

# The applicability of stepwise retrofitting in the Australian residential sector: an exploratory qualitative study

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## Abstract

**Purpose** – Stepwise retrofitting offers a phased, flexible approach to improve building energy performance and overcome the financial and logistical barriers of single-step retrofitting. However, existing research relies on theoretical models and simulations, often overlooking real-world market conditions. This study investigates the practical applicability of stepwise retrofitting in the Australian residential sector, drawing on insights from experts.

**Design/methodology/approach** – An exploratory qualitative research design was employed. The data were collected through 11 expert interviews with industry, policy, and academia, followed by triangulation with a policy analysis. Thematic analysis and directed content analysis were conducted to analyse insights under three core elements of stepwise retrofitting: timing, packaging, and sequencing.

**Findings** – Experts recommend mandated 10-year retrofitting cycles with retrofit steps spaced every three years. This study proposes, for the first time, a hybrid retrofit package approach that combines standardised measures (e.g. insulation, glazing) and customised audits for complex systems (e.g. HVAC). A structured three-step retrofit sequence is recommended: (1) basic envelope improvements, (2) targeted upgrades, and (3) advanced technology integration.

**Research limitations/implications** – Since the study is confined to expert interviews, future studies should focus on conducting longitudinal case studies once the stepwise retrofitting is industrialised.

**Originality/value** – The study establishes a foundational guideline for timing, packaging, and sequencing (see Table 4) and contextualises the guideline within the existing Australian policy landscape (see Table 5). This study presents a novel sequencing approach for stepwise retrofitting and introduces a first-of-its-kind application framework for stepwise retrofitting, providing a skeleton for smart home researchers to build upon (see Figure 4).

**Keywords** Building passport, Energy retrofitting, Renovation cycles, Renovation roadmap, Residential construction, Staged renovation, Step-by-step retrofitting, Sustainable construction

**Paper type** Research article

## Introduction

Globally, buildings account for approximately 36% of energy consumption and 40% of GHG emissions, with residential buildings contributing 19% and 17%, respectively (IEA, 2023; UN Environment Program, 2024). In Australia, residential buildings consume 26% of energy and produce 12% of national carbon emissions (Australian Government, 2023). With approximately 80% of Australian homes projected to still be in use by 2050 (Ho *et al.*, 2021), upgrading existing homes to reduce energy consumption and emissions, known as energy retrofitting, is necessary for achieving Australia's net-zero emissions target (Hulathdoowage *et al.*, 2023).

Each retrofit measure offers a specific intervention, such as installing wall insulation, replacing appliances with energy-efficient options, and adding a Solar Hot Water System



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(SHW) (Adan and Fuerst, 2015). Traditionally, retrofits follow a single-step approach, completing all planned measures simultaneously (Maia and Kranzl, 2019). Although single-step retrofitting offers immediate emissions reductions and lower risks of technical errors (European Commission, 2023), the financial burden and level of disruption involved often make this approach inaccessible for a large portion of homeowners (Fox-Reynolds et al., 2021; Tinarwo et al., 2025).

Stepwise retrofitting, which systematically implements retrofit measures in multiple phases, called “retrofit steps”, within a defined overall timeframe known as a “retrofitting cycle”, offers a promising alternative to overcome financial and practical barriers of single-step retrofits (European Union, 2019; Maia and Kranzl, 2019). Although single-step retrofitting initially provides rapid emission reduction, its long-term emission reduction potential decreases due to material degradation and climate change impacts (Hulathdoowage et al., 2024). Conversely, stepwise retrofitting offers greater flexibility, improved adaptation to technological advancements, and heightened responsiveness to changing climate and occupant needs (Fernandes et al., 2021; Maia et al., 2023).

Nevertheless, research into stepwise retrofitting primarily focuses on a few developed nations, particularly in Europe and North America, due to their advanced policy frameworks (Bergfeld et al., 2021; European Commission, 2023). These studies also rely on theoretical models and simulations, neglecting homeowner perspectives and practical market considerations. For example, Maia et al. (2021) developed a model for timing retrofit steps based on homeowner budgets and energy bill savings; however, they did not empirically validate its assumptions in relation to market conditions. Liu et al. (2021) examined the suitability of stepwise retrofitting for Passivhaus EnerPHit standards in China through simulations, without assessing homeowner acceptance or market feasibility. Lissen et al. (2021) identified the cost-effectiveness of stepwise retrofitting using Life Cycle Cost Analysis (LCCA) but called for future research to examine its practical acceptance. There is no exception in Australia; for example, Kang et al. (2022) assessed stepwise retrofits for Passive House-certified buildings in Melbourne, Australia via a bottom-up dynamic simulation method.

Hence, a significant research gap exists regarding the practical applicability of stepwise retrofitting in diverse market contexts. To address this gap, this study conducts a preliminary investigation of expert perspectives on stepwise retrofitting within the Australian residential sector. This study contributes to existing knowledge by: (1) identifying practical considerations influencing stepwise retrofitting in Australia and positioning stepwise retrofitting within the current policy landscape, and (2) laying the groundwork for future research and policy development for the application of stepwise retrofitting. The study focuses exclusively on owner-occupied homes, as they constitute 66% of Australian households (ABS, 2022). The study does not directly assess technical performance but lays the groundwork for more practical quantitative modelling and simulations, offering deeper insight into Australian market conditions.

