%) (Housing Standardisation, 2023b; LSE, 2024; Woodea, 2024). According to the latest Circularity Gap reports, the Netherlands is considered a front-runner at 24.5% circular, compared to the UK at 7.5%, (Circle Economy, 2022, 2023), notably, Spain remains absent from the reporting to date.

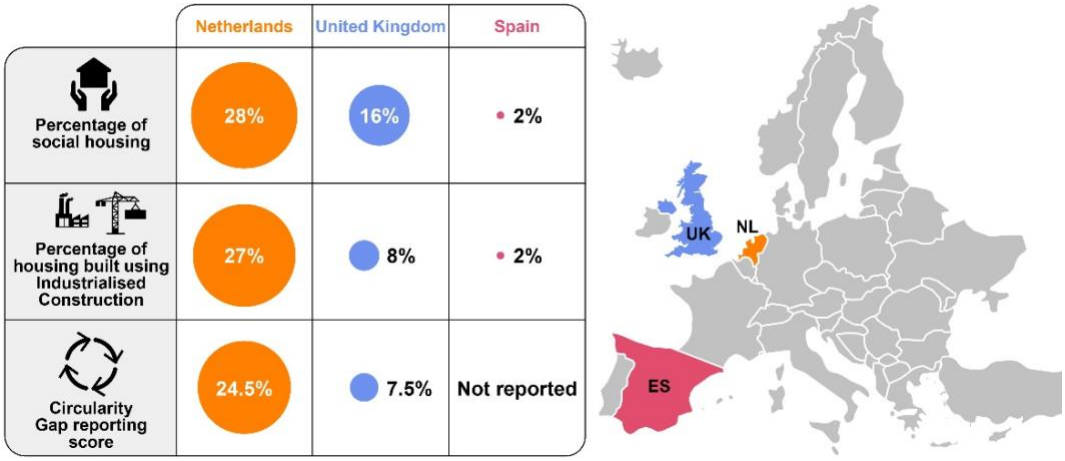


Figure 2. Statistical overview of the Netherlands, UK and Spain

2.1. The United Kingdom

Commonly known as Modern Methods of Construction in the UK, IC is considered essential to deliver recent ambitious national targets for new homes, yet strong negative associations with poor-quality post-war prefabricated housing persist. IC remains niche, with notable recent industrialised housing business closures, which led to an inquiry by the House of Lords Built Environment Committee (2023). The UK has pledged to achieve net zero greenhouse gas emissions by 2050 and has advanced circularity through Circular Economy Statements (BEIS, 2021; GLA, 2022).

2.2. The Netherlands

IC ('Industrieel Bouwen'), often used synonymously with 'Conceptueel Bouwen', has achieved mainstream integration in Dutch housing (Federatie Ruimtelijke Kwaliteit, 2025). With capacity increasing year-on-year, it plays a key role in the Dutch 1 Million Homes initiative (BouwTotaal, 2023; L. Oorschot & Asselbergs, 2021). The Netherlands is recognised as a front-runner in circularity, aiming to become a fully circular country by 2050 (PBL, 2021). CIH developments are supported by exemplary 'lighthouse projects' such as EnergieSprong (2015) and Super Circular Estate (Durmisevic, 2018).

2.3. Spain

Recent IC ('Construcción Industrializada') uptake remains minimal, despite sharing a history in prefabricated post-war housing. Spain has officially promoted circularity over the past five years through España 2030 (MITECO, 2020) and has notably used a significant share of EU Next Generation funds, supporting economic

recovery post-COVID, to enhance green and digital transitions in housing (Pablo-Romero et al., 2024). CIH has recently been applied to a flourishing cooperative housing sector in Catalonia, an alternative 'third route' to affordable housing gaining international attention (Housing Europe, 2025).

Based on the statistics presented in this section, it is hypothesised that empirical data gathered through interviews and surveys, supported by in-person factory visits, will broadly align with reported developments, confirming the Netherlands as most advanced in CIH implementation, Spain as least advanced, and the UK occupying an intermediate position.

3. Methodology

A comparative mixed-methods approach examines CIH implementation across the UK, the Netherlands and Spain through semi-structured interviews and post-interview surveys, complemented by the first author's observations of off-site housing factories in the three countries. This triangulation strategy strengthens data reliability, whilst capturing both qualitative insights and quantitative patterns.

The study employed a predefined framework developed in previous research (Davis, Audí, et al., 2025; Davis, Bortel, et al., 2025) structured around six holistic factors and four key lifecycle processes, overcoming constraints from a linear stage-based approach, previously illustrated in Figure 1. The methodology is described through preparation, data collection, data analysis and presentation of the results (Figure 3).

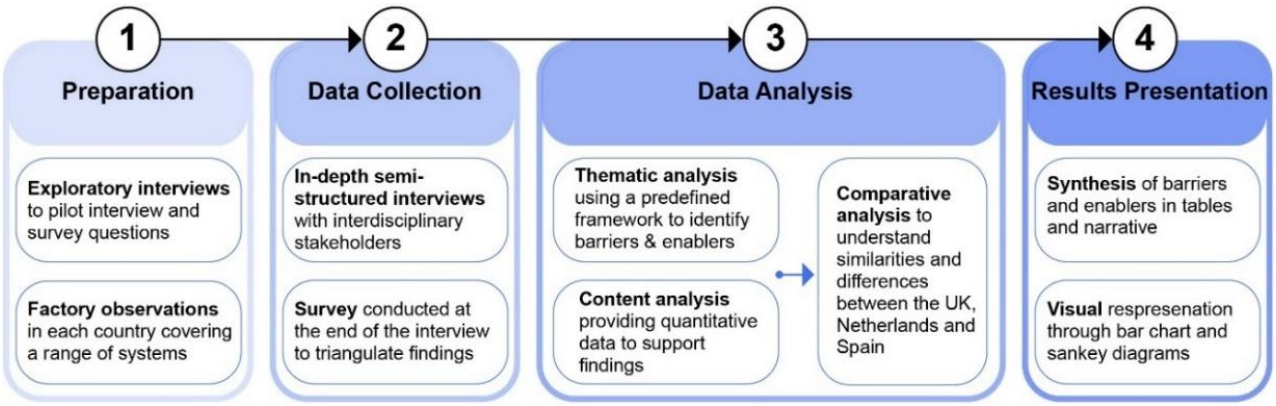


Figure 3. Methodology overview

3.1. Preparation

Exploratory interviews with industry practitioners were conducted between 2021 and 2023, informing the interview questions, survey design and interviewee recruitment. Two pilot interviews were conducted: one with a UK commercial architecture practice and one with a Spanish off-site construction company. Through nine factory visits, between 2022 and 2024, construction practices within off-site housing factories were observed for affordable, social and private market housing. The visits supported participant recruitment while informing the survey design and interview follow-up questions. Visits examined automation and optimisation in construction processes, connection details and construction methods across steel, timber, concrete and hybrid structural materials, in addition to 2D panelised and 3D volumetric systems. Six factories were visited in total - two per country - with three repeat visits to observe a greater variety of production processes: two additional visits with a Spanish factory and one with a Dutch factory.

3.2. Data Collection

Semi-structured interviews were conducted between 2024 and 2025 with 31 senior professionals (CEOs, founders, department heads) involved in circular and industrialised housing projects across the UK, Netherlands and Spain (approximately 10 participants per country). In total, 27 interviews were completed, of which four involved two participants from the same organisation. An interdisciplinary recruitment strategy

targeted four interviewee categories with distinct roles across the building lifecycle: (a) policymakers and disseminators, (b) housing providers, (c) designers, and (d) industrialised housing contractors. Some interviewees pertained to two categories, including local authority departments acting as both policymakers and housing providers, a housing association body operating directly across both policy and housing provision, and a housing association that also owns its own off-site construction company (Figure 4). A detailed interviewee list is provided in Appendix A. The number of participants was considered sufficient to achieve data saturation across all interviewee categories and countries. All interviews were conducted in English, with the exception of one conducted in Spanish.

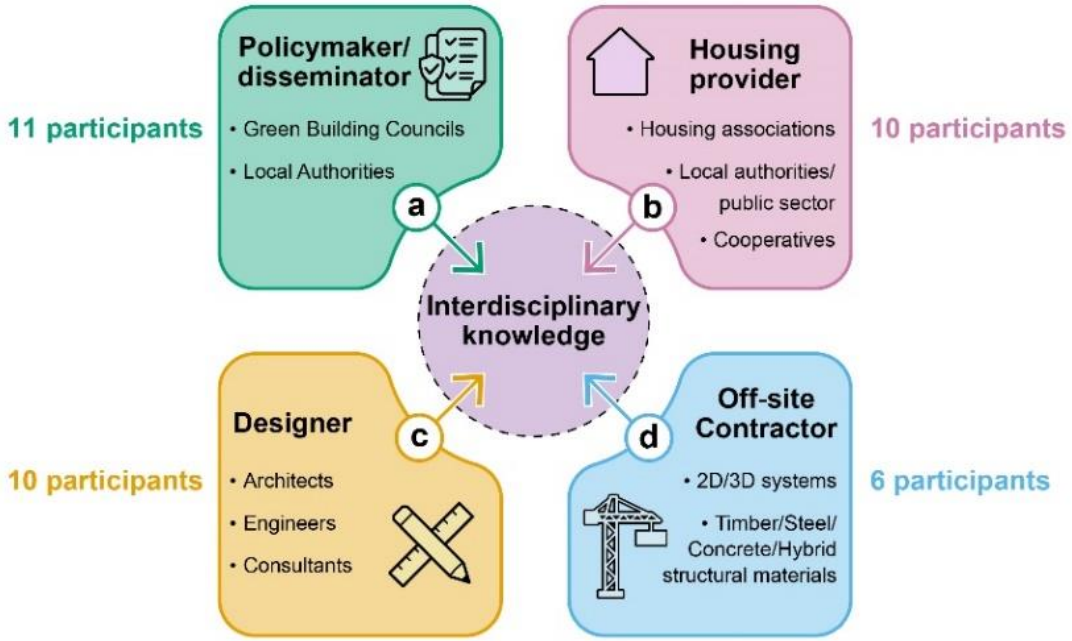


Figure 4. Interdisciplinary interviewee categories and distribution

Of the 31 interview participants, 25 subsequently completed a post-interview survey, yielding 23 completed surveys for quantitative analysis (approximately 8 per country); in two instances two participants from the same organisation completed joint surveys. A detailed participant survey list is provided in Appendix A. No additional selection process was required, as the survey formed a direct continuation of the interview and was carried out in most cases immediately afterwards, alongside the first author. Survey participants quantified perceptions of critical barriers/enablers and lifecycle processes, to support triangulation with interview findings and enhance cross-country comparisons. Part 1 asked participants to rank from 1 to 5 (1 = least critical and 5 = most critical) the overall perceived challenges and opportunities for CIH for each lifecycle process. Part 2 asked participants to describe and rank in order the three most critical barriers and enablers and connect each example to the relevant lifecycle process. Interview and survey questions are included in Appendix B.

