

# Decarbonised Steel Framing in Australia's Detached Housing: An Integrative Review of Performance, Adoption Conditions and Property Implications

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## Abstract

Lower-emission steel production and prefabrication create opportunities for Australian detached housing, but adoption does not establish improved outcomes. This critically conducted integrative review examines decarbonised steel framing using contemporary timber and conventional steel as bounded comparators. Academic, technical and policy evidence is appraised through qualitative coding and thematic integration informed by circular economy, life-cycle thinking, sustainable supply chains and socio-technical transitions. The synthesis distinguishes production-emissions reductions, material-specific design and delivery effects. Policy analysis identifies separate requirements for product classification, recognition of emissions evidence and implementation timing. Housing-delivery reform, manufacturer assurance and green-material support do not necessarily cover the same products or operate on the same timetable. Affordability is examined through production, installed construction, development expenditure, prices or rents, and ongoing housing costs; savings are not assumed to pass between these stages. The Conditional Assessment Framework connects supported findings and trade-offs to decision holders, evidence obligations and reassessment triggers. Its applied property contribution distinguishes benefit creation, recognition and realisation, providing an evidence-linked basis for procurement, completion and whole-life ownership decisions.

Keywords: Housing; Decarbonised Steel; Prefabrication, Sustainability; Circular Economy; Housing Policy

## 1. Introduction

Framing decisions connect housing production with development expenditure and whole-life performance ([Newell & Steglick, 2006](#); [Ong et al., 2017](#)). Timber and steel are established lightweight-framing options, including prefabricated applications ([Reardon et al., 2020](#)). Lower-emission production and Design for Manufacture and Assembly (DfMA) provide reasons to reassess their use ([Gao et al., 2020](#); [IEA, 2020](#)). Here, decarbonised steel refers to steel produced through a specified pathway that reduces greenhouse-gas emissions relative to a stated conventional-steel baseline; it implies neither zero emissions nor superiority over timber ([IEA, 2024](#)).

Housing-delivery pressures provide the contemporary rationale. Australian research identifies interacting approval, workforce, productivity and market constraints, while governments are supporting manufacturing and revising prefabrication assurance (O'Neil & Husic, 2025; Productivity Commission, 2025; Sharam et al., 2026). These developments create an opening for alternative framing systems, not proof of their benefits. The issue is whether housing-delivery reform and green-material requirements connect at the product and project levels, and whether any production gains improve completion, environmental performance and household costs.

Previous research addresses steel decarbonisation, prefab supply chains, comparative performance and circular manufacturing-oriented design (Dewagoda et al., 2024; Kim et al., 2022; Masood et al., 2022; Tavares et al., 2021). The gap addressed here is the connection between these forms of evidence: what supports a specified decarbonised-steel framing option, which adaptations are required, and whose outcomes improve? The review separates product, building-system and property claims. Affordability is examined as a possible outcome pathway rather than inferred from a lower factory price or faster assembly.

The aim is to critically assess the sustainability, housing-delivery and whole-life implications of decarbonised steel framing in Australian detached housing, and identify the design and implementation conditions associated with supported improvements. Four objectives guide the study: to characterise the evidence and its applicability; evaluate comparative benefits and trade-offs; examine implementation conditions; and integrate the findings into a conditional assessment framework for property-development and ownership decisions.

The main research question asks:

What does existing evidence indicate about whether, and how, decarbonised steel framing can improve sustainability, housing delivery and whole-life performance in Australia's detached housing sector?

**RQ1.** What benefits, limitations and trade-offs are reported for decarbonised steel framing relative to functionally comparable contemporary timber-framing systems?

**RQ2.** What design, fabrication, supply-chain, workforce and institutional adaptations are supported by the evidence as means of realising potential improvements?

The study adopts a critically conducted integrative review, informed by circular economy, life-cycle thinking, sustainable supply-chain management and socio-technical transitions. Decarbonised light-gauge/cold-formed framing is the focal adoption pathway; timber is a relevant comparator, not a parallel forestry review. Section 2 establishes the literature and research gap; Section 3 specifies the analysis; Sections 4–6 present the findings, contribution, practical application and conclusion.

## 2. Literature Review

The literature review connects comparative decarbonised-steel performance with circularity, supply-chain organisation, technological and workforce adaptation, and housing-delivery

and sustainability policy. These strands inform the two research questions and the concepts used in analysis. The final subsection positions the inquiry against previous reviews; Section 4 reports the present synthesis.

### **2.1. Decarbonised steel and comparative framing performance**

The distinction between conventional and decarbonised steel concerns the production pathway and its emissions, rather than a separate category of structural behaviour. The [IEA \(2020\)](#) identifies scrap-based electric-furnace production, hydrogen-based direct reduction and other process innovations, together with the influence of energy supply, raw materials and existing production assets. [Kim et al. \(2022\)](#) review steel-decarbonisation technologies and their wider implementation conditions. For detached housing, these production developments must be connected to the specification and availability of a suitable framing product.

The [IEA \(2024\)](#) distinguishes emissions designations and stresses transparent accounting. Verified product evidence, modelled production routes and prospective claims therefore have different evidential roles. A reduction at ironmaking or crude-steel production cannot be assigned directly to an installed frame. Conventional-steel research can inform design and baseline performance, with its applicability to the focal product stated explicitly.

Contemporary timber framing provides a substantive comparator. Australian Government guidance recognises timber and steel as lightweight-framing options, including offsite timber wall frames and trusses, and discusses their different detailing and installation requirements ([Reardon et al., 2020](#)). The comparison therefore concerns appropriately designed alternatives, rather than advanced steel prefabrication against an exclusively site-built representation of timber.

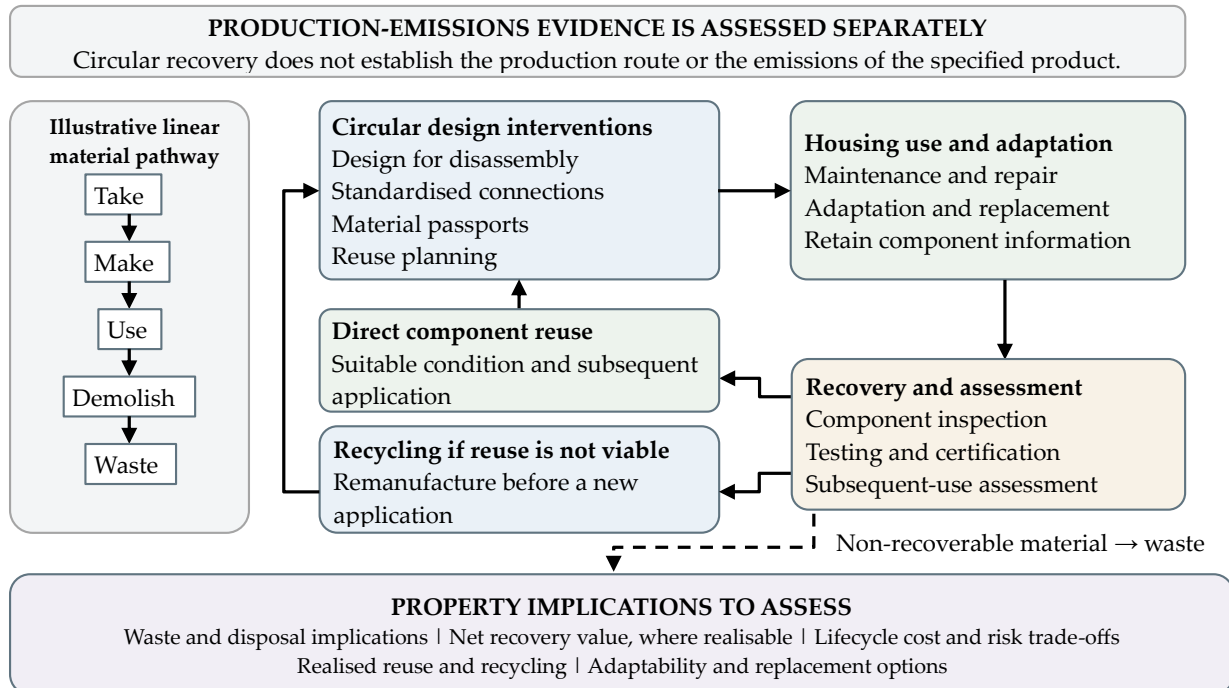
The available studies address different comparisons. The publisher preview of [Tavares et al. \(2021\)](#) identifies a single-family comparison of prefabricated wood and lightweight steel with conventional alternatives; its detailed findings are not extracted here because full text was not obtained. [Dani et al. \(2022\)](#) provide a fully inspectable residential lifecycle comparison, while [Iuorio et al. \(2023\)](#) examine wall and roof assemblies and [Wasim et al. \(2023\)](#) model alternative steel configurations. These sources inform different levels of assessment rather than one interchangeable material effect.

### **2.2. Circular economy and life-cycle thinking**

[Bocken et al. \(2016\)](#) distinguish slowing, closing and narrowing resource loops. For framing, these concepts direct attention to useful service and repeated use, material return, and resource efficiency. Longer service, direct component reuse and remelting are distinct strategies with different design and organisational requirements. They provide a more precise foundation than treating recyclability alone as evidence of sustainable construction.

[Selvaraj and Chan \(2024\)](#) identify design for deconstruction, assessment and business arrangements as relevant to direct structural-steel reuse. This literature directs attention to connections, access, documentation, testing and subsequent applications. Transfer to thin-gauge housing components requires scrutiny, since recovery of larger structural sections does

not by itself establish the reuse potential or financial value of every framing product. [Korhonen et al. \(2018\)](#) further emphasise the limits of circular-economy reasoning and the importance of evaluating environmental consequences within explicit system boundaries.