The remainder of the paper is structured as follows: the next section presents the theoretical background, followed by the methodology. Findings elaborate on the applicability of stepwise retrofitting in Australia. The discussions section contextualises the findings within existing literature before concluding with key remarks.

## Literature review

### *Stepwise retrofitting in the residential sector*

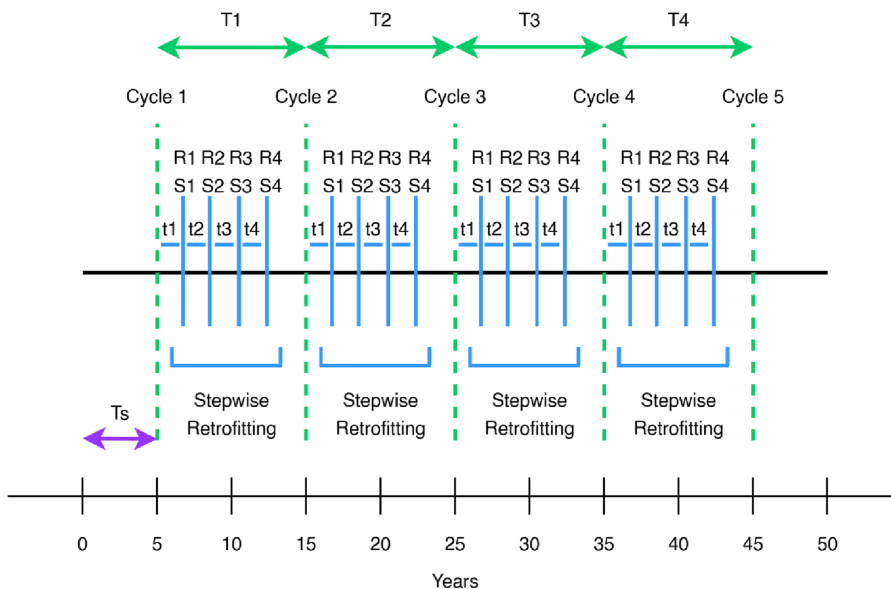
Despite single-step retrofitting offering immediate improvements, its high upfront costs and disruptive nature limit homeowner participation (Fox-Reynolds et al., 2021). Consequently, 80–90% of real-world retrofits are partial, involving uncoordinated and isolated retrofit measures (Blücher, 2016). In response, some decision-makers adopt the stepwise retrofitting approach to reduce the consequences of isolated measures by achieving deep retrofitting through coordinated retrofit steps (Galiotto et al., 2012).

For example, in the UK Superhomes project, over half of the homes were retrofitted using this stepwise approach, spanning several years to over 3 decades (Superhomes, 2013). Although both approaches achieved over 60% energy savings, homeowners favoured the stepwise approach, accepting retrofitting as ongoing (Fawcett, 2014; Superhomes, 2013). Nevertheless, homeowners highlighted several challenges of the stepwise approach: (1) integration issues of upgrades at different times, (2) technical mismatches of sequential upgrades, and (3) potentially higher cumulative costs resulting from repeated interventions and corrections, which emphasise the need for a strategic framework to guide stepwise retrofitting (Fawcett, 2014).

While policy has traditionally supported single-step retrofits for their immediate impact (European Commission, 2023), the Energy Performance of Buildings Directive (EPBD) 2018/844/EU now formally recognises stepwise retrofitting through renovation passports, which document past and planned upgrades to support informed decision-making and optimise building performance (European Union, 2019). Similarly, the Passive House Institute advocates for stepwise retrofitting, with pre-certification of an EnerPHit Retrofit Plan (ERP), ensuring feasibility for compliance upon completion (Traynor, 2020). This formal recognition from the EPBD and the advocacy from the Passive House Institute provide a strong foundation for the legitimacy and effectiveness of stepwise retrofitting.

A structured stepwise retrofitting process typically spans multiple ‘retrofit steps’ within each ‘retrofitting cycle’ (European Union, 2019; Maia and Kranzl, 2019). Figure 1 illustrates such a process across a typical 50-year building lifespan, assuming four 10-year cycles, each comprising four retrofit steps.

Buildings require multiple retrofitting cycles due to material degradation, technological advances, changing regulations, climate adaptation, and evolving occupant needs (Barlow et al., 2023; Goodarzi et al., 2025; Kang et al., 2022; Lawrence et al., 2022; Santamouris, 2020). Each cycle targets specific performance goals, such as improving energy ratings or



**Figure 1.** An indicative stepwise retrofitting process for 50 years. Note: Start time for retrofit cycles ( $T_s$ ); Timing between retrofitting cycles ( $T_1 - T_4$ ); Retrofit steps (Blue unbroken lines from S1 to S4); Intervals between retrofit steps ( $t_1 - t_4$ ); Retrofit packages (R1 – R4). Source: Developed by authors

achieving net-zero emissions. Collectively, these cycles form a strategic framework for retrofitting, known as a retrofitting roadmap (Fabbri *et al.*, 2016).

The effectiveness of stepwise retrofitting hinges on coordinating three interdependent elements (Maia *et al.*, 2021).

- (1) Timing (t1 - t4, and T1 - T5)
- (2) Designing retrofit packages (R1 - R4)
- (3) Sequencing retrofit packages (The order of R1- R4 in each cycle)

*Timing* determines the durations for retrofit cycles and intervals between retrofit steps, driven by technical, financial, social, and environmental considerations (Hulathdoowage *et al.*, 2024; Maia *et al.*, 2021). Kang *et al.* (2022) emphasise that timing retrofit cycles must consider climate change, recognising its dynamic nature; for example, temperate climate zones will likely see a significant rise in cooling demand this century (Lawrence *et al.*, 2022; Santamouris, 2020). Retrofit intervals should align with the homeowner's budget, allowing for either gradual implementation or accumulation of funds for larger upgrades (Maia *et al.*, 2021, 2023).