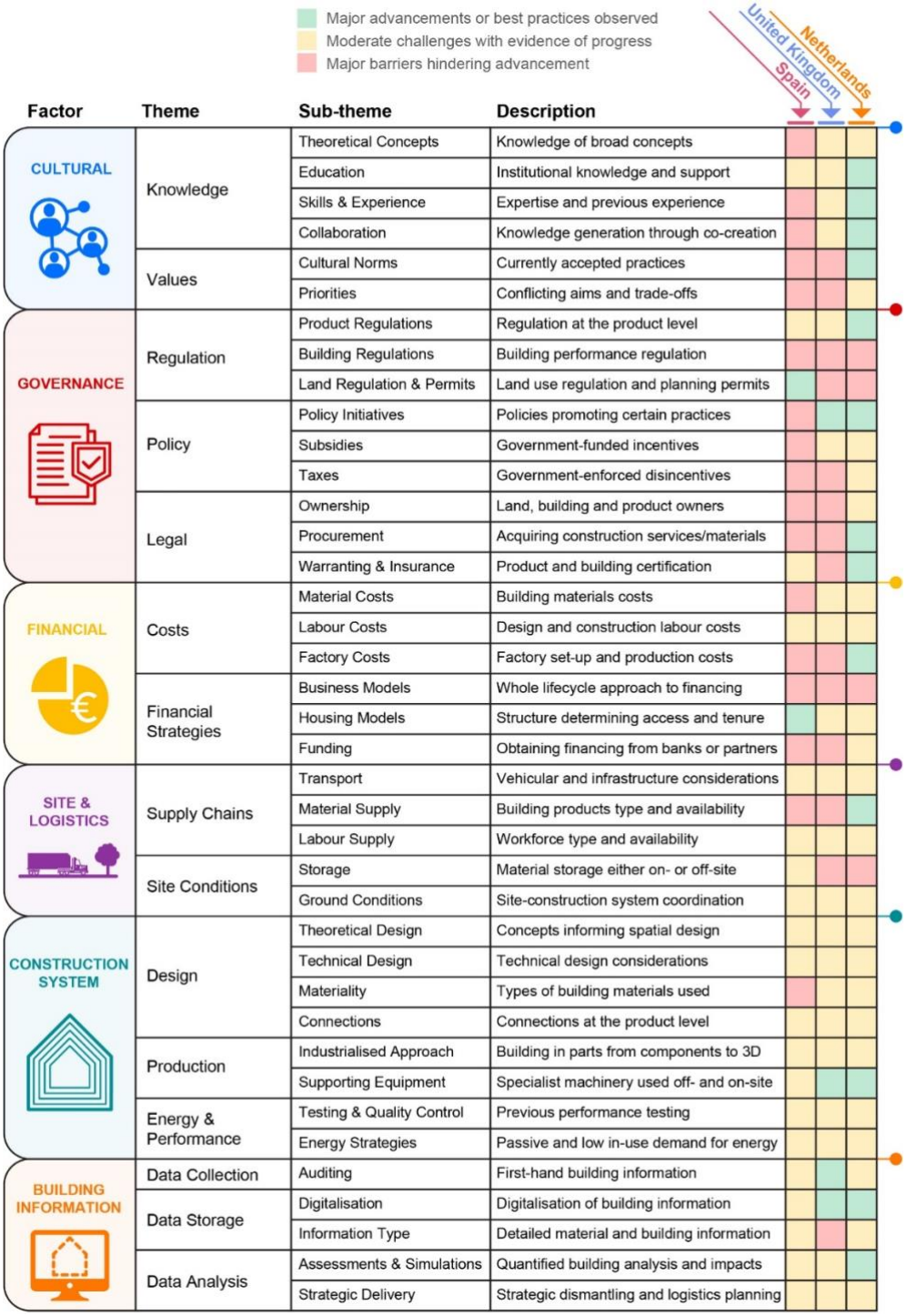
3.3. Data Analysis

Interview transcripts underwent thematic analysis based on Braun & Clarke's (2006) methodology. The coding process followed a semi-inductive approach. Themes and sub-themes used in previous studies by the authors were considered in the initial text analysis. New sub-themes were identified when necessary, considering both interview and survey data. The levels of success in circular and industrialised construction implementation for each sub-theme within each country were assessed and categorised by the authors using a colour-coded traffic-light system for major advancements (green), moderate challenges (amber) and critical challenges (red). The survey examples provided were assigned a sub-theme, quantified and weighted corresponding with their assigned ranking by participants (1 = least critical and 3 = most critical), facilitating deeper analysis and cross-country comparisons.

4. Results

4.1. Identified Sub-themes

In total, 39 sub-themes were identified across the interview and survey data, described in Figure 5. Overall, most critical challenges (red) are present in 'cultural', 'governance' and 'financial' factors, whilst best practices (green) are largely distributed across all factors. Spain faces the most critical challenges (17) and is currently experiencing minimal success factors (2). The UK exhibits an intermediate number of critical challenges (14) and modest advancements (4). The Netherlands is found to have the lowest number of critical challenges (4) and the highest number of success factors (13).



Factor	Theme	Sub-theme	Description
CULTURAL	Knowledge	Theoretical Concepts	Knowledge of broad concepts
		Education	Institutional knowledge and support
		Skills & Experience	Expertise and previous experience
		Collaboration	Knowledge generation through co-creation
	Values	Cultural Norms	Currently accepted practices
		Priorities	Conflicting aims and trade-offs
GOVERNANCE	Regulation	Product Regulations	Regulation at the product level
		Building Regulations	Building performance regulation
		Land Regulation & Permits	Land use regulation and planning permits
	Policy	Policy Initiatives	Policies promoting certain practices
		Subsidies	Government-funded incentives
		Taxes	Government-enforced disincentives
	Legal	Ownership	Land, building and product owners
		Procurement	Acquiring construction services/materials
		Warranting & Insurance	Product and building certification
FINANCIAL	Costs	Material Costs	Building materials costs
		Labour Costs	Design and construction labour costs
		Factory Costs	Factory set-up and production costs
	Financial Strategies	Business Models	Whole lifecycle approach to financing
		Housing Models	Structure determining access and tenure
		Funding	Obtaining financing from banks or partners
SITE & LOGISTICS	Supply Chains	Transport	Vehicular and infrastructure considerations
		Material Supply	Building products type and availability
		Labour Supply	Workforce type and availability
	Site Conditions	Storage	Material storage either on- or off-site
		Ground Conditions	Site-construction system coordination
CONSTRUCTION SYSTEM	Design	Theoretical Design	Concepts informing spatial design
		Technical Design	Technical design considerations
		Materiality	Types of building materials used
		Connections	Connections at the product level
	Production	Industrialised Approach	Building in parts from components to 3D
		Supporting Equipment	Specialist machinery used off- and on-site
	Energy & Performance	Testing & Quality Control	Previous performance testing
		Energy Strategies	Passive and low in-use demand for energy
BUILDING INFORMATION	Data Collection	Auditing	First-hand building information
	Data Storage	Digitalisation	Digitalisation of building information
		Information Type	Detailed material and building information
	Data Analysis	Assessments & Simulations	Quantified building analysis and impacts
		Strategic Delivery	Strategic dismantling and logistics planning

Figure 5. Identified sub-themes assigned high, medium and low progress per country

4.2. Survey Results Part 1: A Lifecycle Process Lens

Whilst the identification of recurrent themes shaping CIH is important, there is a crucial need to understand when these enablers and barriers present themselves throughout the building lifecycle, referred to as circular processes within this study. Four circular processes were previously identified by the authors through a developed framework, encompassing all activities that may (re)occur throughout lifecycle loops. These are: (re)planning, (re)designing, (re)manufacturing, and (dis)assembly, which were introduced to participants through interview questions (see Appendix B).

Following the interview, participants were asked in Part 1 of the survey to rank which processes overall presented the most challenges or opportunities for CIH (Figure 6). This provided insights into practitioners' perceptions of how realistic the circular and industrialised transition in housing appeared in their country and provided a greater understanding of where their focus and concerns lie.