*Note: Pathways are conceptual recovery options, not measured flows. Production-emissions verification is separate; property implications require assessment.*

*Source: Authors' conceptual synthesis; design-for-deconstruction and reuse concepts informed by [Selvaraj and Chan \(2024\)](#); emissions-verification distinction informed by [IEA \(2024\)](#).*

Figure 1. Circular design and recovery pathways for decarbonised steel framing: potential property implications.

Figure 1 relates circular design and recovery options to property implications requiring assessment. Production emissions, net recovery value and lifecycle risks remain separate questions, dependent on the specified product, component condition, costs and subsequent application. It is a conceptual foundation rather than an empirically validated housing-outcomes model.

Life-cycle thinking considers impacts across production, use, maintenance and end-of-life; life-cycle assessment estimates those impacts using a specified quantitative method ([LCI, 2026](#)). This review interprets published assessments rather than undertaking a new LCA or lifecycle-cost model. Keeping the stages distinguishable allows gains in one stage to be assessed alongside burdens elsewhere.

The Royal Institution of Chartered Surveyors' whole-life carbon guidance provides a property-professional basis for considering production, construction, operation, end-of-life and potential benefits beyond the asset life ([RICS, 2023](#)). The relevant ownership questions concern maintenance, replacement, adaptation and recovery. [Wu et al. \(2016\)](#) add the distinction between environmental or energy-related performance and economic benefits

recognised in valuation. Physical performance and market recognition therefore require different evidence.

### **2.3. Sustainable and circular supply-chain management**

[Seuring and Müller \(2008\)](#) distinguish supplier management for risk and performance from supply-chain management for sustainable products. [Farooque et al. \(2019\)](#) connect circular-economy objectives with the organisation of supply chains. These perspectives help examine both the forward provision of a framing product and the arrangements required for its subsequent recovery, including actors, information, responsibilities and costs.

[Masood et al. \(2022\)](#) review supply-chain management in prefabricated housebuilding. Australian interview research also identifies the commercial significance of cost, risk and supporting arrangements, while questioning whether faster construction necessarily reduces total costs ([Steinhardt & Manley, 2016](#)). For the focal material, the implementation questions concern whether a specified lower-emission product can be verified, procured, fabricated and incorporated into a housing design, and whether production benefits depend on coordinated procurement and information.

The property interpretation requires identification of the stakeholder and time period affected. A manufacturer's saving does not logically establish a corresponding reduction in development expenditure or purchase price. Similarly, shortening one activity need not advance overall completion. [Newell and Steglick \(2006\)](#) and [Ong et al. \(2017\)](#) establish the relevance of development risk and delivery conditions; the present review examines the evidence connecting framing and procurement arrangements to those outcomes.

### **2.4. Socio-technical transitions, technological integration and workforce capability**

[Geels \(2004\)](#) examines the relationships among technologies, actors, users and institutions. This socio-technical perspective is used selectively to interpret established routines, learning and alignment between technologies and work practices. Its role is to explain implementation and capability change, not to presume a sector-wide transition from timber to steel.

Upstream and downstream changes must remain distinguishable. Upstream, steel-decarbonisation research addresses production technology and industrial requirements ([Kim et al., 2022](#)), while [Maldonado-Mariscal et al. \(2023\)](#) examine skills intelligence in the European steel sector. Downstream, the relevant activities are housing design, component manufacture, procurement and installation. Production-sector skills evidence can inform the upstream discussion without establishing the adequacy of Australian housing-construction competencies.

Design for Manufacture and Assembly provides a more specific approach to the relationship between design and production. [Gao et al. \(2020\)](#) identify DfMA as a design process, evaluation approach and production-oriented philosophy. [Wasim et al. \(2023\)](#) link these concerns to a prefabricated steel-building design. Component configuration, fabrication planning and assembly interfaces are therefore relevant adaptations to investigate. DfMA is not the literature-review method, and its relevance is not exclusive to steel.

[Daly et al. \(2025\)](#) examine Australian prefabrication experiences and identify limited quantified sustainability information. These accounts support closer examination of what practices change and which outcomes are observed or anticipated, without establishing the prevalence of deficient steel-framing practice. In applying the socio-technical perspective, continuing a familiar arrangement may reflect suitability or commercial constraints rather than resistance. Training provision, demonstrated competence and improved workmanship likewise represent different evidence.

### **2.5. Housing-delivery and sustainability policy**

Housing-delivery, building-sustainability and industrial-decarbonisation measures address different constraints. The [Productivity Commission \(2025\)](#) identifies approvals, innovation, industry structure and workforce issues. [Sharam et al. \(2026\)](#) relate offsite-manufacturing viability to demand stability, design repeatability and financing; their inquiry spans detached and higher-density housing rather than isolating framing material. These sources justify examining production arrangements within development conditions, not assuming that additional manufacturing capacity yields affordable completed homes.

The Commonwealth's March 2025 announcement coupled manufacturing support with development of national certification ([O'Neil & Husic, 2025](#)). NSW's BASIX changes introduced embodied-material reporting from October 2023 alongside energy and thermal provisions ([NSW Planning Portal BASIX, 2025](#)). These measures address capacity, assurance and environmental assessment respectively. [Shou et al. \(2026\)](#) map policy instruments, sequencing and jurisdictional differences through June 2025. That policy-mapping approach differs from assessing a specified framing product and its housing outcomes. The question here is whether relevant measures recognise the proposed product, apply to its delivery configuration and operate within its procurement horizon. Selected NSW documents provide a bounded application, not a survey of every jurisdiction.

### **2.6. Synthesis of previous reviews and research gap**

Existing reviews already connect steel-production technologies, supplier integration and manufacturing-oriented design ([Gao et al., 2020](#); [Kim et al., 2022](#); [Masood et al., 2022](#)). [Dewagoda et al. \(2024\)](#) integrate circularity and modularity, while [Shou et al. \(2026\)](#) examine policy mixes. Building on these contributions, the present review focuses on a specified decarbonised-steel framing decision. It distinguishes benefits created in production from benefits recognised in project assessment and realised by housing stakeholders.

The analysis connects production/product evidence, material-appropriate design and delivery arrangements without transferring claims beyond their product, geographical or methodological boundaries. Policy compatibility and affordability extend this attribution question: recognised emissions evidence, applicable approvals and lower production costs are different observations. Section 3.4 specifies how the selected concepts guide extraction and comparison.

[Tavares et al. \(2021\)](#) and [Yang et al. \(2026\)](#) identify close comparative and environmental-review precedents; their previews are used to establish scope, not extract detailed findings. The full-text review by [Shou et al. \(2026\)](#) examines the composition and sequencing of policy

instruments rather than a matched housing-performance effect. The contribution developed here is the product- and decision-specific connection among verification, assessment recognition, implementation and outcome incidence. Source-access limitations are stated in Section 5.4.

Table 1 summarises the principal literature strands and their analytical contribution to the review's two research questions. It distinguishes the evidence required to assess comparative performance from the concepts and evidence used to examine the adaptations associated with realising potential improvements.

Table 1. Literature strands, analytical focus and links to research questions

| Literature strand                                      | Core analytical issue                                                                                                                                                                                                                                        | Key sources                                                                                                                                                                           | Link to RQs                                                        |
|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|
| Decarbonised steel production and product verification | Assess lower-emission production pathways, emissions boundaries and product verification; distinguish production-route potential from evidence for a specified framing product and its practical availability.                                               | <a href="#">IEA (2020)</a> , <a href="#">IEA (2024)</a> , <a href="#">Muslemani et al. (2021)</a> , <a href="#">TRUECORE® steel (2023)</a>                                            | RQ1: emissions claims.<br>RQ2: supply and adoption conditions.     |
| Comparative framing and whole-life performance         | Compare environmental, structural and thermal performance under equivalent housing requirements, identifying lifecycle boundaries and trade-offs. Distinguish conventional-steel evidence from verified decarbonised-steel evidence.                         | <a href="#">Reardon et al. (2020)</a> , <a href="#">Dani et al. (2022)</a> , <a href="#">Iuorio et al. (2023)</a> , <a href="#">Liang et al. (2022)</a> , <a href="#">RICS (2023)</a> | RQ1: comparative benefits, limitations and trade-offs.             |
| Circular economy and material value retention          | Examine material efficiency, service-life extension, adaptability, disassembly, reuse and recycling. Assess the design and recovery arrangements required for circular opportunities rather than assuming positive environmental or residual-value outcomes. | <a href="#">Bocken et al. (2016)</a> , <a href="#">Korhonen et al. (2018)</a> , <a href="#">Selvaraj and Chan (2024)</a> , <a href="#">Dewagoda et al. (2024)</a>                     | RQ1: circularity outcomes.<br>RQ2: design and recovery conditions. |