*Packaging* combines compatible retrofit measures within each step to optimise performance outcomes (Maia *et al.*, 2023). For example, combining insulation, draft-proofing, and glazing yields greater energy savings and facilitates efficient on-site work compared to individual measures (Fernandes *et al.*, 2021). Effective package design must consider technological interdependencies, compatibility, and homeowner affordability (Fernandes *et al.*, 2021).

*Sequencing* involves the order of retrofit steps. Poor sequencing can create lock-in effects, restricting future efficiency improvements; for example, installing Heating, Ventilation, and Air Conditioning (HVAC) before adequate insulation results in oversized systems (Maia and Kranzl, 2019). A fabric-first strategy is often recommended to avoid lock-in effects, whereas room usage patterns or component replacements lead to room-by-room or measure-by-measure approaches, respectively (Fawcett, 2014; Maia *et al.*, 2021; Topouzi *et al.*, 2019). Priore *et al.* (2023) highlighted the critical impact of sequencing, demonstrating that sequencing can alter cumulative GHG emissions by up to 30% in a multi-family Swiss building.

The primary factor enabling stepwise retrofitting is the lower initial cost, as the investment is spread across multiple stages (Maia and Kranzl, 2019). Other than that, stepwise retrofitting provides higher capacity to tailor the process for the occupants' needs, life events, and preferences (Fawcett, 2014). However, like any other new approach, a few potential barriers have been recognised for the application of stepwise retrofitting, including information and trust gaps, the complexity of the process, uncertainty about realised savings, and the risk of lock-in effects (Maia *et al.*, 2024; Mehta and Zörner, 2024). Most of these barriers could be overcome by establishing building renovation passports, which are available as an electronic/paper documents and outline a long term (15–20 years) stepwise retrofitting roadmap for a specific building (Sesana and Salvalai, 2018), and one-stop shops, which act as integrated single entry services providing advice, design, contractor coordination, and administration through one provider instead of a fragmented supply chain (Bertoldi *et al.*, 2018).

#### *Strengths and limitations of existing models and frameworks related to stepwise retrofitting*

Empirical evidence shows that current models and frameworks on stepwise retrofitting possess certain strengths, while also highlighting some context-specific limitations. Table 1 presents these strengths and limitations, further showing the historical development of the stepwise retrofitting approach. Interestingly, all these pioneering studies originate from Europe.

Table 1 reveals a common limitation in current stepwise retrofitting models: they depend on unvalidated assumptions about market behaviour and retrofitting adoption. Therefore, investigating expert perspectives on the applicability of stepwise retrofitting under various market conditions can guide realistic assumptions for models.

**Table 1.** Strengths and limitations of existing models and frameworks related to stepwise retrofitting

Models/Frameworks	Strengths	Limitations	References
Preliminary guideline for implementing stepwise retrofitting	First conceptualisation; distinguishes from the single-step approach; examines attractiveness to households, potential technical issues, and the lock-in risks; establishes the worthiness for further exploration	Scoping only; limited to basic characteristics at the initial concept stage	<a href="#">Fawcett (2014)</a>
MILP optimisation for timing each retrofit step, while maximising the household energy-related cash flow	First quantitative model for timing retrofit steps; integrates budget constraints, material ageing, and the interdependence among retrofit steps; reinvests homeowner savings of earlier retrofit steps	Calibrated to Austrian household finance; omits the impact of climate change; validated only in Europe; (4) no expert validation for the model's market assumptions	<a href="#">Maia et al. (2021)</a>
UK stock model which assesses stepwise retrofit scenarios to achieve the Passive House Standard	20 reference buildings (five age categories and four building sizes); bottom-up energy demand estimation for the UK housing stock; five-staged plan to retrofit UK houses; achieved an 87% energy saving and 76% carbon reduction in five steps over 15 years	Depends on uptake and performance assumptions; no sensitivity analysis or expert validation for the assumptions; no step-level financial analysis	<a href="#">Bennadji et al. (2022)</a>
A framework for timing retrofit steps based on cumulative emissions and carbon budgets	Uses cumulative and time-aligned carbon metrics; evaluates climate friendliness via cumulative carbon; compares optimal timing as a function of cost and cumulative carbon; cross-country comparison (Spain, Germany, Sweden)	Lacks socioeconomic diversity of occupants and retrofitting markets; limited policy guidance; no expert validation for the market assumptions	<a href="#">Maia et al. (2023)</a>
LCA*-based timing and sequencing framework	Full LCA* of renovation strategies; sequences renovation measures using carbon payback time and cumulative emissions	Excludes occupant behavioural patterns; limited generalisability across broader housing types; limited to the Swiss context	<a href="#">Priore et al. (2023)</a>
Holistic approach for retrofitting gradually, utilising local resources	Parametric simulation of novel and sustainable insulation materials; adaptable to similar high-altitude communities	No experimental testing for the harvested materials; validated only for Kyrgyzstan's high-altitude rural housing	<a href="#">Mehta and Zörner (2024)</a>
A framework for assessing the impact of household budget constraints on the optimal timing of retrofit steps	Data-driven budget constraints for owner-occupied, rented single/multi-family homes; optimise timing of retrofit steps within budget constraints	Same share of annual income for retrofitting across households, misrepresenting low-income groups who often experience energy poverty; validated only for Spain; no expert validation for the market assumptions	<a href="#">Maia et al. (2024)</a>