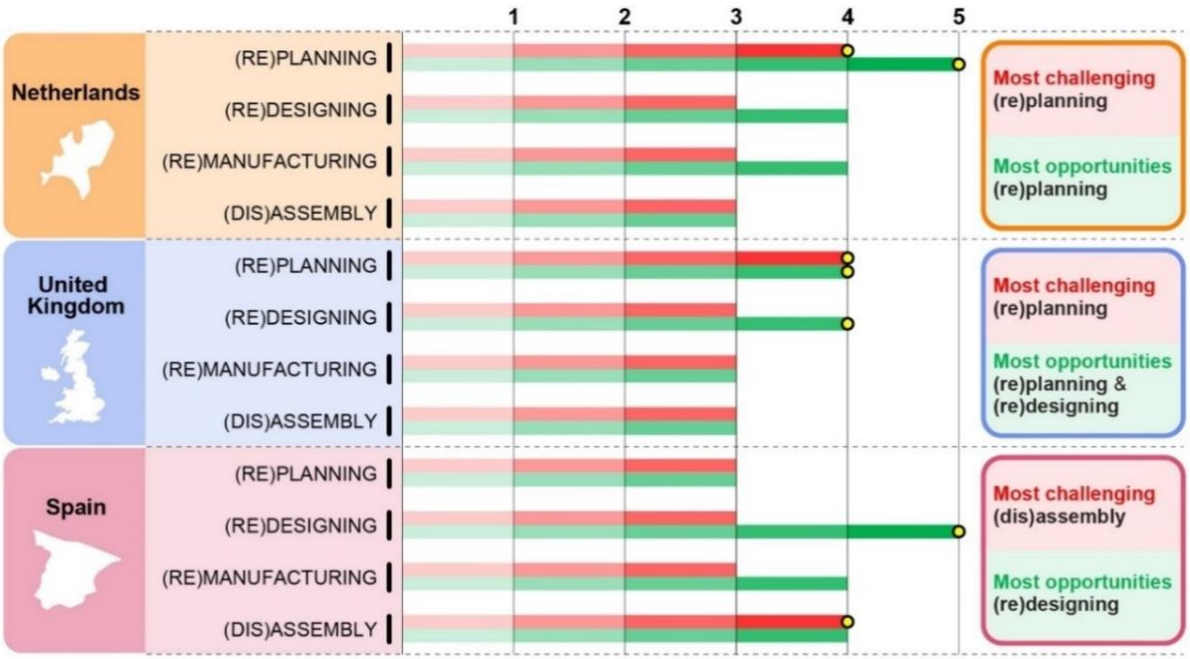


Figure 6. Survey results: Most challenging and enabling processes perceived by participants per country

The results reveal similarities between the Netherlands and the UK, with a shared focus on (re)planning challenges (ranked 4), although Dutch interviewees identified greater opportunities within (re)planning compared to British interviewees, who also focussed equally on (re)designing. Similarly to the UK, Spanish participants identified the greatest opportunities within (re)designing but notably perceived (dis)assembly as the most challenging (ranked 4).

The following sections examine the critical factors and processes, and their interrelationship for each country respectively, synthesising the main findings regarding CIH advancement in Spain, followed by the UK and the Netherlands. This analysis synthesises the key challenges and success factors identified by the authors, followed by those perceived as most critical by participants from Part 2 of the survey. The final section of the results highlights key similarities and differences observed across the three contexts.

4.3. Spain: Critical Challenges and Opportunities

Interviewees identified entrenched cultural norms, outdated building regulations, and conservative central government policy as compounding barriers to CIH. Small-scale movements, particularly within cooperative housing, are emerging but lack the institutional weight to drive systemic change, unlike larger housing associations seen in the UK and the Netherlands in particular. CE and IC principles remain largely absent from policy frameworks, in part as these concepts are yet to be formally defined.

4.3.1. Spain Critical Challenges

- **Cultural**

Whilst CE has entered the mainstream discourse as a **theoretical concept**, it remains poorly understood by practitioners. Regarding IC, regional groups are engaging with national government to formalise understanding, as one Spanish architect interviewed for this study stressed that *"we still don't have a definition to know what is industrialised or what is not"*, preventing policy development and subsidies. Designers and contractors lack the **skills and experience** to implement CE and IC; industrialisation remains niche in Spanish housing and is more commonly applied in lower-quality farming and office buildings. Stakeholders operate in silos, with a lack of **collaboration** to advance CE and IC, particularly amongst designers and with contractors, and asset owners. Emerging IC and CE industry groups show promise but remain small-scale and localised. Current **cultural norms** favour conventional construction, shaped by dominating traditional concrete companies, while few small, young companies endeavour to introduce innovation, most practitioners are *"waiting for others to start the movement"*. Although some cooperatives are investing in some CE and IC when possible, budget conscious housing providers such as local authorities **prioritise** affordability over sustainability and innovation and focus lies on the 'easier' energy transition.

- **Governance**

Current **building regulations** are described as *"very conservative and not adaptable"*, actively favouring wet construction, restricting recycled content, and failing to support reuse. Although EU **policy initiatives** are positively influencing change towards CIH, and circularity in particular with the EU Taxonomy and revised Energy Performance of Buildings Directive (EPBD), central Spanish government remains conservative and does not sufficiently support market changes while national rules block innovative local initiatives (e.g. joint tenders). The absence of IC definition prevents government **subsidy** support, with housing providers and cooperatives instead relying on EU funding, although some interviewees questioned whether subsidies alone could meaningfully shift market behaviour. **Ownership** complexities are commonplace as most homes are privately owned, perpetuated within the 'Vivienda de Protección Oficial' social housing model, which transfers to private ownership after a set period. Innovative **procurement** using joint designer-contractor tenders piloted in Catalonia proves effective for CE-IC integration but is blocked from repeating in future due to conflict with national law.

"Building regulations is a big issue. I mean, we cannot face 21st century sustainability challenges with regulations that are from the late 20th century. But that's a battle and a war that we are fighting to change. The new EPBD will kind of try to push and improve and to push forward on that." Spanish policymaker/housing provider

- **Financial**

With few circular product producers and lack of timber industry, **material costs** are significantly high, and additionally notably higher for circular industrialised solutions in conservation areas and refurbishments. IC is considerably more expensive compared to traditional construction in Spain, where construction companies exhibit substantial inertia to invest in 'expensive' **factory costs** and technologies. The large volumes needed for economies of scale are lacking due to the limited social housing sector and small cooperatives producing one-off projects. **Business models:** A fragmented value chain, lack of CIH demand, and particularly high cost of circular renovation limit CE and IC viability; innovations in these areas don't yet 'make business sense'. Asset owners significantly lack **funding** for CIH, often relying on European Horizon and Next Generation funds to advance CE and IC research within private companies and support sustainability-conscious cooperatives. Crucially, Spanish banks do not finance upfront borrowing for off-site works, fundamentally undermining IC.

- **Site & Logistics**

Material supply chains are ill-equipped to support circularity as the lack of domestic timber industry prevents transitions to bio-based materials, instead relying on imports while reuse markets are undeveloped.

Critically, there are few IC contractors to work with or standardised solutions on the market for designers to specify.

- **Construction System**

Regarding **materiality**, concrete dominates, with most off-site contractors utilising prefabricated concrete, limiting end-of-life material recovery to downcycling. Designers continue to favour concrete structures due to perceived durability and familiarity, though a gradual shift towards timber is emerging.

4.3.2. Spain Best Practices

- **Financial**

The cooperative **housing model** and movement is increasingly embracing innovation through the integration of CE and IC, principally via off-site CLT construction. Given the acute shortage of government-owned housing stock, Spain's reliance on a diverse mix of cooperatives, public-private partnerships, and social housing models to deliver affordable housing presents a meaningful opportunity to advance circularity across the housing sector.

- **Governance**

Housing model innovation is supported by **land regulation & permits**, which are designed to lease municipal land through Grant of Use agreements that unlock future social housing, as demonstrated by La Borda. Whilst this approach remains largely concentrated in Barcelona, there is considerable potential for replication across Spain.

4.3.3. Spain Survey Results Part 2 - Stakeholder Perceptions Spanish participants identified 'building regulations' and 'cultural norms' as equally the most critical barriers, followed by high 'material costs'. The greatest opportunities were perceived in 'material supply' - specifically market provision of CE and IC products - followed by supportive 'policy initiatives' and 'procurement' methods.

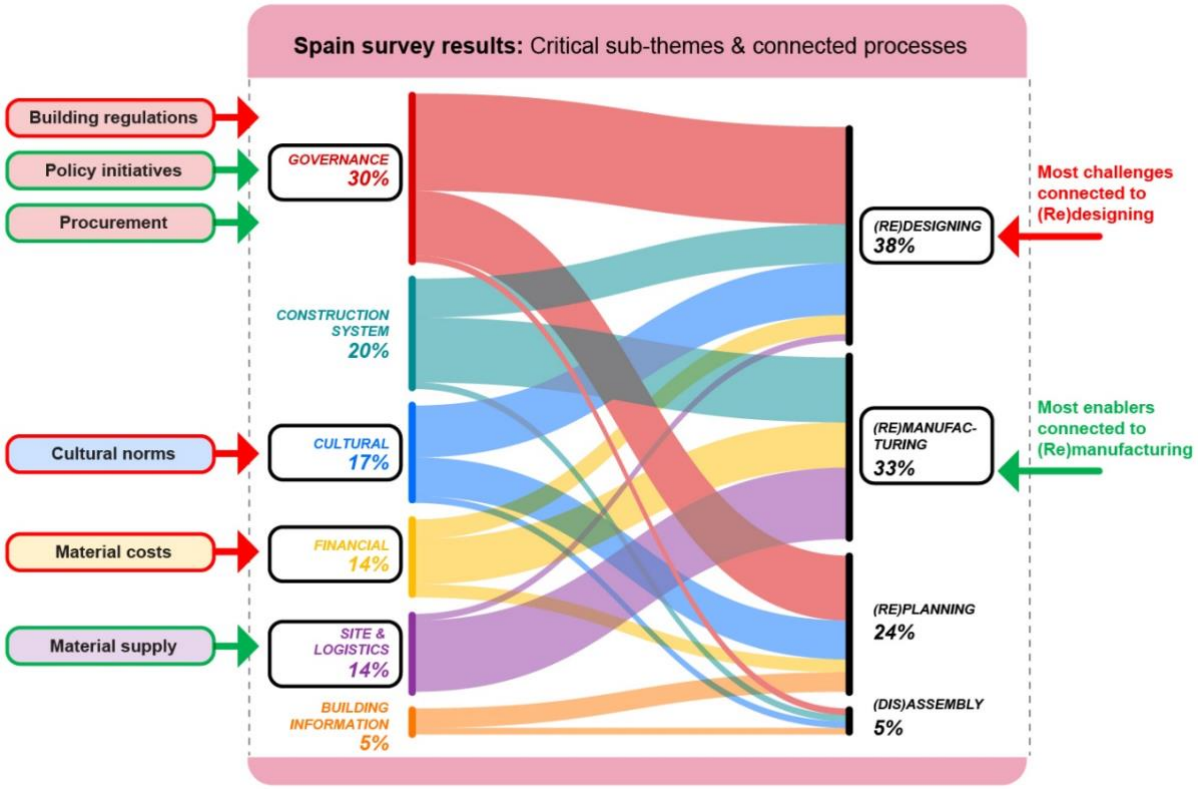


Figure 7. Spain survey results: critical factor and lifecycle process relationships

Critical challenges were most strongly associated with the (re)designing process and opportunities with (re)manufacturing. This diverges from the Part 1 of the survey results, where (dis)assembly was considered the most challenging process overall.