| Literature strand                                                    | Core analytical issue                                                                                                                                                                                                                                                  | Key sources                                                                                                                                                                                                                            | Link to RQs                                                                   |
|----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Prefabrication, DfMA and technological integration                   | Examine how material-specific design, digital coordination, fabrication and assembly relate to housing performance. Separate material effects from production-method effects and retain prefabricated timber as a relevant comparator.                                 | <a href="#">Gao et al. (2020)</a> , <a href="#">Wasim et al. (2023)</a> , <a href="#">Iuorio et al. (2023)</a> , <a href="#">Daly et al. (2025)</a>                                                                                    | RQ1: performance implications.<br>RQ2: design and production adaptations.     |
| Sustainable supply chains, development feasibility and affordability | Examine procurement, logistics, programme and cost incidence from manufacture through installed construction and development to price/rent and ongoing housing costs; identify whether gains reach the stakeholder claimed.                                            | <a href="#">Seuring and Müller (2008)</a> , <a href="#">Masood et al. (2022)</a> , <a href="#">Newell and Steglick (2006)</a> , <a href="#">Sharam et al. (2026)</a>                                                                   | RQ1: development outcomes.<br>RQ2: organisational and procurement conditions. |
| Socio-technical transitions and workforce capability                 | Interpret established routines, learning and alignment between technologies and work practices. Distinguish upstream steelmaking competencies from downstream design, fabrication and installation capabilities, and training provision from demonstrated performance. | <a href="#">Geels (2004)</a> , <a href="#">Maldonado-Mariscal et al. (2023)</a> , <a href="#">Steinhardt and Manley (2016)</a> , <a href="#">Daly et al. (2025)</a>                                                                    | RQ2: technological, organisational and workforce adaptation.                  |
| Housing-delivery and green-material policy                           | Distinguish policy purpose, classification, product recognition and implementation timing; examine the passage from policy intent to industry use and housing outcomes.                                                                                                | <a href="#">Muslemani et al. (2021)</a> , <a href="#">NSW DPHI (2026a)</a> , <a href="#">NSW DPHI (2026b)</a> , <a href="#">NSW DPHI (2026c)</a> , <a href="#">ABCB (2026a)</a> , <a href="#">Shou et al. (2026)</a> , policy mapping. | RQ2: institutional conditions.<br>RQ1: supported market implications.         |

Source: Authors' synthesis of the cited literature. Sources serve conceptual, empirical or documentary roles and are appraised separately for applicability.

Abbreviations: DfMA = Design for Manufacture and Assembly; IEA = International Energy Agency; ABCB = Australian Building Codes Board; RICS = Royal Institution of Chartered Surveyors. NSW DPHI = NSW Department of Planning,

*Housing and Infrastructure; DISR = Department of Industry, Science and Resources; BASIX = Building Sustainability Index.*

### 3. Review Methodology

The critically conducted integrative review connects claim-level appraisal, qualitative coding and thematic integration to the comparative-performance and adaptation questions.

#### 3.1. Integrative review design and critical orientation

[Whittemore and Knafl \(2005\)](#) identify review purpose, searching, evaluation, analysis and presentation as connected requirements of integrative review. [Torraco \(2005\)](#) emphasises critical examination and synthesis rather than descriptive compilation. These principles suit an inquiry combining empirical, modelling, conceptual and documentary evidence around a bounded framing-and-delivery question.

Critical appraisal concerned the support and applicability of each claim, not whether a source favoured the focal material. Structured qualitative coding retained the comparator, production status, method, data period, assumptions and contrary evidence. Thematic integration related those records to implementation conditions and property decisions. [Seuring and Gold \(2012\)](#) inform this traceable content-analysis approach. Published quantities were interpreted within their reported boundaries; no meta-analysis, new carbon inventory, financial model or causal transition forecast was undertaken.

#### 3.2. Search strategy and source selection

Source selection was purposive and question-led, starting with the supplied 147-entry bibliography assembled during the development of the original study and its revision, together with the associated evidence registers. Each entry received a metadata-level disposition in Supplementary Register S1: analytical evidence, conceptual/methodological use, positioning, contextual or relevant reserve, outside the focal synthesis, or an identity/version issue. This initial classification was distinct from claim-specific appraisal. Selection prioritised identifiable production/product claims, comparative framing performance, material-specific design, Australian delivery practice, circular recovery and role-specific assurance. Direct and adjacent evidence, including findings unfavourable to steel, was retained where its contribution and applicability could be stated.

Verification used exact-title, DOI and official-document lookups through web search and document retrieval, including Exa, to locate publisher pages, university repositories and official sources. The main verification and documentary extraction were undertaken on 22–23 September 2026. A final check on 25 September reconciled citation metadata, revisited the NSW regulator and ABCB timetable, and examined the accessible full text of [Shou et al. \(2026\)](#) for prior-review positioning. S1 records the retrieval routes, inspected passages, source roles and unsuccessful access attempts. The design does not claim an exhaustive subscription-database search or independent duplicate screening.

The verification set contains 37 document records: 34 analytical/contextual records and three positioning records. [Tavares et al. \(2021\)](#) and [Yang et al. \(2026\)](#) remain limited to publisher previews; [Shou et al. \(2026\)](#) was examined in full-text form for its methods, 14 and contribution, without re-extracting its policy dataset or estimating policy effects. Analytical

records include technical, conceptual and institutional evidence, not 34 independent empirical studies. Related ABCB and NSW documents are linked as source families. Claim-specific appraisal concerns the passages inspected rather than every calculation in the cited literature or all 147 library entries. Source access and finalisation changes are documented in S1.

Table 2 distinguishes the source groups informing the review and their respective analytical roles. Substantive findings, conceptual foundations, contextual information and methodological guidance are differentiated so that each source contributes within its evidential scope.

Table 2. Source groups and analytical role

| Source group                                  | Examples of evidence used                                                                                                                                                                                                                                                                                                                                          | Analytical role in the review                                                                                                                                    |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Peer-reviewed empirical and modelling studies | <a href="#">Dani et al. (2022)</a> , <a href="#">Iuorio et al. (2023)</a> , <a href="#">Wasim et al. (2023)</a> , <a href="#">Daly et al. (2025)</a> , <a href="#">Lopez et al. (2022)</a>                                                                                                                                                                         | Compare system performance and reported implementation; distinguish modelled findings, case descriptions and experiences, with context and comparators retained. |
| Theoretical and conceptual literature         | <a href="#">Bocken et al. (2016)</a> , <a href="#">Geels (2004)</a> , <a href="#">Seuring and Müller (2008)</a> , <a href="#">Farooque et al. (2019)</a>                                                                                                                                                                                                           | Specify evaluation and explanatory concepts; not independent empirical confirmation of their anticipated mechanisms.                                             |
| Existing reviews and syntheses                | <a href="#">Masood et al. (2022)</a> , <a href="#">Selvaraj and Chan (2024)</a> , <a href="#">Dewagoda et al. (2024)</a> , publisher preview of <a href="#">Yang et al. (2026)</a>                                                                                                                                                                                 | Compare existing explanations and position contribution. Preview-only material supplies scope, not detailed findings; underlying studies are not double-counted. |
| Contextual datasets and sector sources        | <a href="#">Productivity Commission (2025)</a> overview and <a href="#">Sharam et al. (2026)</a> selected inquiry sections; <a href="#">ABS (2025)</a> , <a href="#">ABARES (2026)</a> , <a href="#">ABARES (2025a)</a> , <a href="#">ABARES (2025b)</a> and <a href="#">EPiC Crawford et al. (2020)</a> remain contextual/reserve records unless explicitly used. | Explain housing-production constraints and relevant implementation conditions; not framing-specific shortage, price or causal affordability estimates.           |

| Source group                             | Examples of evidence used                                                                                                                                                                                                                                                                                                                                                                                                                                             | Analytical role in the review                                                                                                                                                                     |
|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Institutional and professional documents | <a href="#">IEA (2024)</a> , <a href="#">IEA (2020)</a> , <a href="#">ABCB (2026a)</a> , <a href="#">ABCB (2026b)</a> , <a href="#">ABCB (2026c)</a> , <a href="#">ABCB (2024)</a> , <a href="#">ABCB (2025)</a> documents and FAQ; NSW approval/BASIX guidance and manufacturing programme ( <a href="#">NSW Planning Portal BASIX, 2025</a> ), <a href="#">DISR (2026)</a> green-iron information; Commonwealth funding announcement ( <a href="#">CBA, 2026</a> ). | Record policy object, coverage, status, mechanism and evidence of implementation/outcomes. Distinguish normative requirements, proposals and observed effects; date point-in-time interpretation. |
| Product and commercial documentation     | <a href="#">TRUECORE® steel (2023)</a> EPD, <a href="#">CBA (2026)</a> prefab lending.                                                                                                                                                                                                                                                                                                                                                                                | Identify the declared product, lifecycle boundaries and actual transaction conditions. Neither supplies a general whole-house or financial-benefit estimate.                                      |
| Workforce and training evidence          | ( <a href="#">Maldonado-Mariscal et al., 2023</a> ), ( <a href="#">Victoria University, 2026</a> ), Australian practice studies.                                                                                                                                                                                                                                                                                                                                      | Separate industrial production, design, manufacture and installation roles, and provision from demonstrated competence and performance.                                                           |
| Methodological literature                | <a href="#">Whittemore and Knafl (2005)</a> , <a href="#">Torraco (2005)</a> , <a href="#">Seuring and Gold (2012)</a>                                                                                                                                                                                                                                                                                                                                                | Support the critically conducted integrative review, claim-level appraisal, coding and integration; not substantive material-performance evidence.                                                |

Source: Authors' classification of the selected source base. Analytical uses and inspected passages are specified in Supplementary Register S1.

Abbreviations: IEA = International Energy Agency; ABCB = Australian Building Codes Board; RICS = Royal Institution of Chartered Surveyors; DfMA = Design for Manufacture and Assembly.

Note: Source role is not a quality ranking. A source can perform more than one role, but related publications and reused evidence are not counted as independent confirmations.