**Note(s):** \*Life Cycle Assessment

**Source(s):** Developed by authors

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*Applicability of stepwise retrofitting in Australia under the socio-economic interactions between occupants and building systems*

The Applicability of stepwise retrofitting depends on socio-economic interactions between occupants and building systems. The occupants' capacity, preferences, tolerance for disruption, time availability, and motivation not only shape retrofitting decisions but also impact the applicability of stepwise retrofitting (Armstrong *et al.*, 2024; Fawcett, 2014; Kim *et al.*, 2023). Occupants' daily actions, such as thermostat settings, window and shading control, and appliance timing, as well as their clothing level and metabolic rate, can increase or decrease the level of intervention needed and influence the outcomes observed in Post-Occupancy Evaluations (POEs) (Ahmed *et al.*, 2024; Alsharif *et al.*, 2022). Stepwise retrofitting can tailor subsequent measures for occupants based on what is learnt during the POE.

Evidence on stepwise retrofitting in Australia is limited, with few isolated studies compared to the US and Europe. Kang *et al.* (2022) tested a four-step retrofit approach for a Passive House student accommodation in Melbourne and showed that the spreadsheet-based PHPP tool under-represents occupant-building interactions over time. Their staged monitoring demonstrated that the effectiveness of each retrofit step should be assessed under real occupant-building interactions and should inform subsequent retrofit steps. Their four-step retrofit approach reduced overheating from 26% to 6% and energy consumption from 80.8 to 75 kWh/m<sup>2</sup> per year.

Australia's retrofit market remains dominated by single-step projects, facing various socio-economic challenges, such as high upfront costs, significant disruptions, and low homeowner awareness, all of which limit participation rates (Armstrong *et al.*, 2024; COAG Energy Council, 2019; Fox-Reynolds *et al.*, 2021; Fyfe, 2025). These barriers are acute for renters, social housing residents, low-income households, culturally diverse communities, and First Nations households, who often occupy the least energy-efficient homes and have the least capacity for extensive retrofits (ACOSS, 2024; Bird and Hernandez, 2012). By tailoring scope, timing, budget, and disruption level, stepwise retrofitting can lower entry barriers and mobilise private investment (European Union, 2019; Fawcett, 2014; Maia *et al.*, 2023, 2024).

Australians have exhibited maladaptive behavioural responses to heat stress, such as increasing soft drink or alcohol consumption, avoiding outdoor exposure, and relying on air conditioning, which impact both health and energy demand (Zander *et al.*, 2024). Thus, stepwise retrofitting plans should combine each stage with POE and incorporate findings into the next stage to ensure occupants' comfort and well-being. Time-sensitive climate metrics can further refine the sequencing and the overall length of the stepwise retrofitting roadmap (Maia *et al.*, 2023).

Once properly adopted, stepwise retrofitting presents a significantly greater potential for widespread application in Australia due to its higher capacity to incorporate occupant-building interactions compared to the single-step approach (Kim *et al.*, 2023; Maia *et al.*, 2021). Given its promising benefits, further investigation into stepwise retrofitting is not only justified but essential. Despite the absence of commercial implementations to date (Kang *et al.*, 2022), this study takes a crucial first step by exploring expert perspectives on the applicability of stepwise retrofitting in Australia.

### **Research methodology**

Drawing on Creswell and Creswell (2022), this study employed an exploratory qualitative research design, combining expert interviews and a policy analysis, to examine the practical applicability of stepwise retrofitting in Australia's residential sector.

#### *Data collection*

*Phase 1: Expert Interviews.* As one of the first studies, semi-structured expert interviews provided foundational insights into stepwise retrofitting in Australia, enabling rich contextual

exploration through guided yet open-ended responses (Creswell and Poth, 2017). As research in underexplored areas should rely on participants' subject-specific knowledge, experts were purposively selected, adhering to two criteria: (1) at least 10 years of retrofitting or sustainable construction experience, and (2) active leadership in energy efficiency or building policy (Etikan *et al.*, 2016). Table 2 presents the profiles of the selected experts, while maintaining anonymity.

Interviews continued until data saturation was reached, at which point further interviews yielded no new insights (O'Reilly and Parker, 2013). The final sample of eleven experts exceeded the recommended minimum (5 participants) for expert-based qualitative research (Jallow *et al.*, 2021; Ghalenoei *et al.*, 2022). The sample consisted of highly experienced professionals holding extensive leadership roles, which enhances the credibility and