4.4. United Kingdom: Critical Challenges and Opportunities

UK interviewees identified strong interconnections between risk-averse cultural norms, inadequate regulatory ambition in embodied carbon and net zero, and the dominance of speculative developers as compounding barriers to CIH. A historically fragmented industry, resistant to net zero commitments, is further constrained by government reluctance to challenge developer interests. Negative public associations with post-war prefabrication and heightened timber aversion following the Grenfell Tower fire present particularly entrenched cultural obstacles to CE and IC advancement.

4.4.1. UK Critical Challenges

- **Cultural**

Cultural norms reflect preference for traditional brick aesthetics and home ownership, compounding resistance to IC, which is strongly associated with low-quality post-war prefab housing; proponent designers consequently avoid terms such as 'prefab' or 'volumetric' with clients, instead adopting language such as 'new technology'. Crucially, extreme risk aversion to unconventional technology or materials directly impede financial and legal support for CE and IC. A strong activism and lobbying culture is present, particularly amongst designers, to overcome blockers to establishing greater environmental regulation. Whilst small, experimental housing associations increasingly **prioritise** sustainability and actively embrace CIH, speculative developers and traditional contractors dominate the market and demonstrate waning commitment to net zero and affordable housing delivery. IC has also been exploited for greenwashing purposes, as one off-site construction interviewee noted: *"there's a lot of greenwashing that goes through MMC companies"* and *"a lot of smoke and mirrors"*, with sustainability used to mask profit-driven motives.

- **Governance**

Interviewees believe current **building regulations** on zero embodied carbon are "not serious", with both industry practitioners and policymakers unanimously supporting the introduction of 'Part Z'. The infrequency of regulatory updates - approximately every decade - further impedes CE and IC integration. Post-Grenfell fire regulations for timber construction have become unjustifiably onerous, disincentivising CE strategies. Regarding **land regulation & permits**, the British planning system, described by architects as *"consent and permission based"* favours profit-driven development and traditional brick aesthetics, creating persistent barriers to CIH pipelines. **Tax** exemptions favouring demolition and new build over retrofit, specifically VAT, continues to undermine the CE business case. Home **ownership** dominates whilst council housing stock is eroded from Right to Buy and exacerbates multiple ownership issues. One interviewee suggests providing a steady supply of permission service plots *"going straight to families and groups and allowing housing associations to just crack on and build"*. Building **procurement** and how risk is structured in agreements presents a major blocker, currently innovation in CIH systems such as dry construction, DfD and reuse are assumed risky and therefore priced up by traditional delivery contractors. This detachment counters the superior quality products, reduced project programme and future cost gains CE and IC methods can deliver. **Warranting & insurance** are difficult to obtain due to the perceived CE and IC risk. BOPAS and NHBC Accepts accreditation are costly and burdensome to obtain and often ineffective if a claim is made. As elements cannot legally be reused for the same architectural function, they are instead used creatively for finishes or features.

"Our land system is dominated by speculative house builders who have no long-term interest in the maintainability or performance or quality of housing as a place to live. So the only thing that will make them make better homes is regulation, basically. Because the market doesn't have really a competition in effect, it's such a stitched-up market that unfortunately it doesn't function in a reactive way to kind of regulate and improve quality really at all." UK Architect

- **Financial**

In terms of **factory costs,** interviewees provide mixed feedback as to whether IC is cost neutral to traditional, which is highly dependent on previous experience working with the same delivery team. The UK has historically suffered from investment in "white elephant" factories targeting high volumes (e.g., 1,000 units annually), however, *"the constant demand is just not there"*. It is difficult for off-site contractors to compete with traditional contractors, who are not obligated to pay high costs for testing to meet warranty and funding requirements. Housing association **business models** operate on 35 to 45-year financial planning horizons and express readiness to adopt CE and IC, but the market has not matured sufficiently. Misaligned incentives and higher upfront costs relative to traditional construction mean CIH is widely perceived as an additional financial burden while increasing risk exposure. **Funding** from mortgage lenders presents a significant barrier to industrialisation, requiring ten-year warranties, effectively excluding many IC products from financing eligibility. Similarly, banks remain reluctant to finance unproven methods such as DfD and reuse. Designers undertaking CE and IC research and development operate on severely constrained budgets, reliant on unpredictable external funding sources, such as the Forestry Commission and Innovate UK grants. Investor-dependent funding models introduce additional instability, with some IC companies unable to effectively manage large capital injections.

- **Site & Logistics**

Regarding **material supply**, new IC products are beginning to enter the market, including prefabricated facade panels, insulation systems, and internal wall systems, however, standard CIH systems remain commercially unavailable for procurement. The reuse market is severely underdeveloped; as one architect observed, *"the market is so primitive for reuse of building materials, it's almost laughable".* Supply chain unpredictability and contractor reluctance to commit to materials early has negative knock-on effects on procurement. A severe lack of **storage** infrastructure compounds these challenges, particularly on inner-city sites, and whilst pilot commercial hubs are emerging, scaling reuse requires coordinated government and local authority intervention that is currently absent.

- **Building Information**

Information type is fundamental for CE and IC transitions, which depend on digitalisation and material passport adoption, yet the data currently available is insufficient and unreliable. Designers operate with basic in-house passporting but lack the infrastructure for robust adoption and estimates of use cycles for housing units and components are produced crudely by contractors and architects alike, likely representing significant underestimates.

4.4.2. UK Best Practices

- **Governance**

Positive developments in **policy initiatives** focus on circularity, namely CE Statements, and a growing focus on embodied carbon aligned with net zero targets. Specific local authorities are leading practice, notably Westminster's Retrofit First policy, though progress remains largely London-centric. Scotland has produced a CE route map and Wales has introduced emergency measures for IC housing, indicating emerging momentum across devolved governments. A Part Z regulation would strengthen mandated policy.

- **Construction System**

Supporting equipment advancements in CNC machining within mainstream housing facilitates a distributed IC model for small-scale timber projects, offering an alternative to the significant investment required by larger factories. Laser scanners and 3D printed bricks and stone have been successfully applied in conservation areas and listed buildings. Paperless, screen-based assembly demonstrates promising improvements to IC delivery and quality, though fit-out remains predominantly manual.

- **Building Information**

Assessing existing buildings through formalised 'pre-redevelopment' **audits** prove increasingly crucial for planning authorities and designers, with 'pre-demolition' audits also considered best practice, though robust standardised templates remain absent. Where sustainability consultants are proactively engaged, audit recommendations can be effectively translated into on-site KPIs.

Digitalisation is generating considerable enthusiasm, with open-source CE and IC solutions such as WikiHouse being adopted by housing associations, designers are developing kit-of-parts and BIM 'libraries' and 'digital warehouses', which are shared with off-site contractors, enabling QR-code-linked assembly, supporting digital passporting and digitalisation of the supply chain. Digitalisation is widely seen as central to enabling upfront reuse, though full implementation across the sector remains early stage.

4.4.3. UK Survey Results Part 2 - Stakeholder Perceptions British participants considered 'business models' the most critical challenge, followed by misaligned 'priorities' and 'building regulations' equally. The greatest opportunities were considered in 'material supply', followed by 'business models', 'information type' and 'digitalisation' equally.

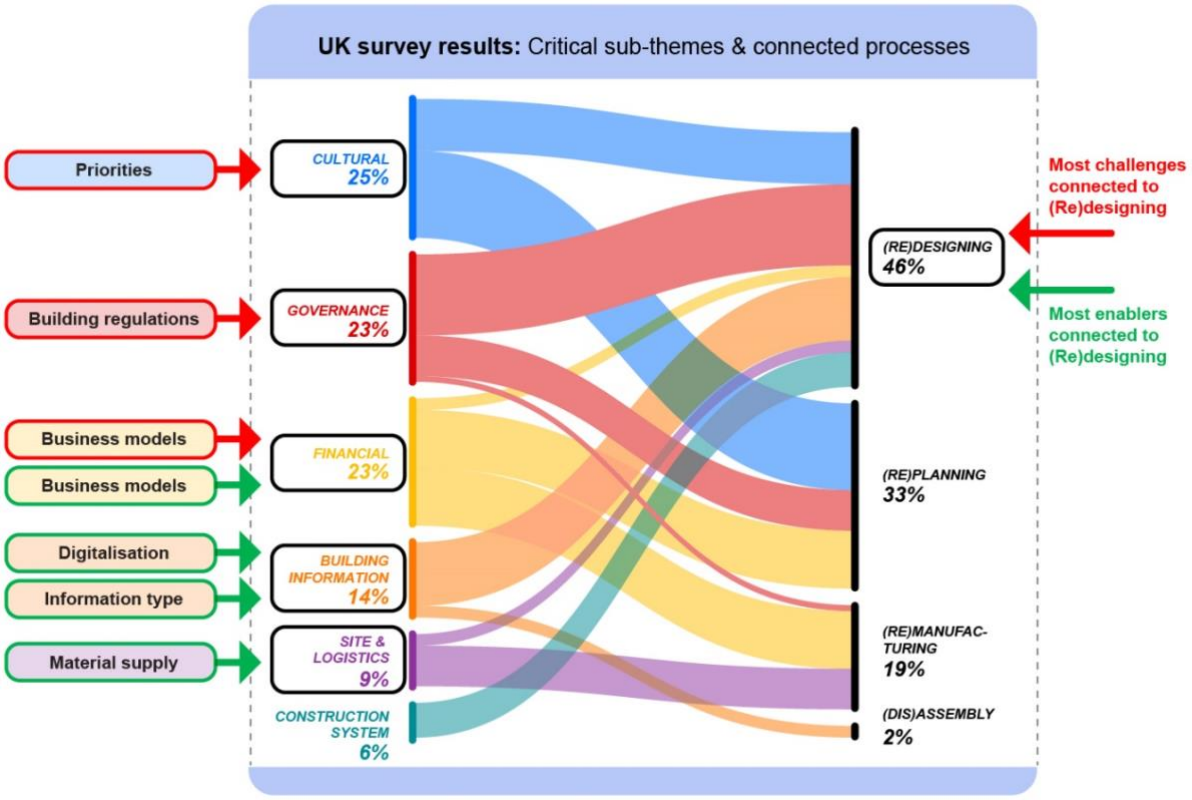


Figure 8. UK survey results: critical factor and lifecycle process relationships

Examples of both critical challenges and opportunities were most connected to (re)designing. This differs slightly from the Part 1 of the survey results, where (re)planning was also considered a hotspot for enablers.