### 3.3. Evidence appraisal and comparative boundaries

Appraisal separated credibility from applicability. Comparative studies were examined for the functional unit, system design, context, lifecycle boundary, data and model assumptions. Interview studies were examined for recruitment, participant setting, period, analysis and the distinction between reported experience and measured effects. Declarations were assessed for the actual product, production route, inventory period and declared modules. Institutional material was assessed for authorship, jurisdiction, scope and draft or operative status. Particular attention was given to manufacturer and commissioned evidence, reporting inconsistencies, proxy inventories and prospective outcomes. S1 records both the inspected passages and the limitations that affected their use; it does not certify the original research.

Three comparison types guided interpretation: material systems meeting comparable housing requirements; conventional and lower-emission routes for a comparable steel product; and design or delivery changes within a material system. Appropriate designs for each material were permitted, while differences in building size, envelope, loading, prefabrication level and lifecycle assumptions remained explicit. Multi-attribute comparisons were interpreted as combined system effects. A source's documented condition was not upgraded to proof of causal necessity, and repeated claims within reviews were not treated as independent observations.

### 3.4. Theory-to-analysis specification

Table 3 translates the Section 2 concepts into evidence questions, initial codes and comparative operations. Circularity and lifecycle perspectives guide evaluation; supply-chain and socio-technical perspectives guide interpretation of arrangements, learning and capability. DfMA and property-development concepts link design and delivery to the outcomes assessed. These concepts guide analysis without predetermining favourable findings.

Table 3. Theory-to-analysis specification

| Perspective                            | Evidence and initial codes                                                                                                                                                                           | Analytical operation                                                                                                                          | Question / output                                                               |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Circular economy / life-cycle thinking | Service life; material efficiency; reuse versus recycling; functional unit; production, use and end-of-life boundaries ( <a href="#">Bocken et al., 2016</a> ; <a href="#">LCI, 2026</a> )           | Compare functionally relevant systems and lifecycle assumptions; identify burdens as well as benefits and prospective recovery credits.       | RQ1; T1–T2. Qualified environmental and whole-life comparisons.                 |
| Sustainable / circular supply chains   | Actors; product verification; procurement/payments; recovery duties; manufacturer-to-household cost incidence ( <a href="#">Farooque et al., 2019</a> ; <a href="#">Seuring &amp; Müller, 2008</a> ) | Link reported outcomes to the arrangements that support them; identify who pays, benefits or bears risk.                                      | RQ1–RQ2; T2, T4. Conditions for procurement, recovery and development outcomes. |
| Socio-technical transitions            | Routines; learning; technology/practice alignment; policy adoption, administrative availability and industry implementation ( <a href="#">Geels, 2004</a> )                                          | Compare roles, applicable requirements and documented responses; distinguish policy intent, classification and uptake from achieved outcomes. | RQ2; T3–T5. Evidence of adaptation and capability conditions.                   |

| Perspective                          | Evidence and initial codes                                                                                                                                                                                     | Analytical operation                                                                                                               | Question / output                                                               |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| DfMA / property-development concepts | Design–production interfaces; fabrication/assembly changes; activity versus project duration; cost boundary and stakeholder ( <a href="#">Gao et al., 2020</a> ; <a href="#">Newell &amp; Steglick, 2006</a> ) | Distinguish material, production-route and delivery effects; test whether process improvements reach the property outcome claimed. | RQ1–RQ2; T3–T4. Supported design adaptations and bounded property implications. |

*Source: Authors' analytical specification, informed by Section 2 and applied to the selected claim records in S1.*

### 3.5. Data extraction, coding and thematic integration

The extraction unit was a source-supported claim or result within its context (Table 4). S1 contains 84 linked records, distinguishing documentary statements, modelled findings, reported experience, source proposals, appraisal observations and review-derived applications. Each retains its locator, comparator/scope, conditions, uncertainty, decision holder and manuscript use. The policy extension added C57–C84 and the documentary fields in Table 5.

The initial domains were T1, steel decarbonisation and comparative whole-life performance; T2, circular design and material value retention; T3, steel-framing design and prefabricated production; T4, supply-chain organisation and development feasibility; and T5, workforce capability and institutional adaptation. Additional distinctions emerged within them: manufacturer assurance versus onsite responsibility, panel/kit effects versus volumetric effects, and context-appropriate onsite assembly versus maximising prefabrication. Negative and mixed findings were retained alongside favourable ones.

Integration compared evidence within each domain and then examined what changed, the reported outcome, its conditions, the affected party and any inferential step to a property consequence. Eight qualitative source-restriction checks examined dependence on particular evidence groups, including three policy-specific checks: excluding prospective measures, restricting policy evidence to applicable NSW residential requirements, and removing policy outcome claims lacking observed evidence. S1 records the effects on interpretation. These are claim-dependence checks, not model reruns, causal effect estimates or independent validation.

Table 4. Minimum claim-level extraction record

| Record component      | Information retained                                                                                                 |
|-----------------------|----------------------------------------------------------------------------------------------------------------------|
| Provenance and role   | Source/family and locator; method, location, data period, access level, interests and analytical/positioning status. |
| System and comparison | Product and emissions status; housing/component and delivery level; functional comparator; combined changes.         |

| Record component        | Information retained                                                                                                                                                                  |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Outcome and evidence    | Claim/measure and boundary; documentary, modelled, observed/reported, proposal, appraisal or review-inference status.                                                                 |
| Conditions and decision | Documented/proposed/inferred conditions; U1–U5 or access limits; counterevidence, decision holder, supported property link and trigger. Documentary sources additionally use Table 5. |

*Source: Authors' extraction specification. Supplementary Register S1 contains E01–E37 and C01–C84; policy records P01–P08 add the fields in Table 5, with access and evidential limits retained.*

### 3.6. Documentary extraction and policy–outcome integration

Policy documents were analysed within the integrative review, not treated as a separate policy-effect evaluation. The additional fields in Table 5 preserve purpose, coverage, status, implementation and outcomes. Announcement, legal enactment, administrative availability, industry use and achieved outcomes were recorded separately where applicable; measures can develop in parallel rather than in one sequence. Government adoption was not coded as industry implementation, and unavailable outcome data were not evidence of policy failure. The documentary cut-off is 23 September 2026; a final regulator/ABCB status check on 25 September is recorded separately in S1.

Table 5. Documentary-extraction extension: analytical fields and information retained

| Analytical field                   | What to record                                                                                                                                                                                                                               |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Provenance and instrument identity | Issuing body; title and document type; exact version, publication/update/access dates; URL and page/section; source family; links to superseding or supporting documents.                                                                    |
| Purpose and intended mechanism     | Problem addressed; housing-delivery, building-sustainability or industrial-production objective; instrument and proposed behavioural/administrative change; distinguish the source's intent from the review's interpretation.                |
| Coverage and responsible actors    | Jurisdiction; dwelling and prefabrication category; product/material and lifecycle stage; eligible/regulated actors; decision holder and beneficiary; limits of transfer to detached steel framing.                                          |
| Status and policy evolution        | Record announcement, consultation, enactment, commencement, administrative availability, amendment and closure separately where applicable. Identify provision-specific dates and unresolved status; do not impose a single linear sequence. |
| Implementation and outputs         | Participation, funding awards and actual expenditure, contracts, accepted assessments, operating capacity and delivered units where reported. An announcement, award or approval does not establish completed housing.                       |

| Analytical field                          | What to record                                                                                                                                                                                                                                               |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Outcomes and counterfactual               | Outcome definition, unit, period and comparator: approval duration, installed/total cost, completion, defects, verified emissions or household cost. Identify method, attribution limits and unintended effects; distinguish intended from observed results. |
| Cost incidence and affordability          | Locate costs/savings at manufacture, delivered-and-installed construction, total development, price/rent and ongoing household costs. Record payer, recipient, tenure, income/location context and evidence of pass-through; avoid double-counting.          |
| Integration, uncertainty and reassessment | Link to RQ/T domain, U1–U5 and framework checkpoint; record source-derived condition versus inference, evidence missing, accountable party, current applicability and trigger for reassessment.                                                              |

*Source: Authors' extension of the claim-level extraction procedure. Populated records P01–P08, source links, policy dates and affordability boundaries are supplied in S1. The fields support critical integration; they do not substitute for project-specific legal or financial assessment.*

### 3.7. Conditionality, uncertainty and framework development

The proposed adoption pathway is the possible use of a specified decarbonised-steel framing product together with its relevant design, fabrication, procurement and installation arrangements. It is not a forecast of national timber displacement. Conditionality concerns the circumstances within which an outcome applies; uncertainty concerns incomplete, conflicting or assumption-dependent knowledge about that outcome or its conditions. A well-understood relationship may be conditional without being highly uncertain. Partial adoption describes extent and is not a substitute for either concept.

The claim record distinguishes documented conditions, source-author proposals and review-derived inferences. Uncertainty is classified as product verification/inventory (U1), boundary or functional comparison (U2), attribution from process to outcome (U3), transfer across applications or settings (U4), or future production, recovery, market or institutional assumptions (U5). Unsuccessful retrieval is recorded separately as a review-access limitation. It is not coded as evidence that the field lacks knowledge. Missing data are not interpreted as zero impacts or no benefit; unresolved claims remain unresolved.

For each integrated claim, the framework identifies the supported outcome, applicable conditions, relevant decision holder, outstanding evidence and a reassessment trigger. A claim can be supported within context, conditional/prospective, mixed, or not established by the selected evidence without receiving a numerical score. The four checkpoints in Section 5 were derived from those records, including contrary cases and the source-restriction checks. The hypothetical application illustrates use; it does not establish the framework's practical effectiveness.