**Table 2.** The profile of experts

ID	Designation and experience	Leadership in relevant sectors
<i>Industry</i>		
ID01	Director, Builder, and Energy Rater (22 years)	Founder of an award-winning energy retrofitting company; Performs energy performance assessments; Board member for several peak bodies
ID04	Executive Chairman (35 years)	Senior executive and technologist in the sector of advanced manufacturing, covering research and development of energy-efficient building materials
ID05	Director and Builder (30 years)	Founder of an architecture firm, specialising in sustainable building design with people in mind; Expertise in design and technical skills with any new build, refurbishment, home energy rating or design consultation
<i>Policy</i>		
ID03	Senior Policy Officer (34 years)	Founder of a leading policy consultation company focused on climate policy, energy retrofitting and energy efficiency of buildings; Expertise in economic and policy analysis in both France and Australia
ID07	Sustainability Consultant (16 years)	Environmental, Social and Governance (ESG) policy officer and sustainability consultant specialised in building energy and daylight modelling; Expertise in facade optimisation for policy analysis
ID08	Policy Officer (27 years)	Senior policy officer with extensive experience in energy retrofitting in residential and commercial buildings in both the United Kingdom and Australia
ID11	Policy Officer (12 years)	Senior policy officer for a leading government institute in Australia; Has collaborated on many policy-oriented projects to estimate and overcome carbon emissions in the built environment
<i>Academia</i>		
ID02	Professor (31 years)	Serves as Deputy Vice Chancellor for Research and Innovation in a university; Chief Investigator in over 100 industry-linked research projects across urban sustainability and low-carbon transitions for houses
ID06	Senior Lecturer (16 years)	Has contributed to many research projects related to energy retrofitting and sustainable building materials
ID09	Adjunct Professor (30 years)	Has worked on numerous research projects to advance the energy efficiency of existing residential buildings and contributed to the development of a Building Renovation Passport (BRP) for Australia
ID10	Professor (26 years)	Experienced researcher related to sustainable building designs and energy efficiency of existing building stock; Initiative leader and team leader for two green urban institutes

**Source(s):** Developed by authors

contextual relevance of the findings (O'Reilly and Parker, 2013). For balanced representation, experts were evenly distributed across the three key sectors: industry, policy, and academia.

Given the emerging nature of stepwise retrofitting, each interview commenced with a brief explanatory overview. Interview questions, developed from existing literature, addressed two themes: (1) the current status of retrofitting in Australia, and (2) applicability of the three core elements of stepwise retrofitting: timing, packaging, and sequencing. Experts were first asked directly about their perspectives on each element, followed by discussions on potential challenges, opportunities, driving factors, and household benefits of structured stepwise retrofitting. Interviews (45–60 min each) were conducted virtually between February and March 2024.

*Phase 2: Policy Analysis.* This study conducted a policy analysis to examine the compatibility of experts' recommendations regarding stepwise retrofitting with current policy directives. Thirty-one policy programs were selected for analysis based on Walt and Gilson's (1994) policy analysis triangle, encompassing context (energy retrofitting and climate targets), content (aimed at improving the energy efficiency of existing dwellings), process (funding and legislative mandates), and actors (federal and state governments). These policy programs were identified primarily from Armstrong *et al.* (2024), the latest report on Australia's home renovation wave, and the Department of Climate Change, Energy, the Environment, and Water (DCCEEW) Website. Appendix 1 lists these policy programs.

#### *Data analysis*

The data analysis process is presented in Figure 2, based on the two phases of data collection.

In Phase 1, thematic analysis, a robust method for qualitative research (Hulathdoowage and Chandanie, 2023), was employed to identify patterns in expert interviews, guided by Braun and Clarke's (2006) six-phase approach. First, interviews were transcribed verbatim while familiarising. Second, the parent themes (Codebook Version 1) were developed from the interview guide using a deductive approach. Third, the sub-themes (Codebook Version 2) were generated through reading and comparing the interview transcripts following the inductive approach. Fourth, sub-themes were grouped into parent themes via focused and axial coding. Focused coding minimises noise, sharpens category boundaries, and creates a more concise codebook (Brooks *et al.*, 2023), i.e. "can't afford all at once" becomes "affordability constraints". Axial coding maps relationships among codes (Siva and Ershadi, 2025), i.e. "the need for restumping in old houses", grouped into both "timing for floor insulation" and "opportunities for stepwise retrofitting". Fifth, a two-level analysis was conducted to capture sector-specific patterns and compare among sectors. Finally, experts' recommendations were summarised and tabulated in Table 4.

A directed content analysis, a theory-informed approach, was employed in Phase 2 to refine and extend the recommendations of the experts, based on existing policy frameworks (Ghafoor *et al.*, 2024; Hsieh and Shannon, 2005). First, housing-related policies of the state and territories were selected for analysis (see Appendix 1), and then, their objectives and key characteristics were extracted verbatim. Third, each policy was mapped to the three core elements of stepwise retrofitting based on the scope of policies (see Appendix 2). Fourth, an initial coding frame was developed based on the scope of existing policy programs and the findings of Phase 1. Finally, the overall policy support level for each element was tabulated in Table 5 based on the rubric given in Table 3, along with a summary of the strengths and limitations of existing policies.

Drawing on findings from both Phase 1 and Phase 2, an application framework was developed to illustrate interconnections among stepwise retrofitting elements, present policy-oriented recommendations and guide future research. Finally, insights from expert interviews and policy analysis were triangulated and contextualised within the broader literature.