4.5. The Netherlands: Critical Challenges and Opportunities

Interviewees identified strong interconnections between collaboration, policy, and education as key enablers of CIH in the Netherlands, with policy initiatives both supporting and shaping cultural change, fostering industry-wide knowledge exchange. The Dutch housing industry demonstrates collaboration both amongst off-site housing contractors, housing associations, designers and policymakers and cross-industry collaboration with agriculture and steel to collectively lobby for regulatory change towards a Circular Economy. Whilst CIH pilot projects are expanding, their scale remains modest.

4.5.1. Dutch Critical Challenges

- **Governance**

Reuse of housing units presents **building regulation** challenges, particularly where recertification of modules is required under evolving building codes. Designers and housing associations advocate for more ambitious embodied carbon targets within the 'Milieu Prestatie Gebouwen' (MPG), which is currently mandatory for new builds, though the revised EPBD may positively influence existing stock. Interviewees highlight that tightening environmental regulations do not sufficiently push circularity, existing CIH systems can meet standards by switching to virgin bio-based materials, rather than requiring reuse. While the Netherlands' predictable rules-based planning system holds advantages over the UK system, current **land regulations & permits** are based on rigid plot dimensions. These prove incompatible with standardised IC 'concepts'; interviewees suggest the government should stimulate uniformisation to enable replication across municipalities. Strict aesthetic planning rules favouring brick present further limitations.

- **Financial**

Business models struggle to match supply with demand for CE and IC, with reuse largely absent from IC companies. Housing associations use a total cost of ownership approach but find lifecycle costing difficult to predict and challenging to balance financial risks across the value chain. Circular approaches incur higher short-term costs while interviewees consider long-term projected residual value beyond five years too distant to inform viable business cases.

"I got a message from the guy that works at a demolition company asking Are these your housing units? So I went to some guys who have worked at our company for 40 years. And they said yeah, I know these things. We made them 30 years ago... And he asked will you take them back and do your refurbishment? And we said, no, it's too old. So it's not part of our business anymore. But then I started to wonder, what is going to happen? And I know there is a marketplace for these used units and used modules." Dutch Off-site Contractor

- **Site & Logistics**

Although not highlighted significantly by interviewees, **storage** pressures due to land scarcity are likely to present a significant bottleneck in the near future as reuse markets develop, exacerbated by acute land scarcity. Some large construction companies have developed circular hubs enabling housing associations to utilise reclaimed materials at project inception. Reuse supply chains and deconstruction contractors are more developed than in the UK, though government intervention to scale reuse infrastructure remains limited.

4.5.2. Dutch Best Practices

- **Cultural**

Effective **education** in CE and IC is delivered through peer-to-peer cross-stakeholder learning that is driven equally by housing associations, off-site contractors and designers. Experience gained from pilot projects is shared through network workshops such as NH Bouwstroom, alongside practitioner training in emerging CE certifications including the Building Circularity Index (BCI). Interviewees suggest that improved storytelling is needed to broaden support across the supply chain. **Skills and experience:** although CIH is "far from mainstream" according to interviewed Dutch housing associations, the Netherlands demonstrates greatest experience in integrating CE with IC principles, where deconstruction contractors are more common compared to the UK and provide valuable expertise. **Collaboration** is well established through cross-industry knowledge exchange programmes, particularly in social housing, and through industry-government working groups that facilitate joint problem solving, partnership formation and regulation, engaging a broad range of stakeholders including deconstruction contractors, designers, housing associations, off-site contractors and cross-sector partners in agriculture and steel. **Cultural norms** in the Netherlands, characterised by direct communication in both formal and informal settings, a strong lobbying culture and a willingness to experiment, are broadly advantageous for CE adoption. While IC housing is gradually normalising, planners and architects tend to

prefer traditional brick construction, and public acceptance of material reuse remains a challenge. One housing association reported that tenants *"did not appreciate"* reusing old roof tiles, who questioned, *"Was there not enough money to put new tiles on?"*.

- **Governance**

Product regulation has seen progress in developing CE-compatible standards for second-life structural steel, achieved through self-initiated cross-industry networks and based on built demonstration projects and lobbying activity. The Dutch Norm Institute subsequently produced a 'pre-norm' giving engineers a workable framework, though the process took approximately five years. **Policy initiatives** demonstrate notable national commitment to CE, although not yet mandatory, the housing ministry's Lente Akkoord, which involved several actors from the construction sector, stands as a pioneering multi-year programme that uniquely combines CE and IC objectives. The Paris Proof policy limits embodied carbon nationally, housing association ESG reporting requirements also support the social dimensions of CE, and some local authorities have previously mandated IC on specific sites. Although considered a frontrunner in CE according to the Circularity Gap report, a Dutch policy advisor considers it as "only just at the beginning of taking off" in the Netherlands. They add that although thresholds for indicators such as embodied carbon could be more ambitious, policymakers must always adjust to *"follow the possibilities of the market"*. **Procurement** advancements are largely attributed to established joint tendering frameworks for housing associations via Bouwstroom initiatives, which interviewees described as transformative, and DfD and CE criteria are increasingly embedded in tender requirements. However, standard supplier clauses prohibiting the reuse of products elsewhere continue to impede circularity in practice. Although **warranting** second-life materials remains challenging, with onerous batch-testing requirements and limited secondary material data leading to over-engineering, designers are directly engaging with insurers to develop standard CE warranties. According to a Dutch architect, this is being advanced through translating recent advancements in Germany, where an insurer is developing guarantees for a defined catalogue of secondary products. Discussions are underway with a major Dutch insurer to establish a similar framework.

- **Financial**

Factory costs for IC are broadly comparable to those of traditional construction, though evidence remains limited and some practitioners report higher costs. IC companies typically target larger volumes, with emerging 'assembler companies' within partnering IC ecosystems. Factory cost savings are enhanced by the NH Bouwstroom framework; off-site contractors are assigned specific housing types at scale, a condition the UK market has yet to replicate. Traditional contractors are also increasingly investing in IC, driving greater market competition.

- **Site & Logistics**

Material supply demonstrates strong integration of CE and IC principles through market ready housing 'concepts' (defined housing types and rental classes) formalised within the Conceptenboulevard platform. Standardised typologies embed KPIs, which increasingly incorporate bio-based and circular principles, while Bouwstroom partners collaborate to co-produce customised housing elements for participating housing associations. In parallel, housing associations and contractors are establishing material banks, and architect-led initiatives such as Pretty Plastic address gaps in sustainable material supply within the market. Off-site contractors utilise a range of high-tech to low-tech **supporting equipment**, with assembly-line set-ups, CNC machining, automated vehicles, and semi-automatic robots for framing increasingly in use. Integration of 3D scanning with BIM and AI models is also being applied to industrialised renovations and retrofitting on-site, extending IC benefits beyond new build and supporting reuse further.

- **Building Information**

Digitalisation follows a broadly similar trajectory to the UK, with off-site companies employing customised design systems such as BAM's Flow system and pursuing AI integration across design and manufacturing workflows, supported by platforms such as Madaster and the Conceptenboulevard. **Assessments & simulations** are being advanced through the BCI developed by Alba Concepts, which embeds CE and DfD principles through a pioneering disassembly index, that according to interviewees the EU is

considering adopting, though it remains non-mandatory and is applied predominantly in public projects. The MPG assessment adopted into policy for new builds represents a positive step for environmental lifecycle assessment, although several interviewees recognised limitations and loopholes in the methodology.

4.5.3. Dutch Survey Results Part 2 - Stakeholder Perceptions Dutch participants considered 'business models' and 'building regulations' equally as the most critical challenges, followed by 'land regulation & permits'. The greatest opportunities were considered 'policy initiatives', followed by 'theoretical design', and 'priorities' aligned to CIH.

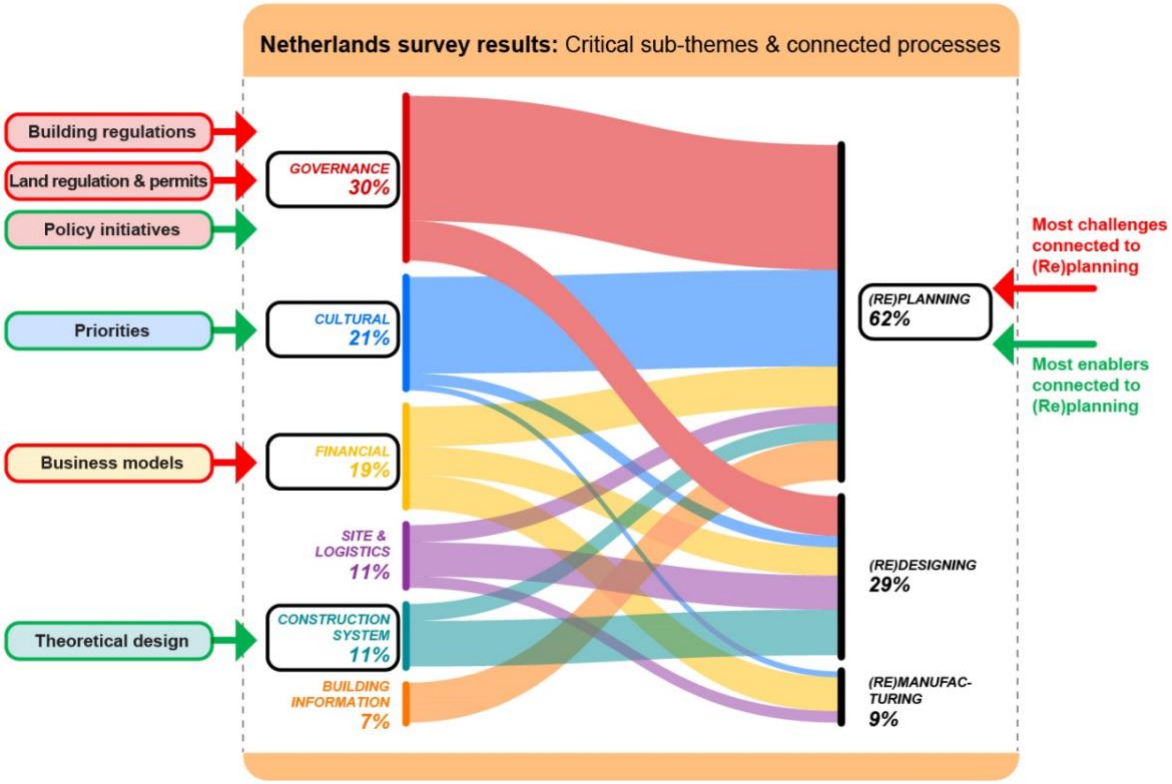


Figure 9. Netherlands survey results: critical factor and lifecycle process relationships