## 4. Review Findings

### 4.1. Evidence coverage and interpretation

The selected set contains 34 analytical/contextual document records and three positioning records, two of which remain preview-only. The documentary evidence addresses housing constraints, approval classification, emissions-factor recognition, manufacturing support and assurance/production horizons. These sources supplement the product, comparative-performance and organisational literature. Their roles, inspected passages and source-family links are documented in S1; the 147-entry master library remains the candidate reference pool rather than an included-study count.

No selected source combines verified lower-emission steel framing, material-appropriate design, equivalent timber prefabrication and measured development and whole-life outcomes in a matched Australian detached-house comparison. This limits generalisation from the selected corpus. Nevertheless, cross-source synthesis identifies specific assessment and implementation conditions, with inferential links to property decisions made explicit. The source-restriction checks support conditional decision guidance rather than a general material-effect estimate.

#### **4.2. Steel decarbonisation pathways and comparative whole-life performance**

Decarbonisation can improve steel's production-related emissions profile, but the assessment must reach the offered framing product. The [IEA \(2024\)](#) and [IEA \(2020\)](#) reports identify production routes and accounting requirements rather than certifying an unspecified frame. [Muslemani et al. \(2021\)](#) complement this with interviews concerning product definition, accounting and assurance: a process-related environmental claim is not necessarily visible in the product's physical utility. Their 27 participants included six automotive experts; their discussion of niche demand is not evidence of Australian housing buyers' willingness to pay. The source-supported issue is verification and market interpretation, not an assumed framing premium.

The TRUECORE declaration identifies blast-furnace/basic-oxygen-furnace production and one flat square metre of coated steel at specified thicknesses, with an indicative rollforming extension before fabrication and assembly ([TRUECORE® steel, 2023, pp. 16–19](#)). Installation and use-stage impacts are undeclared, not zero. The declaration therefore informs product assessment without verifying a decarbonised route. Procurement requires matching it to the offered product and obtaining the additional information needed for framing and dwelling assessment.

Comparative findings show trade-offs rather than a universal direction. [Dani et al. \(2022\)](#) report lower modelled whole-life carbon for its timber house than its steel house, including assumed end-of-life credits. Its 90-year Auckland comparison uses different designs and assemblies; floor-area/time normalisation does not isolate framing. [Iuorio et al. \(2023\)](#) also find different outcomes across impact categories in CFS, cross-laminated-timber and masonry walls/roofs. Those one-square-metre, production-stage comparisons involve different thermal/structural configurations and proxy product data. Both studies supply counterevidence to an automatic steel advantage, not the effect of substituting verified decarbonised steel into a matched Australian house.

Structural and envelope choices can be assessed together. [Iuorio et al. \(2023\)](#) identify structural and non-structural contributions to impacts; [Liang et al. \(2022\)](#) examine structural-thermal optimisation; and Australian guidance addresses steel thermal bridging and corrosion alongside timber's biological and moisture vulnerabilities ([Reardon et al., 2020](#)). This supports assembly-level assessment of quantities and protection measures. Maintenance or market-value consequences require additional ownership or market evidence.

#### **4.3. Circular design and material value retention**

Circular design creates options for retaining components in useful service rather than treating remelting as the only recovery route. [Selvaraj and Chan \(2024\)](#) link direct structural-steel reuse with deconstruction design, inspection, documentation and subsequent use. Its take-back business model is proposed, not evidence of net revenue from Australian thin-gauge housing frames. Component condition, testing, storage, transport and the next application remain part of the economic and physical assessment.

[Dewagoda et al. \(2024\)](#) already integrate circularity with manufacturing and assembly design. Its conceptual development and Chinese modular-apartment illustration identify relevant design relationships, but do not establish the same outcomes for detached steel framing in Australia. Together with the recovery literature, it supports considering access to connections, component identity and later disassembly at the design stage. Those are identifiable design and information requirements, not a claim that every recovery scenario is viable.

Circular value retention links present design decisions with later recovery arrangements. Owners can preserve specifications, component records and recovery assumptions, and identify who can assess subsequent use. Net recovery value depends on receipts after deconstruction, preparation and logistics costs. The framework records this option and its evidence requirements rather than automatically capitalising salvage value or a property premium.

#### **4.4. Steel-framing design and prefabricated production**

Steel's suitability for prefabrication is assessed through material-design-production fit, not the location of work alone. Contemporary timber frames and trusses also have established offsite applications ([Reardon et al., 2020](#)). [Iuorio et al. \(2023, section 2.1\)](#) documents a useful counterexample to maximising prefabrication: constrained site access led to factory-cut steel members assembled onsite. That Italian school is not direct Australian housing evidence, but it shows why onsite assembly cannot itself establish inadequate adaptation. The applicable production level is a design and logistics choice.

[Wasim et al. \(2023\)](#) demonstrate an integrated structural, thermal, energy and cost-analysis workflow. The abstract describes a prefabricated residential building, whereas the methods describe a two-storey structural model and a 70 m<sup>2</sup> office energy model. These different scopes limit transfer to a matched detached-housing comparison. The study informs integrated steel design, not a measured timber-steel effect or realised housing saving.

Australian accounts provide the organisational counterpart. [Daly et al. \(2025\)](#) conducted 21 interviews with 24 professionals, beginning in June 2022, and reports variation from relatively

conventional factory work to advanced manufacturing. Repeatability, material-use planning, customer variation and transport affect the opportunities described. [Lopez et al. \(2022\)](#), in timber/MEP and mixed-project settings, likewise documents design-information and supplier interfaces, including differing locations of technological capability. These studies support examining specific practices and responsibilities, not a national claim that steel-framing builders generally underperform.

Effective adaptation can combine design coordination, appropriate component production and reliable assembly interfaces without every builder owning automated equipment. The location of technological capability and information is therefore an implementation consideration. DfMA provides an assessable approach; its contribution to defects, expenditure or completion requires evidence at those levels rather than inference from factory production alone.

#### **4.5. Supply-chain organisation, development feasibility and affordability**

Production speed and development cost remain separate outcomes. In 14 interviews conducted in Queensland and Western Australia during 2014, [Steinhardt and Manley \(2016\)](#) identify speed expectations alongside doubts about total-cost reductions. [Daly et al. \(2025\)](#) connect reported commercial viability to repeatable work, investment and order pipelines. [Masood et al. \(2022\)](#) explain why component, panel and volumetric suppliers present different integration problems. These findings identify conditions to assess, but do not estimate a current national cost saving.

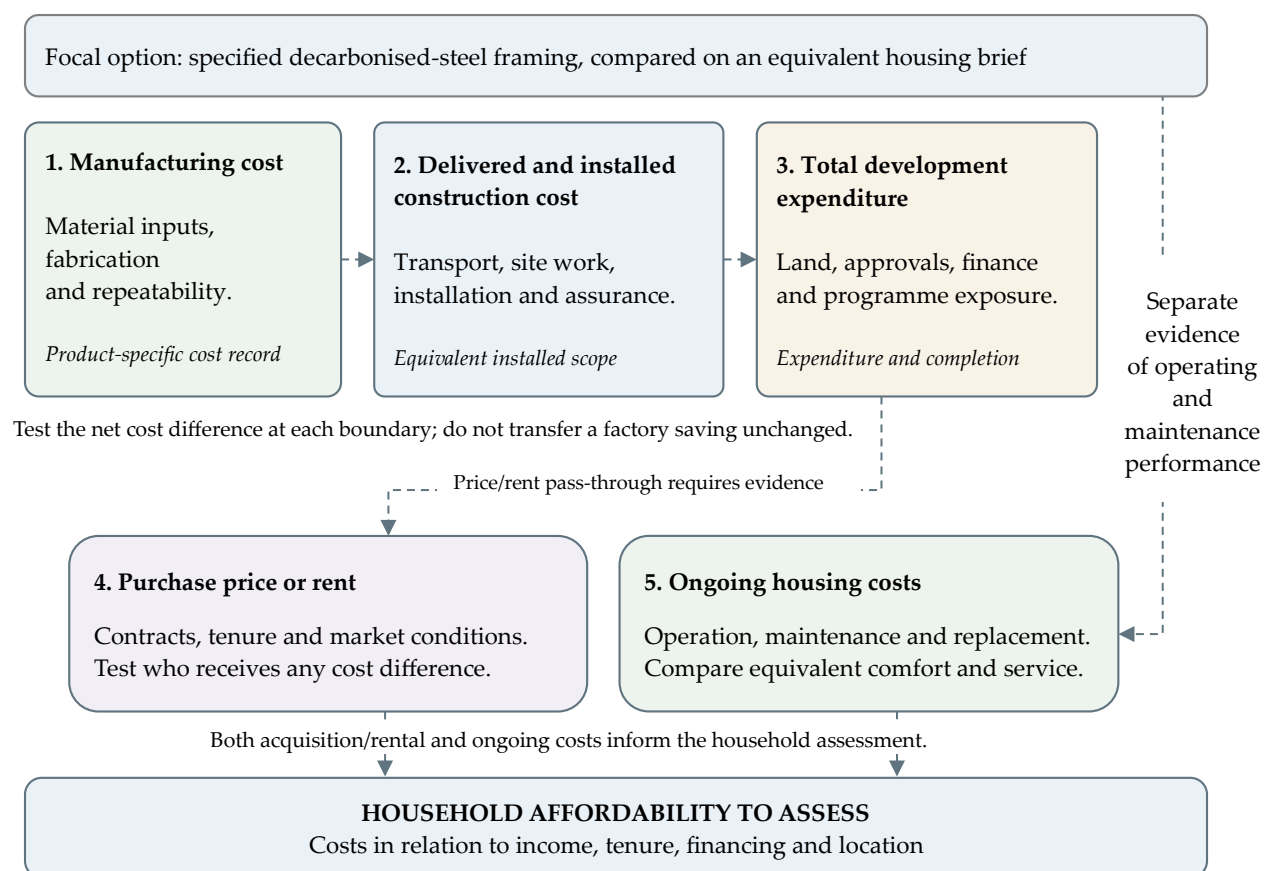
The contractual interface is also visible in the evidence. [Lopez et al. \(2022, sections 5.1.4–5.1.9\)](#) reports design-information exchange, quality monitoring and commercial arrangements around payments and supplier performance. The study reports 40 interview events across four builders and four suppliers; it does not securely establish 40 unique participants or isolate detached steel framing. Read alongside the development-risk study by [Newell and Steglick \(2006\)](#), it supports examining who carries expenditure and delay exposure. The further critical-path and cash-flow connection is an analytical inference: faster erection affects holding costs only if completion and the relevant expenditure period change.