Multiple strategies ensured the reliability and validity of the findings, including (1) cross-sector triangulation, transcending any single sector's viewpoint, (2) purposive sampling of

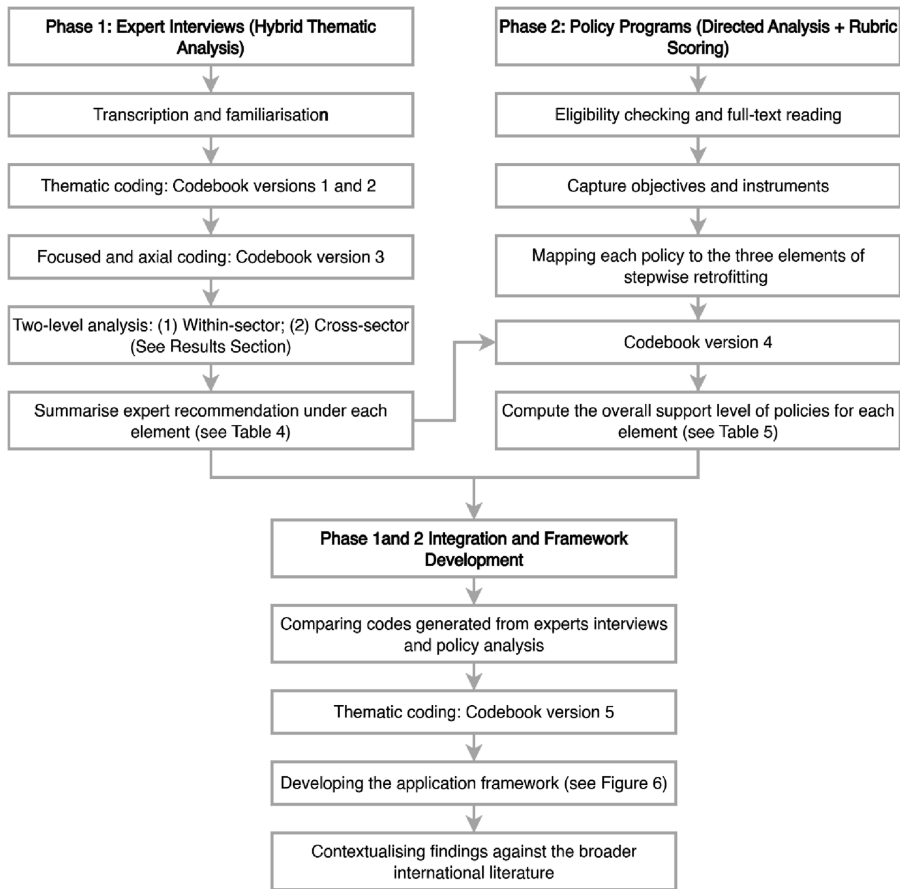


Figure 2. The flowchart of data analysis. Source: Developed by authors

Table 3. Rubric for implicit policy support

Support level	Definition	Typical policy characteristics
Negative	Policy conflicts with or contradicts expert recommendations	No relevant policies exist; Existing ones discourage the stepwise approach
Very limited	Policy offers minor, indirect, or incidental alignment but does not intend to support stepwise retrofits	Target the single-step approach, but no restrictions for phased implementation; Isolated triggers such as point-of-sale
Limited	Policy partially and unintentionally supports the stepwise approach	Some small grants/loans focused on elements; Guidance lacks depth and clarity
Moderate	Policy supports expert recommendations in multiple ways, but not comprehensively	Policies exist aligned with elements; Uneven sector coverage, i.e. limited to one state
Positive	Policy intentionally supports expert recommendations through comprehensive, structured mechanisms	Multiple integrated programs directly promote and guide stepwise retrofitting elements; Mandated performance tracking

**Note(s):** Elements refer to stepwise retrofitting elements

**Source(s):** Developed by authors

**Table 4.** A comprehensive overview of expert perspectives regarding stepwise retrofitting elements

Industry	Policy	Academia	Cross-sector summary
<i>Timing</i>			
Prefer flexible 10-year cycles with several retrofit steps in each cycle, considering homeowner needs, technology adoption, climate adaptation, and real estate trends	Advocates for standardised 10-year cycles, aligning with regulations, financial support, and real estate trends like property turnover rates	Recommend 3–5 year cycles to adapt homes to technological advancements, climate risks, and real estate cycles, while balancing homeowner preferences	Recommend 10-year cycles, which vary based on real estate trends, climate adaptation, technological advancement, degradation; with steps spaced every three years, considering affordability, replacements, and homeowner preferences
<i>Packaging</i>			
Should be tailored to existing-home conditions, budget constraints, acceptable disruption levels, and planned maintenance routines	Advocate for standard and tenure-specific retrofit packages, supported by BRPs, regulations, incentives, and climate goals	Recommend a combined approach that integrates data-driven assessments with standardised retrofit packages, accounting for technological dependencies and long-term compatibility	Recommend a hybrid approach, including (1) standardisation of common measures like double/triple glazing and insulation, and (2) detailed audits for complex systems like HVAC and SHW, to maximise efficiency, ensure system compatibility, and mitigate lock-in effects
<i>Sequencing</i>			
Support a flexible three-step sequence: (1) simple, low-cost measures, (2) targeted insulation and glazing upgrades, and (3) advanced technology integration	Advocate for a structured four-step sequence: (1) insulation, (2) insulation and draft-proofing, (3) HVAC upgrades, and (4) heat pump hot water system	Recommend a structured three-step sequence: (1) low-cost insulation upgrades, (2) window enhancements, and (3) HVAC system upgrades	Recommend a three-step sequence: (1) initial envelope improvements, including basic insulation and draft-proofing; (2) targeted envelope upgrades, including wall insulation and double glazing; (3) advanced technology integration, including high-efficiency HVAC systems and renewable energy sources

**Source(s):** Developed by authors

highly experienced professionals, (3) accurate data recording and transcribing, (4) incorporating direct quotations for transparency (Guest *et al.*, 2012), and (5) using policy analysis to examine the compatibility of experts' recommendations with existing policies. This methodological rigour provides a robust foundation for examining the applicability of stepwise retrofitting in the Australian residential sector.