Examples of both critical challenges and opportunities were most connected to (re)planning. This matches results from Part 1 of the survey, where (re)planning was considered the process with greatest potential overall.

4.6. Key Similarities and Differences

Across all three countries, certain factors simultaneously emerged as hotspots for both critical challenges and best practices. This reflects the presence of opposing sub-themes within the same factor category: within governance, building regulations were identified as a barrier in all three countries while policy initiatives were recognised as an enabler (in Spain and the Netherlands); within the financial category, in the UK circular business models were identified as both a critical challenge and an opportunity. This duality is an inherent feature of the analytical framework, reflecting how critical challenges can simultaneously represent key opportunities, and should be expected in future applications to other national contexts.

4.6.1. Similarities The governance factor presents the greatest concentration of critical challenges across all three countries, while sub-themes 'building regulations' and 'business models' are common bottlenecks, although the nature of regulatory challenges differ by context. EU policy frameworks are advancing sustainability in the Netherlands and Spain, whilst the UK's exit from the EU limits alignment and presents missed opportunities to advance circularity, with future divergence likely. All three countries have benefited

from international knowledge transfer, and notable shared trends include the increasing digitalisation of IC, the perception of IC as a first step towards circularity, and CE-IC application found to be easier in new build compared to existing buildings. The factors and processes identified as most critical are partially shaped by professional background across the countries: architects prioritised (re)designing, housing providers and policymakers (re)planning, and contractors (re)designing and (re)manufacturing.

4.6.2. Differences Key differences reflect the varying maturity levels of the three countries. The Netherlands has largely resolved cultural blockers through supportive policy, collaborative partnerships and education, whilst cultural resistance remains significant in both the UK and Spain. Governance approaches diverge considerably: Spain has virtually no regulation supporting CE or IC; the UK has fragmented local CE policy but lacks national regulation; and the Netherlands combines CIH-targeted policy with mandatory whole-life carbon assessment, though Dutch practitioners consider this insufficiently ambitious. Collaboration and lobbying occur in all three countries but differ in scope, ranging from small-scale and regionally siloed in Spain, to designer-led in the UK, to genuinely cross-sectoral in the Netherlands. The scale of social and affordable housing provision in the Netherlands further shapes conditions for market maturation in ways not currently available to the UK or Spain. At the time of data collection (2024-2025), UK participants reported a declining number of IC companies whilst Dutch participants noted a growing market, consistent with the maturity levels described above. Reuse activity was reported as increasing across all three countries.

5. Discussion

Overall, interviewees across all three countries view CE and IC as complementary and mutually reinforcing, with their integration considered one of several key strategies for improving housing affordability, environmental sustainability and socially inclusive solutions. The connection between CE and IC hinges upon several common principles and goals. IC's controlled manufacturing environment, standardisation, and product-based approach create the practical conditions that make circularity more achievable (Kieran & Timberlake, 2004). Prefabrication enables greater precision in material use and component specification, whilst standardised building systems support DfD and future reuse, remanufacturing and reassembly (Crowther, 2005). Digitalisation and product traceability, inherent to industrialised processes, further facilitate closed-loop material flows by enabling components to be tracked, recovered, and retained within supply chains across multiple building lifecycles (Çetin, De Wolf, et al., 2021; Qi et al., 2021). Continuous learning and collaborative refinement of housing products, characteristic of mature IC markets, similarly support iterative improvements in environmental performance, quality control, regulation and auditing that are difficult to achieve through traditional bespoke construction (De Wolf et al., 2024; European Commission, 2020b; Lessing, 2006).

Housing industries worldwide are transitioning gradually towards industrialisation, a trajectory that interviewees across all three countries considered inevitable given declining skilled construction workforces, a concern for the construction sector that industry and grey literature has recognised over the past decade, particularly in the UK (Farmer, 2016; Holmes & Burgess, 2025; McKinsey, 2020). The CE transition proves more challenging, remaining at an earlier stage than IC. Its relatively recent application to construction, alongside the inherent complexity of buildings, partly explains current limitations in advancement. Notably, whilst the Circularity Gap Reports position the Netherlands as a CE frontrunner, Dutch experts were humble about progress within the affordable industrialised housing sector. In contrast, Spain lacks equivalent official reporting, yet practitioners and policymakers are driving meaningful local CE developments. These findings highlight the limitations of grey literature as a representation of real-world activity.

Housing providers are universally grappling with CIH's potential for long-term financial benefits whilst focussing on immediate obligations to deliver affordable housing. Energy efficiency's tangible short-term financial returns currently prove more compelling than CE's extended timeframes, revealing an implicit prioritisation of affordability over environmental or social considerations. Housing associations, councils and increasingly cooperatives, however, demonstrate growing willingness to justify longer-term investments in circular and industrialised methods.

The results support the hypothesis that the Netherlands is most advanced in integrating circular and industrialised practices within the social and affordable housing sectors, evidenced by a greater number of best practices, fewer blockers, and participants' wider implementation experience. Spain is least developed, with the UK occupying an intermediate position. In more mature contexts, both challenges and success factors concentrate around the early, brief-defining and pre-design processes encompassed by (re)planning, suggesting a shift in focus towards systemic transformation once barriers within the other lifecycle processes have been sufficiently addressed.

The mixed methods approach adopted in this study complements and extends those of comparable studies, including Leising et al. (2018), Kedir et al. (2023) and Kaewunruen et al. (2024). Their findings identify governance, financial and cultural factors as hotspots for critical challenges and opportunities in CE and IC practice, corresponding with the results of this study, further emphasising that non-technical factors are key determinants of CIH success.

Kaewunruen et al. (2024), exploring CE in existing buildings across five European countries, identify central government, asset owners and managers, and financial institutions as the most influential factors, consistent with the governance, cultural and financial factors highlighted as key across Spain, the UK and Netherlands. Kedir et al. (2023), examining CIH in three African nations, identify building regulations (governance) and supply chains (site and logistics) as major barriers, findings that particularly parallel with Spain, the least mature context in this study, where the supply of national CIH products remains under-developed. Leising et al. (2018), engaging a range of Dutch interviewees across the supply chain lifecycle focussed on CE business models in existing buildings, found ownership (governance) alongside cultural challenges in collaboration and establishing circularity as a priority from the outset to be the most significant, consistent with the importance of (re)planning in this study's findings.

Previous framework iterations by the authors identified (re)planning and governance as underexplored in CIH literature and in application to affordable housing models. This study confirms their critical importance and reveals that they are deeply interconnected in practice, with governance conditions directly shaping (re)planning. This interconnection, alongside financial and cultural factors, highlights the value of cross-national comparison in identifying transferable best practices and shared challenges in CIH implementation.

5.1. Advancing CIH Maturity: Top-down Versus Bottom-up Change

As practitioners and policymakers advance towards CIH and improved affordability, this study provides insights into why different maturity levels are observed and what the roadmap towards greater maturity could entail. Whilst Spain, the UK and the Netherlands exhibit context-specific conditions, they are broadly representative of three distinct maturity levels generalisable to other European and non-European contexts. Examining institutional constraints alongside industry trends, three modes of change emerge: top-down, bottom-up and hybrid approaches, exhibited by Spain, the UK and the Netherlands respectively, operating across both national and local scales. The conversations with practitioners and survey results illuminate how policy and regulation, pertaining to governance factors, described here as 'institutional', and market reactions and developments, described as 'industry' shape CIH maturity.

These three models, alongside their institutional and industry characteristics, are described in Table 1 and illustrated in Figure 10.

Table 1. Top-down, Bottom-up and Hybrid models

Model	Institutional		Industry	
	National	Local	National	Local
Top-Down: Slower maturity. Exhibited by Spain	• Central government policy does not support CE/IC or affordable housing. • Insufficient environmental regulation. • Lack of subsidies.	• Local policies supporting CIH blocked by national regulations and policy frameworks. • Innovative CIH delivery mechanisms remain one-off examples.	• Siloed industry remains traditional, lacking the education, skill and experience for CIH. • Asset owners lack financial means/will to implement CE/IC practices.	• Designers/supplier efforts hindered by institutional blockers. • Perpetuating minimal CIH demand and inhibiting technical innovation.