Commonwealth Bank of Australia ([CBA, 2026](#)) documents conditional offsite residential-construction funding and security/non-completion exposure before a dwelling is attached to land. This is one customer-lending arrangement, not developer finance or every framing transaction. Assessment must identify the contract, payment schedule and evidence holder: manufacturer productivity, builder margin, developer holding costs and purchaser price remain distinct outcomes.

Affordability extends this assessment beyond producer efficiency. [Sharam et al. \(2026, pp.31–36\)](#) identify stable demand, standardisation and finance as important to offsite-manufacturing viability, particularly for volumetric systems. The review-derived outcome pathway distinguishes manufacturing cost, delivered-and-installed construction cost, total development expenditure, purchase price or rent, and ongoing housing costs. Each link requires evidence about the payer, recipient, tenure and household income/location context. Imported components, completed modules and local fabrication must therefore be compared

on equivalent delivered scope, including transport, site works and assurance, not on ex-factory quotations alone. Figure 2 distinguishes the conditional links to development and market outcomes from the separate contribution of operating and maintenance performance to household affordability.

A development saving does not establish a matching reduction in price or rent. Conversely, a higher initial cost may accompany improved operating performance, which requires assessment at comparable comfort and service levels. The present evidence does not estimate these pass-through effects. Affordability is an outcome to test through actual contracts, completion and household-cost records, with land, financing and market conditions retained as alternative influences—not an additional benefit assigned to steel by assumption.



Note: Dashed arrows denote conditional links to examine, not measured savings or an assumed causal sequence. Ongoing housing performance has a separate evidence link.

Source: Authors' analytical integration of manuscript Section 4.5, informed by [Steinhardt and Manley \(2016\)](#), [Newell and Steglick \(2006\)](#), [Daly et al. \(2025\)](#) and [Sharam et al. \(2026\)](#).

Figure 2. Affordability as a conditional outcome pathway for decarbonised steel framing

#### 4.6. Workforce capability and institutional adaptation

Capability has distinct upstream and downstream objects. [Maldonado-Mariscal et al. \(2023\)](#) examine skills intelligence in European steel production, including ways to identify emerging job-specific and transversal needs. Its relevance is the organisation of learning around technological change, not proof of Australian housing-installer competence. Downstream

evidence concerns design, fabrication, procurement, installation and assessment. Socio-technical interpretation links these roles without assuming that new production technology automatically changes work practices or that familiar practices are unsuitable.

[Victoria University \(2026\)](#) specifies timber framing and steel-frame preparation and erection in CPCCCA3004. [Zhang et al. \(2022\)](#), drawing on 21 responses across 16 organisations in October 2019–April 2020, identify challenges across delivery stages. These sources specify tasks and interfaces, but do not measure the effect of training on completed-housing performance. Provision, participation, workplace competence and outcomes remain distinct.

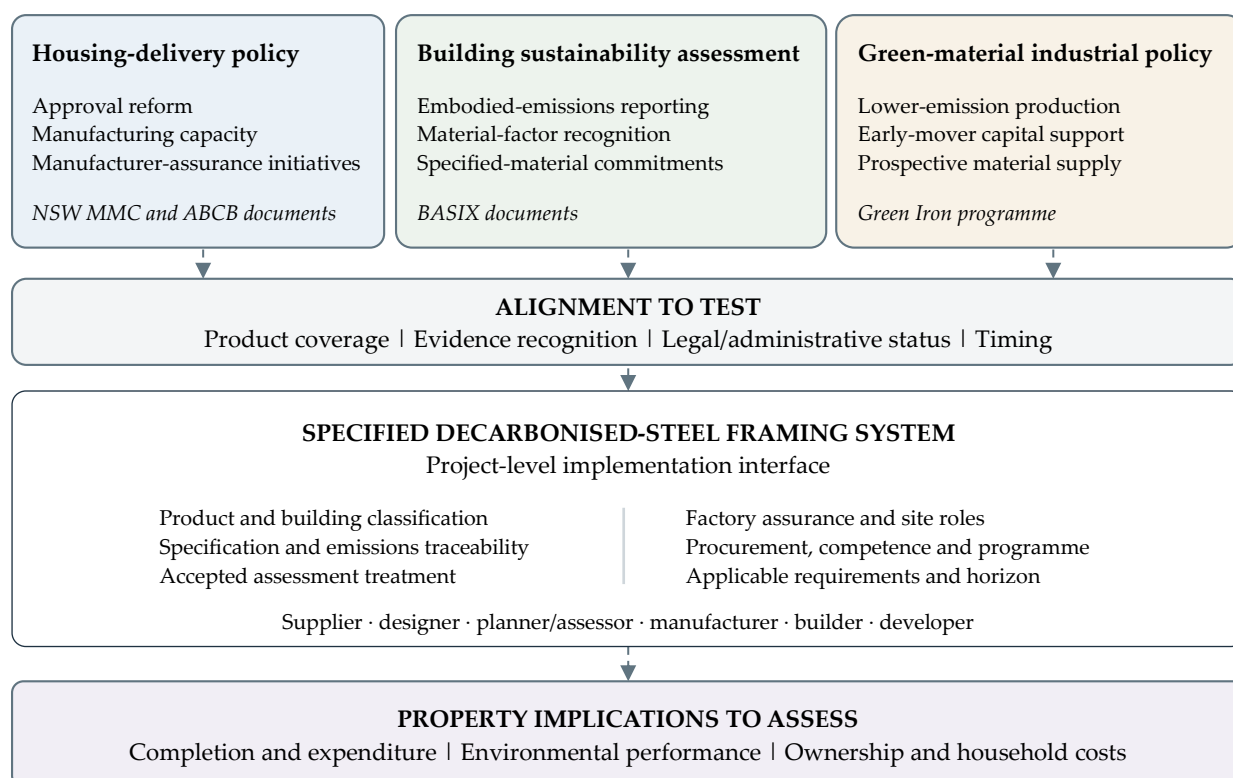
The institutional evidence similarly distinguishes the object of assurance. The inspected Australian Building Codes Board consultation concerns a proposed manufacturer-certification scheme; it closed on 15 September 2026 ([ABCB, 2026b](#)). Its draft rules generally exclude onsite installation and assembly unless expressly included, while addressing transport and receipt information ([ABCB, 2026c, section 4.1; section 2.5.13](#)). The linked economic assessment distinguishes anticipated inspection savings for volumetric manufacturers from assumed throughput effects for panel and kit-of-parts manufacturers ([ABCB, 2026b](#)). These documents support stage-specific questions, not realised cost or approval-time effects. Product-emissions verification, factory assurance and site-performance responsibilities cannot be treated as one certificate or one outcome.

#### **4.7. Housing-delivery and green-material policy interfaces**

Documents issued by the NSW Department of Planning, Housing and Infrastructure make regulatory classification an observable implementation condition. The 1 July 2026 practice note distinguishes manufactured homes from flat-pack kit homes outside caravan parks and manufactured-home estates, assigning different approval routes and BASIX requirements. It states that manufactured homes do not require BASIX, whereas flat-pack homes requiring development consent do ([NSW DPHI, 2026a, pp.1–4](#)). This is dated guidance, not evidence of a universally simpler route or a classification for bare framing panels. The inference is that the actual completed configuration must be identified before its approval, sustainability and cost obligations are compared.

Environmental recognition is a separate link. The March 2026 technical note describes BASIX reporting at product stages A1–A3. Where a specific material is absent from the Materials Index, an applicant may submit verified factor information through alternative assessment; modification requires review and approval. Although no materials-index target applies, selected materials are certificate commitments ([NSW DPHI, 2026b, pp.2–3](#)). A supplier's lower-emission declaration consequently needs an applicable assessment route and traceability to the supplied material; neither an EPD nor compliance with reporting alone establishes whole-life improvement.

Figure 3 summarises the classification, evidence-recognition and timing interfaces linking housing-delivery, building-sustainability and green-material measures to the specified framing system.



*Note: Dashed links represent analytical relationships, not proof of policy effectiveness. Record policy scope, status and demonstrated effects separately.*

*Source: Authors' analytical integration of manuscript Section 4.7, drawing on [NSW DPHI \(2026a\)](#), [NSW DPHI \(2026b\)](#), [Building Commission NSW \(2026\)](#), [ABCB \(2026a\)](#), [ABCB \(2026b\)](#), [ABCB \(2026c\)](#), [DISR \(2026\)](#).*

Figure 3. Housing-delivery and green-material policy interfaces for decarbonised steel framing

The policy measures also operate at different stages. At the final check on 25 September 2026, [Building Commission NSW \(2026\)](#) reports passage of the Building (Approvals and Practitioners) Act in August and stated that implementation of the reforms depends on associated regulations. This regulator account is not a complete verification of every provision's commencement. NSW's manufacturing expansion programme had closed expressions of interest and emphasises medium/high-density capacity ([NSW DPHI, 2026c](#)). ABCB's voluntary scheme has indicative mid-2028 availability, while green-iron support concerns upstream projects with a March 2031 commercial-operations horizon ([ABCB, 2026a](#); [DISR, 2026](#)). These dates and product scopes do not establish current coated-framing supply. The supported policy insight is the need to test coverage, recognition and timing against the actual housing option, rather than infer an integrated delivery pathway from several announcements.