## Results

The findings are presented in the following sections. The first section assesses the current state of the retrofitting market based on the expert perspectives. The next section evaluates the experts' recommendations on the applicability of stepwise retrofitting in Australia, while the

**Table 5.** A brief overview of the compatibility of expert recommendations with policy directions

Expert recommendations	Implicit policy support		Overall support
	Strengths	Limitations	
<p><i>Timing</i></p> <p>Recommend 10-year cycles, which vary based on real estate trends, climate adaptation, technological advancement, degradation; with steps spaced every three years, considering affordability, replacements, and homeowner preferences</p>	<p>Very limited alignment through Energy Efficiency Disclosure (EED), which supports retrofits before property sales, typically occurring every 12–20 years in Australia</p>	<p>No policy guidance on timing intervals</p>	<p>Very limited</p>
<p><i>Packaging</i></p> <p>Recommend a hybrid approach, including (1) standardisation of common measures like double/triple glazing and insulation, and (2) detailed audits for complex systems like HVAC and SHW, to maximise efficiency, ensure system compatibility, and mitigate lock-in effects</p>	<p>Incentives and mandatory standards support standardisation. Advisory programs provide detailed audits in some regions (ACT, Victoria)</p>	<p>Limited geographic availability of advisory programs for detailed audits</p>	<p>Moderate</p>
<p><i>Sequencing</i></p> <p>Recommend a three-step sequence: (1) initial envelope improvements, including basic insulation and draft-proofing; (2) targeted envelope upgrades, including wall insulation and double glazing; (3) advanced technology integration, including high-efficiency HVAC systems and renewable energy sources</p>	<p>Mandatory standards implicitly support the initial sequencing step. Advisory services guide homeowners on sequencing</p>	<p>Lack of structured sequencing guidance for broader implementation</p>	<p>Limited</p>

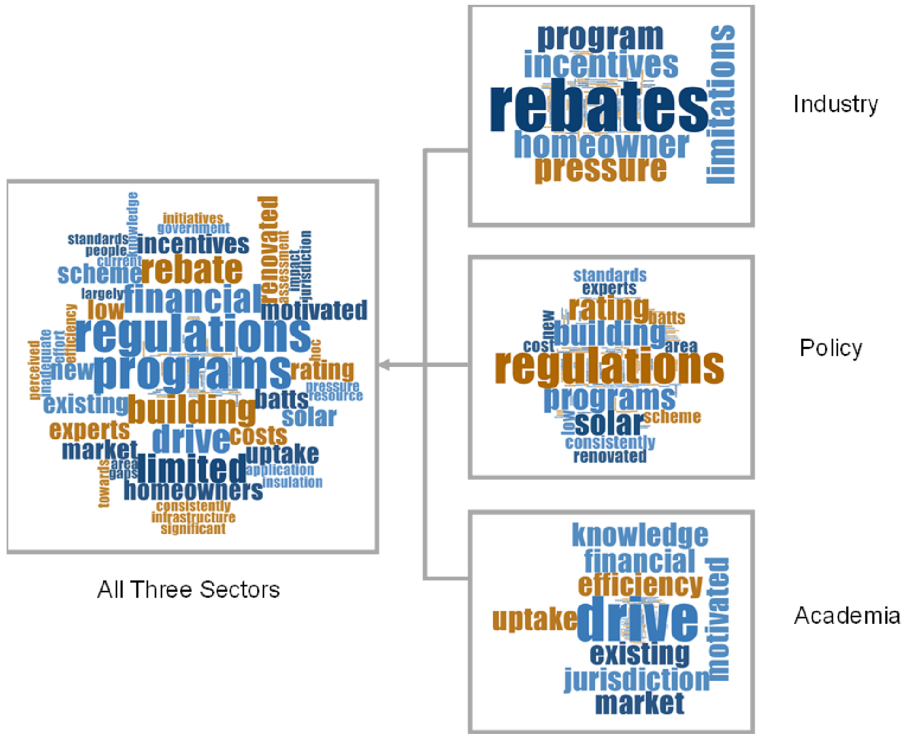
**Source(s):** Developed by authors

final section examines the compatibility of these recommendations with current policy directions.

### *Assessing the current retrofitting market*

A word frequency analysis was conducted to explore the sectoral perspectives on the current status of retrofitting, as illustrated in Figure 3. Using NVivo, the top 200 words were analysed to reveal key themes after excluding common and context-neutral terms and stemming.

From an *industry perspective*, retrofitting is largely ad hoc and reactive, often triggered by financial incentives and regulations rather than homeowner initiatives. Many retrofits occur alongside general renovations, with a limited understanding of what to prioritise. As ID01 noted: “People know their homes are uncomfortable and that retrofitting might help, but they’re unsure what to do or in what order, so they follow the rebates.” There is also resistance within the construction industry as established builders and suppliers are reluctant to adopt energy-efficient technologies due to high cost, existing profit models, and limited market pressure to change. Lack of skilled labour and necessary infrastructure compounds these issues. Past policy failures, such as the “pink batts” insulation rebate program, have eroded homeowners’ confidence in the retrofit market. Consequently, experts emphasise the



**Figure 3.** A word frequency analysis on the current status of retrofitting. Notes: Each word cloud represents the frequently used keywords to describe the current state of the retrofitting market by each sector, as well as a combined version of all three sectors together. These clouds represent the verbatim views of experts. Source: Developed by authors

importance of targeted incentives alongside education, well-defined regulations, and workforce development to effectively scale retrofitting.