Table 1 (cont.). Top-down, Bottom-up and Hybrid models

Model	Institutional		Industry	
	National	Local	National	Local
Bottom-Up: Moderate maturity. Exhibited by the UK	• Weak central government policy for CE/IC or affordable housing. • Insufficient environmental regulation. • Legal barriers to CE and IC. • Limited subsidies.	• Local authorities establishing innovative circular policies. • National frameworks inhibiting wider regional or national adoption.	• Siloed industry does not fully embrace CE/IC and profit-driven actors dominate, influencing regulatory stagnation. • Broad industry-led initiatives developing, demanding greater regulation.	• Companies create products and in-house tools to embed CE/IC. • Limited small-scale reuse/circular hubs. • Industrialised house builders significantly struggle with inconsistent demand pipelines.
Hybrid: Enhanced maturity. Exhibited by Netherlands	• Strong national policy supports CE/IC and affordable housing, enhancing CIH demand. • Enhanced education that encourages CIH uptake. • National-level sustainability regulation (e.g. embodied carbon).	• Local-level policy and pilot projects generally supported by central initiatives. • Remains difficult to replicate CIH across regions. • Rules based planning permit system both supports and limits CIH.	• Established IC market attracts investment by traditional contractors. • Industry unites to create and demand regulatory change. • Cross-industry collaborations develop CIH products. • Cross-sector collaborations harness industrial symbiosis.	• Formal/informal networks connect industry with local and central government, facilitating negotiation. • Local initiatives develop into established regional collaborations and partnerships to co-develop CIH products. • Limited CE hubs.

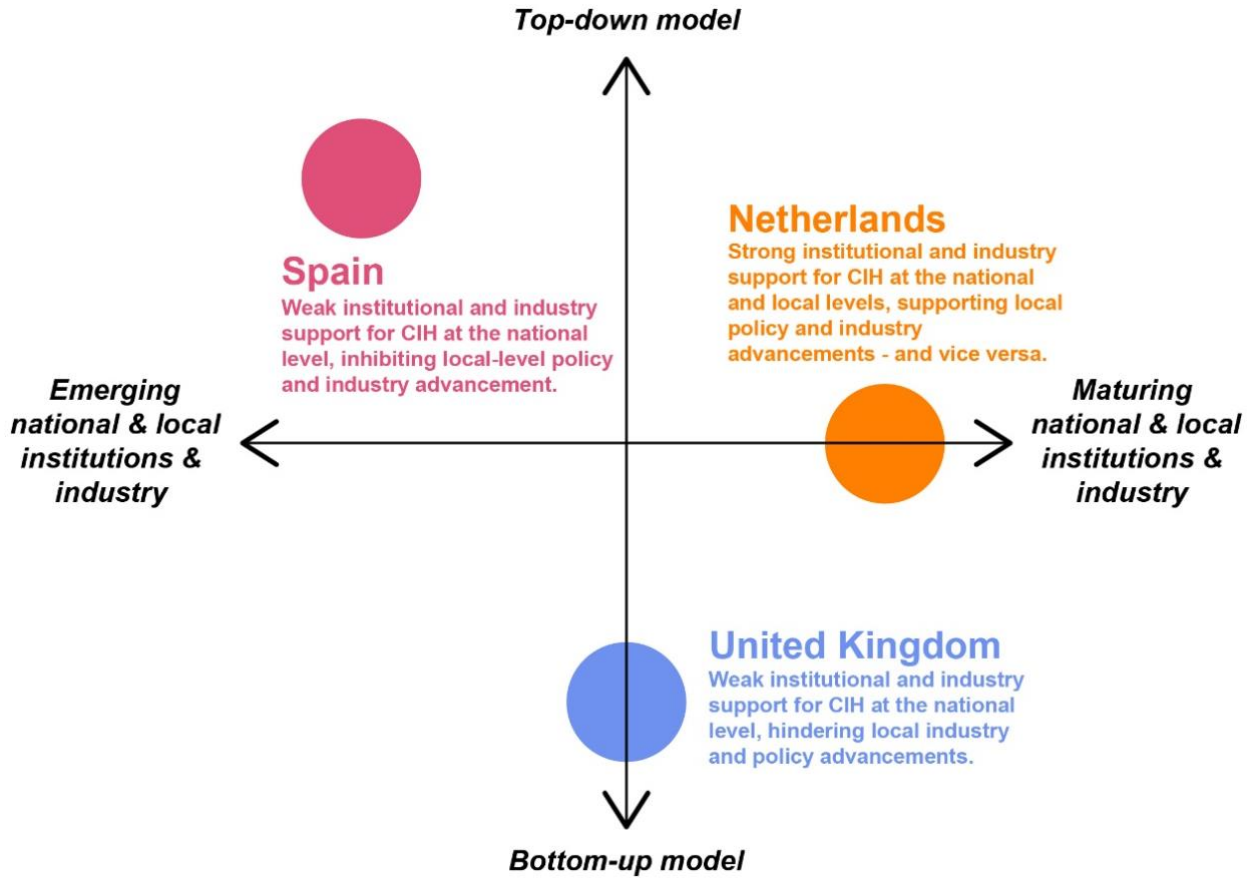


Figure 10. Exploring the relationship between top-down/bottom-up/hybrid models and CIH maturity

These categorisations should not be interpreted as suggesting an absence of progress in Spain or optimised practice in the Netherlands. The hybrid approach continues to face challenges in balancing competing priorities, and market dominance by CIH is neither necessary nor expected. However, establishing a viable CIH market sector is essential for scaling experimental pilots and advancing implementation beyond isolated projects. Whilst some factors may require longer-term systemic change, local-level interventions could prove more immediately achievable in the shorter term.

5.2. Limitations

Whilst this research strives to provide an objective and representative overview of CIH in the UK, Netherlands and Spain, the findings are not definitively representative, as data was collected from a limited sample of individuals. To compensate for this, interviewees were asked to comment on developments across their country, and interviewees from the Green Building Council in each country were included, who possess greater authority on national guidelines and trends. Descriptions of developments in industrialised technologies are limited by the first author's factory visits in addition to interviewee data.

6. Conclusions

This study advances understanding of CIH implementation through practitioner-informed, process-driven analysis across three European contexts, contributing primary empirical data from practitioners at the forefront of CIH in settings representing high, medium and low levels of social and affordable housing provision, industrialised construction and national circularity advancement.

Barriers and enablers to CIH were identified, categorised and compared across the UK, Netherlands and Spain. Practitioners across all three countries view CE and IC as complementary strategies for improving housing affordability, environmental sustainability and social inclusion. A manufacturing approach, built on continuous learning and collaborative product refinement, supports improved quality control and environmental performance compared to traditional construction. As less mature markets develop elsewhere, it is important that circularity is embedded from the outset and avoidable challenges are not repeated.

The interrelation between critical factors and lifecycle processes highlights the particular importance of governance and cultural factors in relation to (re)planning. The lifecycle process lens can help identify where progress is blocked and indicate levels of CIH maturity. These patterns were connected to top-down, bottom-up and hybrid models, shaped by regulatory, behavioural and market phenomena, which can help pinpoint which challenges need to be addressed next on the roadmap towards a mature CIH market.

6.1. Recommendations

Both CE and IC require integration into national policy frameworks, supported by subsidies and sustained engagement to shift cultural norms and public perceptions. CE regulation should expand progressively beyond embodied carbon to include biodiversity, a range of resources and social indicators, taking a quantitative approach through mandatory whole-life LCA as demonstrated by the Netherlands. Policies piloted at the local level must be integrated into national planning frameworks and mandated accordingly, given the urgency of meeting net zero targets. Greater cross-industry and cross-sector collaboration is essential to realise the CE-IC transition, navigate political cycles, and build the infrastructure needed for reuse markets and circular supply chains. International collaboration at both industry and policy levels has proven a consistent driver of change; the UK in particular would benefit from greater alignment with EU standards such as the Taxonomy and EPBD. Presenting findings in formats accessible to policymakers is also vital, and the framework developed in this research can support such communication across different national contexts.

6.2. Future Research

Future studies should overcome the limitations of this study by including a larger number of participants across each of the four categories (policymaker/disseminator, housing provider, designer and off-site contractor), with a minimum threshold per category to ensure balanced representation. A larger sample would also enable more

deliberate engagement with practitioners from different regions within each national context. This should be complemented by a broader survey pool that extends beyond interview participants to capture a wider range of professional perspectives and strengthen triangulation. For studies outside the industrialised housing sector, the 'housing provider' and 'off-site contractor' categories may be adapted to 'asset owner' and 'contractor' respectively, to include deconstruction contractors.

This study opens several avenues for further investigation. The authors will refine the framework based on participant feedback, cross-comparing with previous iterations for testing in practitioner workshops. Future research could explore multi-level dynamics between national and local scales, investigate emerging reuse markets and supplier types in more developed contexts such as the Netherlands, and apply the framework comparatively to additional countries, particularly Northern European nations with established social and industrialised housing sectors. As housing sectors worldwide face growing pressure to balance affordability with environmental impact, this research demonstrates that technical solutions alone are insufficient; governance structures, market maturity and cultural context must be aligned to support the circular and industrialised transitions in housing.

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Data Availability Survey data supporting the findings of this article are available from the corresponding author upon request. Raw interview data cannot be made available, as disclosure would risk identifying the organisations that participated in the study.

Declarations

Competing Interests The authors declare no competing interests.