Table 6. Integrated findings: evidence, conditions, decision holders and uncertainty

| Domain                                  | Supported evidence and scope                                                                                                                                                                                                                                                                                                                                                 | Conditions and decision holder                                                                                             | Remaining uncertainty                                                                       |
|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| Decarbonisation / performance           | <a href="#">IEA (2024)</a> , <a href="#">TRUECORE® steel (2023)</a> , <a href="#">Dani et al. (2022)</a> , <a href="#">Iuorio et al. (2023)</a> : product boundaries and comparative assembly results differ.                                                                                                                                                                | Supplier and designer verify the offered product and compare functional designs and lifecycle assumptions.                 | No matched verified-decarbonised Australian housing effect; U1–U4.                          |
| Circular value retention                | <a href="#">Selvaraj and Chan (2024)</a> , <a href="#">Dewagoda et al. (2024)</a> : recovery depends on design, assessment and subsequent arrangements.                                                                                                                                                                                                                      | Owner/designer identifies documentation, connections, recovery costs and a plausible recipient/use.                        | Future reuse and net residual value are not observed housing outcomes; U4–U5.               |
| Design / prefabrication                 | <a href="#">Wasim et al. (2023)</a> , <a href="#">Daly et al. (2025)</a> , <a href="#">Iuorio et al. (2023)</a> : integration matters; factory-cut/onsite assembly can fit access constraints.                                                                                                                                                                               | Designer, manufacturer and builder assign design/production/site interfaces and appropriate delivery level.                | No universal maximum-prefabrication or steel-alone benefit; U2–U4.                          |
| Development feasibility / affordability | Australian practice and <a href="#">Sharam et al. (2026)</a> : demand, finance, cost and programme boundaries qualify production benefits.                                                                                                                                                                                                                                   | Developer/cost adviser follows expenditure to completion, price/rent and ongoing costs, identifying payer and beneficiary. | No automatic pass-through to household affordability; U3–U5.                                |
| Capability / policy compatibility       | <a href="#">NSW DPHI (2026a)</a> , <a href="#">NSW DPHI (2026b)</a> , <a href="#">Building Commission NSW (2026)</a> , <a href="#">ABCB (2026a)</a> , <a href="#">ABCB (2026b)</a> , <a href="#">ABCB (2026c)</a> , <a href="#">ABCB (2024)</a> , <a href="#">ABCB (2025)</a> , <a href="#">DISR (2026)</a> : category, reporting, assurance and production horizons differ. | Assessor and developer identify applicable classification, accepted emissions evidence, actual supply and competent roles. | Dated guidance and prospective measures are not observed policy effects; U1–U5 as relevant. |

*Source: Authors' integration of the cited selected sources, including C57–C84 in S1. Conditions are not asserted as universally necessary causes; documentary implementation status and review inferences remain distinguishable.*

## 5. Discussion, Contribution and Practical Application

### 5.1. Theoretical interpretation and contribution to knowledge

The two questions produce complementary answers. For **RQ1**, the corpus identifies credible production-emissions approaches and specific opportunities for assembly design and circular recovery; it does not establish general superiority over functionally comparable timber housing. **RQ2** is answered through documented design choices, organisational experiences and assurance requirements: the implementation question concerns how a specified product, production level and set of responsibilities fit the application. Benefits remain criterion-specific, and the strength of the conclusion is limited by the evidence linking those stages.

The conceptual contribution distinguishes benefit creation, recognition and realisation. Circular-economy and life-cycle perspectives separate material loops from net environmental consequences ([Bocken et al., 2016](#); [Korhonen et al., 2018](#)). Supply-chain perspectives identify the information and responsibilities connecting production to an implementable product ([Farooque et al., 2019](#); [Seuring & Müller, 2008](#)). The policy evidence adds an administrative recognition step: a product claim may need to enter the assessment applicable to the chosen housing configuration. Property analysis then identifies whether and to whom cost, completion or whole-life consequences accrue. These are complementary questions, not interchangeable measures of success.

The Socio-technical transitions perspective provides a bounded explanation of technological and capability alignment ([Geels, 2004](#)). The upstream/downstream distinction is operational rather than rhetorical: European steel-sector learning, Australian fabrication practice and a wall-frame competency specification concern different actors and tasks. The onsite-assembly case and differing manufacturer maturity also challenge a simple progression from conventional to advanced practice. The review therefore uses transitions concepts to interpret the co-ordination problem; it neither demonstrates a national regime shift nor labels established practices inherently inferior.

The contribution is a product- and decision-specific analysis of policy compatibility and benefit attribution. [Masood et al. \(2022\)](#) explain supplier organisation, [Dewagoda et al. \(2024\)](#) integrate circular and manufacturing design, and [Shou et al. \(2026\)](#) map policy instruments and their sequencing. This review connects those considerations to the evidence needed for a particular housing option: applicable classification, recognised product information, an appropriate implementation horizon and traceable outcome incidence. It provides a means of distinguishing an improvement in production from its recognition and realisation in a property decision, rather than proposing another general policy map or circular-prefabrication model.

## **5.2. Conditional Assessment Framework for Decarbonised Steel Framing**

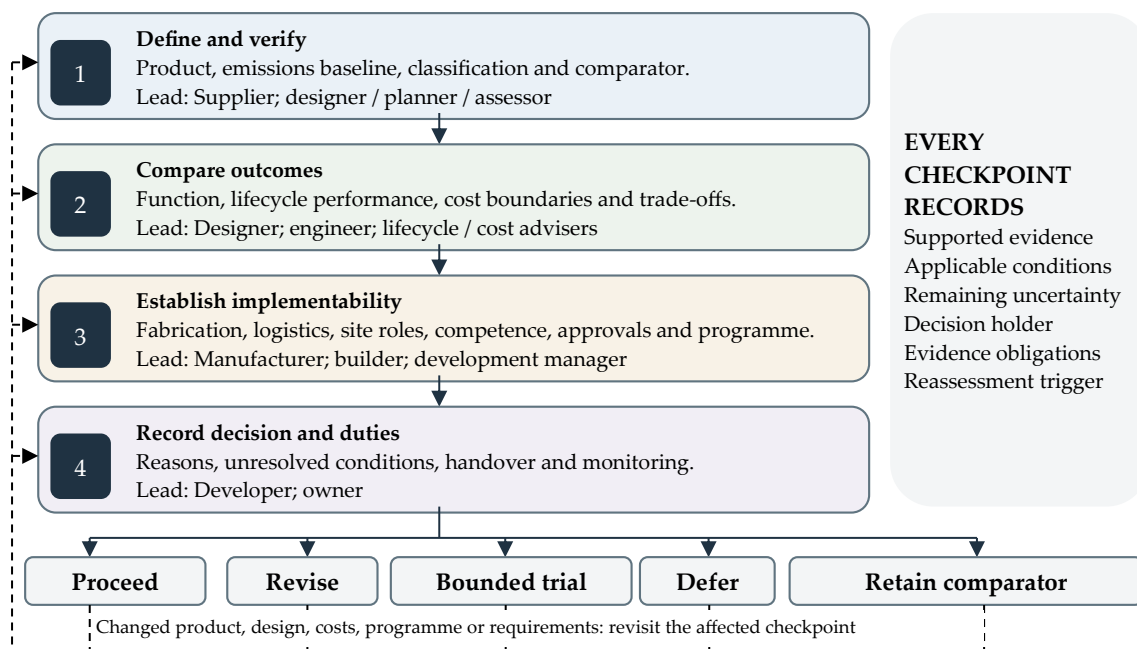
The Conditional Assessment Framework links the synthesis to four checkpoints (Table 7 and Figure 4). Each records the product or comparison, supported outcome, conditions, decision holder, missing evidence and reassessment trigger. Changes in design, supply, programme or requirements return the assessment to the relevant checkpoint. S1 links the checkpoints to supporting claims and source-restriction checks.

Table 7. Conditional assessment framework: evidence, responsibility and decision output

| Assessment checkpoint         | Evidence and responsible parties                                                                                                                                                                                                  | Decision output                                                                                                                    |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| 1. Define and verify          | Supplier/manufacturer: actual product, route, emissions baseline/boundary and traceability. Designer/planner/assessor: housing brief, comparator, completed configuration and applicable current requirements.                    | Record supported or unresolved claim. New product/supplier or declaration triggers re-verification.                                |
| 2. Compare outcomes           | Designer/engineer and lifecycle/cost advisers: comparable functions, accepted assessment treatment where relevant, lifecycle impacts, installed/total-development cost and household-cost boundaries.                             | Criterion-specific trade-offs. Changed design, functional requirement or lifecycle assumption triggers comparison again.           |
| 3. Establish implementability | Manufacturer, builder and development manager: production, logistics, site interfaces, competence, programme and payments. Assessor: current approvals, verification and certification scope; do not rely on prospective schemes. | Assign unresolved conditions and evidence holders. Changed capacity, contract, site or requirement triggers reassessment.          |
| 4. Record decision and duties | Developer/owner: evidence of outcome incidence, conditions, handover and monitoring. Reassess on changed product, configuration, rules, factor acceptance, programme or costs.                                                    | Proceed, revise, trial, defer or retain comparator; record owner/date/evidence and triggers. No automatic material recommendation. |

*Source: Authors' analytical integration, linked to C40–C49 and C57–C84 in S1. Proposed decision support, not certification, empirical validation or a weighted material-ranking model.*

The possible outputs include proceeding, revising, a bounded trial, deferral and retention of the comparator. An unverified emissions claim remains unresolved; it neither qualifies the product as decarbonised nor proves conventional production. Physical design can still be assessed separately. The decision record retains adverse findings and the conditions requiring reconsideration.