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Appendix A

Supplementary Information Code	Number of Interviews	Number of Post-Interview Surveys	Organisation Type	Interviews: Number of Participants	Surveys: Number of Participants	Participant Role	Policymaker/ disseminator (a)	Housing Provider (b)	Designer (c)	Off-Site Contractor (d)
SPAIN: 8 Interviews (10 Participants) & 7 surveys (8 Participants)										
ES-1	1	1	Architecture Company	1	1	Chief Innovation Architect			X	
ES-2	2	2	Regional Government - Ministry of Territory & Sustainability	2	2	Project Coordinator	X	X		
				3		Director Of Operations	X	X		
ES-3	3		Architecture Practice	4		Co-founder			X	
ES-4	4	3	City Council - Municipal Institute of Housing & Renovation	5	3	Project Coordinator	X	X		
				6	4	Project Architect (in-house)	X	X		
ES-5	5	4	Architecture Company	7	5	Owner & CEO			X	
ES-6	6	5	Green Building Council	8	6	Development & Content	X			
ES-7	7	6	Off-site Housing Construction Company	9	7	Director of R&D Department				X
ES-8	8	7	Sustainable Building Consultancy	10	8	Project Management			X	
UNITED KINGDOM: 10 Interviews (11 Participants) & 8 Surveys (8 Participants)										
UK-1	9	8	Architecture Company	11	9	Associate Partner			X	
UK-2	10	9	Off-site Housing Construction Company	12	10	Managing Director				X
UK-3	11	10	Engineering Company	13	11	Regional Director			X	
UK-4	12	11	Housing Association	14	12	Director		X		
UK-5	13	12	Housing Association	15	13	Business Development Director		X	X	
UK-6	14	13	Architecture Company	16	14	Founder			X	
UK-7	15	14	Housing Association	17	15	Assistant Director of New Business		X		
UK-8	16		Architecture Company	18		Associate Director			X	
UK-9	17	15	Local Council (for a London Borough)	19	16	Principal Sustainability Officer	X			
UK-10	18		Green Building Council	20		Head of Nature & Resource Use	X			
				21		Project Officer - Circular Economy & Nature	X			
NETHERLANDS: 9 Interviews (10 Participants) & 8 Surveys (9 Participants)										
NL-1	19	16	Off-site Housing Construction Company	22	17	Commercial Director				X
NL-2	20	17	Off-site Housing Construction Company	23	18	BIM Coordinator				X
				24	19	Project Leader R&D Sustainability				X
NL-3	21	18	Government Commissioned CE Advisory Group	25	20	Chairman	X			
NL-4	22	19	Housing Association	26	21	Quality Manager		X		
NL-5	23	20	Association of Housing Associations	27	22	Program Manager & Sustainability Advisor	X	X		
NL-6	24	21	Architecture Company	28	23	Founder			X	
NL-7	25	22	Housing Association	29	24	Executive Director		X		
NL-8	26	23	Green Building Council	30	25	Programme Manager - Paris Proof	X			
NL-9	27		Architecture Company	31		Founder			X	

Did not participate in post-interview survey

Appendix B

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Interview: Participant Information Sheet

This doctoral research project investigates the circular economy and industrialised construction transitions in housing, aiming to tackle the intertwined challenges of climate change and housing shortages. The aim of this study is to explore the barriers and enablers to circular industrialised housing across the whole building lifecycle, gaining insights from industry practitioners and policymakers in the UK, the Netherlands, and Spain. These findings will contribute towards the development of an interdisciplinary framework that empowers key stakeholders to achieve circular housing solutions through industrialised construction, prefabricating building components off-site that are also designed for future disassembly and reuse.

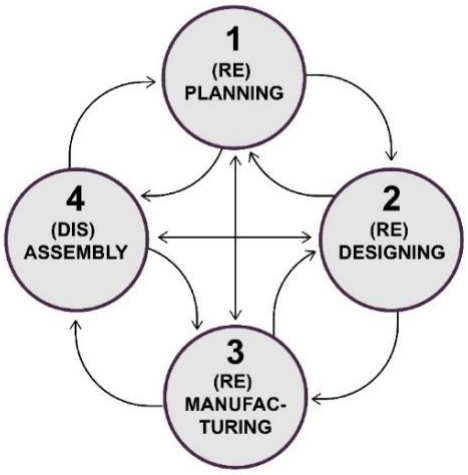
The interviews for this study build upon the development of a circular process framework for industrialised housing, which centres on four key processes, which may occur in varying sequences:

(Re)planning: *Informs the project brief and feasibility, typically occurring before a design team is appointed and largely consists of non-spatial information.*

(Re)designing: *The development of the conceptual and technical design of the building to produce geometric and material information.*

(Re)manufacturing: *The production of building materials and components, which typically takes place in a factory when utilising industrialised construction.*

(Dis)assembly: *Putting together/taking apart of building components and materials, and typically takes place on-site, transportation of parts to site included.*



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Interview Questions

Part 1

1. What does the **circular economy transition** in housing construction look like to you?
2. What is your understanding of **industrialised construction** and its application to housing?
3. What is your understanding of **design for disassembly** and its application to housing?
4. To what extent do you consider building longevity and the **lifespan of building parts**?

Part 2

For each of the previously described processes, please provide **examples of the pertinent challenges** in reuse of building parts and materials during the housing lifecycle and **recommendations** to improve resource efficiency.

5. **(Re)planning**
6. **(Re)designing**
7. **(Re)manufacturing**
8. **(Dis)assembly**

Part 3

9. Do you think the application of industrialised construction and design for disassembly are suitable for all housing projects**, both new build and existing buildings**?
10. From your perspective as built environment professional, **what role do you envision playing** in driving the transition towards a circular economy in housing? If you can, name specific **actions or strategies** that you think your industry can implement to facilitate this transition.

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Survey: Participant Information Sheet

Thank you for completing the interview and for taking part in this short follow-up survey. This study builds upon the development of a circular industrialised housing framework, which centres on four key processes and covers a range of holistic factors, which were discussed in the interview.

You may refer to the table below, which contains the four defined circular processes (rows) and six factors (columns), to answer the survey questions on the following pages.

PROCESSES	FACTORS: CULTURAL	GOVERNANCE	FINANCIAL	SITE & LOGISTICS	CONSTRUCTION SYSTEM	BUILDING INFORMATION
(RE)PLANNING Informs the project brief and feasibility, typically occurring before a design team is appointed and largely consists of non-spatial information.						
(RE)DESIGNING The development of the conceptual and technical design of the building to produce geometric and material information.						
(RE)MANUFACTURING The production of building materials and components, which typically takes place in a factory when utilising industrialised construction.						
(DIS)ASSEMBLY Putting together/taking apart of building components and materials, and typically takes place on-site, transportation of parts to site included.						

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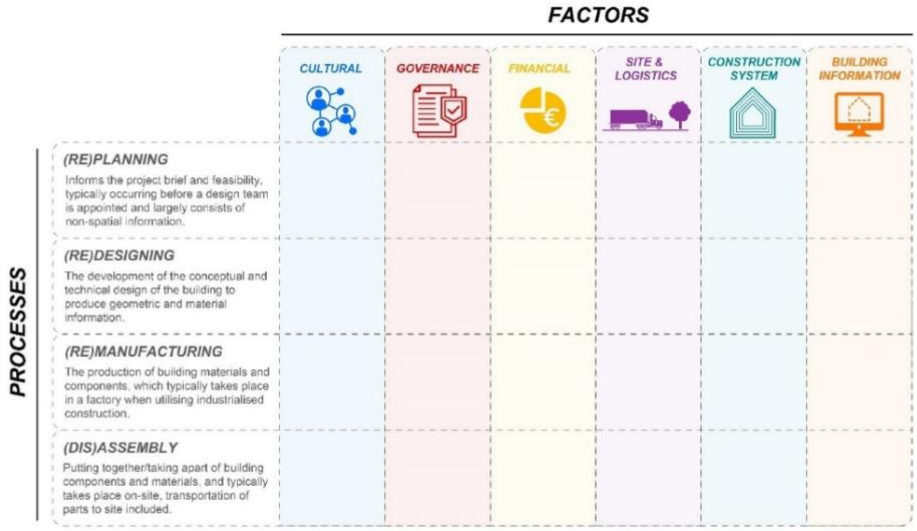
Survey Questions

1. **Considering the four processes discussed during the interview, please give a rating of 1 to 5 in terms of the challenges they present to circular industrialised housing.** 1 being unchallenging and 5 being highly challenging. (Mark with an 'X')

Process	Rating				
	1	2	3	4	5
(Re)planning					
(Re)designing					
(Re)manufacturing					
(Dis)assembly					

Considering the factors described (cultural/governance/financial/site & logistics/construction system/building information), provide *specific* examples of the top 3 greatest challenges, ordered from 1 to 3, and name which process each of these relate to most. Example 1 being the most critical.

Example 1: _____ & related process: _____
Example 2: _____ & related process: _____
Example 3: _____ & related process: _____



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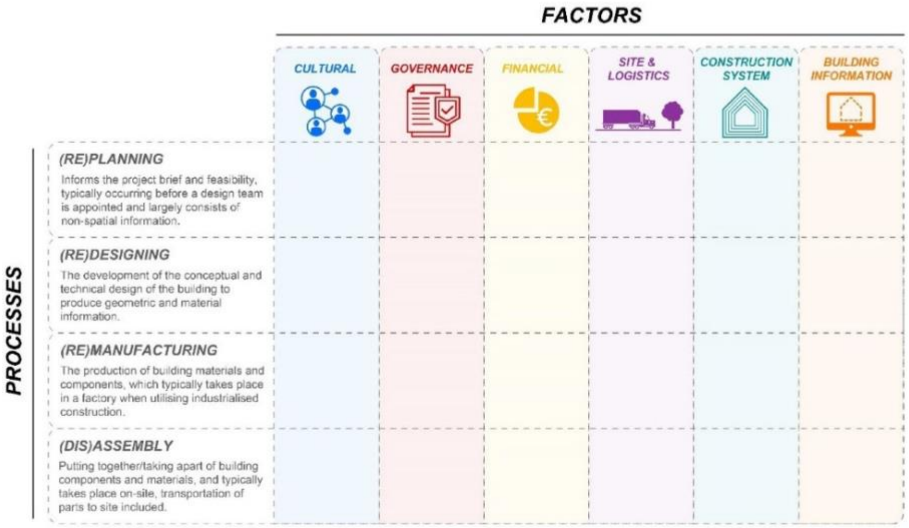
2. **Considering the four processes discussed during the interview, please give a rating of 1 to 5 in terms of the opportunities they present to furthering circularity in industrialised housing.** 1 being least opportunities and 5 being greatest opportunities. (Mark with an 'X')

Process	Rating				
	1	2	3	4	5
(Re)planning					
(Re)designing					
(Re)manufacturing					
(Dis)assembly					

Considering the factors described (cultural/governance/financial/site & logistics/construction system/building information), provide *specific* examples of the top 3 greatest opportunities, ordered from 1 to 3, and name which process each of these relate to most. Example 1 being the most critical.

Example 1: _____ & related process: _____
Example 2: _____ & related process: _____
Example 3: _____ & related process: _____



3. **Are there any factors that have *not* been included in this framework? If so, please name them. Any other suggestions for improvement are also welcome.**

_____