Note: Solid arrows show the assessment sequence; dashed arrows show reassessment. This is proposed decision support, not certification, a validated adoption model or a weighted ranking.

Source: Authors' analytical integration of manuscript Section 5.2 and Supplementary Register S1. Each checkpoint links evidence, conditions, decisions and remaining uncertainty.

Figure 4. Conditional Assessment Framework for Decarbonised Steel Framing in Australian Detached Housing

Figure 4 summarises the iterative assessment of a specified decarbonised-steel framing option. Each checkpoint records supporting evidence, applicable conditions, uncertainty and the responsible decision holder. Product, design, programme or regulatory changes trigger reassessment rather than an assumed progression towards adoption. Property implications follow only from the development and ownership outcomes supported by the evidence.

### 5.3. Policy analysis, practical application and property implications

Table 8 applies the existing framework to two concrete policy interfaces: approval/assurance across a configured delivery system, and recognition of verified material-emissions evidence. The further affordability question is whether changes at those interfaces reach completed compliant housing, total expenditure and household costs. These are source-linked evaluation specifications, not findings that a particular instrument lowers prices or that every policy must share one timetable.

Table 8. Source-linked implications for policy analysis, practice and research

| Application / decision holder             | Source-linked issue                                                                                                                                                                   | Assessment output and evidence needed                                                                                                                            | Remaining uncertainty                                                                      |
|-------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Approval/assurance evaluator; planner     | Configuration-dependent routes and future reforms differ ( <a href="#">Building Commission NSW, 2026</a> ; <a href="#">NSW DPHL, 2026a</a> ).                                         | Record actual category, operative provisions, factory/site responsibilities, consent and completion route; compare approval time, duplication and compliance.    | No site-specific legal classification or demonstrated reform effect.                       |
| BASIX assessor; supplier; certifier       | Material-factor recognition and certificate commitments are separate from a product label ( <a href="#">NSW DPHL, 2026b</a> ).                                                        | Identify actual product/boundary; document any alternative-factor submission and approval, specified/supplied consistency and completed-building assessment.     | No automatic EPD acceptance, embodied cap or whole-life saving.                            |
| Housing/manufacturing programme evaluator | NSW manufacturing focus, national assurance timing and green-iron horizon differ ( <a href="#">ABCB, 2026a</a> ; <a href="#">DISR, 2026</a> ; <a href="#">NSW DPHL, 2026c</a> ).      | Track eligible product/category, awards/spend, utilisation, deliverable framing supply and completed homes. Separate local capacity from imported modules.       | Announcement/tender or upstream output does not establish applicable current frame supply. |
| Developer; builder; cost adviser          | Programme and financing influence outcome incidence ( <a href="#">CBA, 2026</a> ; <a href="#">Sharam et al., 2026</a> ; <a href="#">Steinhardt &amp; Manley, 2016</a> ).              | Compare manufacture, delivered/installed, total-development and household-cost boundaries; record contracts, completion and evidence of price/rent pass-through. | No measured household-affordability effect in this review.                                 |
| Designer; manufacturer; builder           | DfMA and production-site fit require evidence at the affected stage ( <a href="#">Daly et al., 2025</a> ; <a href="#">Iuorio et al., 2023</a> ; <a href="#">Wasim et al., 2023</a> ). | Coordinate drawings, thermal/structural details, fabrication and site interfaces; verify programme/quality outcomes rather than only erection speed.             | Mixed settings and models do not establish a universal steel benefit.                      |

| Application / decision holder          | Source-linked issue                                                                                                                                                         | Assessment output and evidence needed                                                                   | Remaining uncertainty                                           |
|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|
| Employer; training/assurance evaluator | Provision, capability and performance differ ( <a href="#">ABCB, 2026c</a> ; <a href="#">Maldonado-Mariscal et al., 2023</a> ; <a href="#">Victoria University, 2026</a> ). | Connect role-specific tasks, training, demonstrated competence and relevant defect/compliance measures. | Neither a course nor a certificate guarantees site performance. |

*Source: Authors' applications of the cited evidence and C57–C84 in S1. Policy outputs and affordability links specify what should be evaluated; they are not observed intervention effects.*

For policy evaluation, manufacturing capacity and faster assessments are intermediate outputs. The relevant records identify participating manufacturers and configurations, costs of assurance, programme changes, completed dwellings and verified environmental performance. The existing ABCB draft distinguishes volumetric inspection assumptions from panel/kit throughput assumptions ([ABCB, 2026b](#)); the new NSW documents add category and assessment-route differences. An evaluator should preserve those boundaries and identify who receives any saving before claiming an affordability effect. A material-neutral comparison also guards against subsidising one label without demonstrating the intended housing or environmental outcome.

Consider a hypothetical NSW developer comparing timber panels with a proposed lower-emission steel-panel system. The planner and relevant assessor first identify the completed configuration and currently applicable approvals; neither the supplier's prefab label nor a future reform determines that classification. The supplier provides product-specific emissions evidence, and the sustainability assessor checks the applicable BASIX treatment, including alternative factor approval where relevant ([NSW DPHI, 2026a, 2026b](#)). The designer and engineer then compare material-appropriate structural and envelope options against the same housing brief. No project approval, emissions reduction or saving is asserted by this illustration.

Manufacturer, builder and cost-adviser records connect fabrication and logistics with site responsibilities, the controlling completion sequence and total expenditure. They identify whether any cost difference reaches a contract price, rent or ongoing household cost rather than assuming pass-through. Task competence and maintenance/recovery information form part of the implementation and handover record. A changed supplier triggers emissions re-verification; changed panelisation triggers classification and design/logistics reassessment; changed regulations or assessment instructions trigger an approval review; a changed programme prompts reconsideration of the financial claim. The four checkpoints remain intact, with more explicit evidence obligations.

The applied property contribution is an auditable link from construction attributes and policy instruments to development and ownership decisions. Recognition, assurance, lawful occupation, feasibility and household affordability are distinct outcomes. Consistent with [Wu](#)

[et al. \(2016\)](#), valuation, insurance and price consequences require corresponding evidence. The framework makes these links explicit and allocates responsibility for examining them.

#### **5.4. Study limitations and future research**

Claim-specific appraisal and integration concern the declared purposive corpus and inspected passages, not all 147 candidate references. [Tavares et al. \(2021\)](#), [Yang et al. \(2026\)](#) remain preview-only, limiting detailed comparative and prior-review appraisal. The full-text examination of [Shou et al. \(2026\)](#) informed positioning but did not independently reproduce its policy dataset. The policy analysis is a dated, selective Commonwealth/NSW application, not a national regulatory survey or a causal evaluation. Reform status is attributed to Building Commission NSW rather than a complete provision-by-provision statutory verification; project reliance requires checking applicable commencement and transitional provisions.

The evidence differs in geography, building type, production status and outcome definition. The eight qualitative restriction checks identify source-dependent conclusions; they do not rerun models or demonstrate affordability pass-through. Removing prospective policy examples narrows the implementation-horizon discussion but leaves the inspected BASIX reporting process and classification guidance as dated documentary findings. Restricting performance evidence to matched Australian detached housing still supplies no general decarbonised-framing effect estimate. The framework has not been tested with practitioners.

Further work should test matched, material-appropriate housing options using product-specific emissions, bills of quantities, actual programmes and expenditure, and maintenance/recovery records. Policy evaluation should distinguish adoption by government, administrative availability, industry participation and completed-housing effects. Affordability research should follow cost incidence into prices or rents and ongoing costs relative to household circumstances, rather than infer welfare improvement from manufacturing output. Practitioner testing can assess whether the framework improves decisions, including revision, deferral or retention of the comparator.

#### **6. Conclusion**

Decarbonised steel framing is an option to assess rather than an assumed destination for Australian housing. The review separates production-emissions claims, design, delivery and property consequences. It supports product verification and criterion-specific comparison with contemporary timber, not universal environmental, structural or economic superiority.

The adaptation question is answered through conditions made visible in the evidence: design–production fit, appropriate prefabrication level, procurement interfaces, role-specific capability and credible recovery arrangements. These conditions identify where benefits may be created, constrained or shifted between participants; they are not universal causal requirements. Circular-economy, lifecycle, supply-chain and socio-technical perspectives help interpret their relationships without predicting a national material transition.

The four-checkpoint framework links findings to decision holders, evidence duties and reassessment. Housing-delivery and green-material policy must be assessed against the specified product, classification, emissions-recognition route and implementation horizon.

Affordability depends on the passage between construction, development and household costs. The contribution is a source-traceable basis for examining these relationships; stronger claims of policy effectiveness and combined housing benefit require project-level testing.

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## 8. Disclosure statement

The authors report there are no competing interests to declare.

## 9. Data availability

Supplementary Register S1 accompanies the manuscript and documents the source inventory, claim-level appraisal, policy extraction and evidence-to-framework links. No primary participant dataset was generated for this review.

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