From a *policy perspective*, retrofitting is considered unstructured and underdeveloped, with weak regulatory support. Retrofit uptake is generally low and often driven by incentives. ID11 described, “It’s very embryonic.” Although solar panel incentives have garnered considerable participation, overall energy consumption has not declined due to the “solar take-back” phenomenon, where increased energy generation leads to higher consumption. Emerging trends show that low-cost solar is being redirected to EV charging and battery storage during the daytime. During major renovations, homeowners must upgrade at least the renovated part of a dwelling to comply with the new building code; however, adherence to these rules is inconsistent. Hence, experts call for mandatory minimum standards for energy retrofitting along with stricter enforcement. Updated building codes for new structures also indirectly promote retrofits by shaping industry standards. For instance, after triple glazing was incorporated into the new building code, it became the new standard in Europe, making it cheaper than double glazing.

From an *academic perspective*, retrofitting remains voluntary, uneven, and poorly structured. Households, aware of energy efficiency or environmental concerns, are more likely to retrofit if they have sufficient financial resources. As ID02 stated: “Energy retrofitting in Australia is in a woeful state compared to similar countries . . . even our new-building codes are lagging, which slows retrofit uptake.” Academics challenge the assumption that market demand alone drives retrofitting and argue that tools like NatHERS are inadequate for existing

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homes due to their assumption about building inputs. ID02 further reinforced this by stating that “*a model is only as good as the input parameters.*” Overall, academia advocates for stronger policies, greater awareness, and more rigorous assessment frameworks.

In summary, *all three sectors* view Australia’s retrofit market as limited, reactive, and incentive-driven. Industry experts stress practical constraints and low consumer awareness. Policy experts highlight weak governance and insufficient regulation. Academia highlights knowledge gaps and limitations of current assessment tools. Nevertheless, there is consensus on the need for clear regulations, targeted incentives, robust assessments, and homeowner education, supported by a strategic roadmap to advance retrofitting in Australia.

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### *Evaluating experts’ recommendations on the applicability of stepwise retrofitting*

Stepwise retrofitting involves three interconnected elements: (1) timing, (2) packaging, and (3) sequencing, which collectively create a comprehensive retrofitting roadmap. [Table 4](#) summarises the experts’ perspectives on these elements within the Australian setting, providing a foundational understanding of each element.

*Element 01: Timing.* Industry experts recommend retrofitting cycles of over ten years to align with household budgets and planned refurbishments. ID05 noted: “*Most homeowners are not willing or able to undertake major retrofit work frequently, so timing it with their planned refurbishments makes sense.*” They recommend timing retrofits with maintenance tasks, such as restumping [1] or replacing rotten weatherboards, to minimise disruptions and maximise retrofit feasibility. Restumping, for instance, provides a prime opportunity to add underfloor insulation conveniently.

Rapid technological advancements and climate change complicate fixed retrofit schedules, necessitating dynamic, adaptable roadmaps. Equipment like extraction fans and central heating systems often becomes obsolete within approximately 15 years, prompting opportunities for more efficient appliances. Homes initially meeting higher standards may require modifications within 2 decades due to increased cooling demand resulting from climate change. Additionally, current energy assessment tools, such as NatHERS, which rely on historical weather data, may result in designs that retain excessive heat as future cooling demands rise. Thus, flexibility and reassessments of timing are crucial for effectively integrating emerging technologies and adapting to climate change.

Real estate market dynamics also impact retrofit timing as Australians typically relocate every seven years or require more space as their families grow. Aligning retrofits with real estate cycles, thus, optimises practicality and homeowner acceptance. Overall, industry experts recommend a flexible yet structured approach to retrofit timing, considering homeowner preference, technology adoption, climate adaptation and property turnover rates, to foster effective retrofit implementation.

*Policy experts* emphasise that voluntary retrofitting has led to inconsistent uptake, necessitating standardised ten-year retrofitting cycles, aligned with funding mechanisms and emission reduction targets. Structured cycles tailored to household affordability can boost private funding to transition the housing stock toward net zero, supporting Australia’s climate goals. However, experts caution against overly frequent retrofit steps due to the fixed costs, such as tradespeople’s minimum call-out fees.

Longer retrofit cycles also better align with technological advancements, allowing homeowners to replace older equipment with significantly improved versions. Policy experts suggest deep retrofits are more practical during occupancy transitions. As ID03 stated: “*Australian houses are generally sold every 7–10 years, making it a good time for deep retrofits. On the other hand, rentals may have opportunities every 2–3 years.*” Shallow retrofits, such as installing solar panels and heat pumps or replacing gas appliances, can be implemented while homes remain occupied. Overall, policy experts advocate for standardised retrofit timing, aligned with real estate cycles and financial incentives to encourage scalable retrofitting.

*Academic experts* prioritise shorter retrofit cycles (3–5 years), which enable buildings to respond swiftly to changing climate conditions. Nonetheless, optimal retrofit intervals vary based on household finances, property types, and homeowner tolerance. They emphasise that timely retrofits not only achieve energy savings but also enhance Indoor Environmental Quality (IEQ), improve health outcomes, and increase climate resilience, especially for low-income households. Therefore, academics recommend incorporating clear timing and quantifiable benefits into structured retrofitting roadmaps to boost participation in retrofitting.

Experts recommend stepwise retrofits over single-step deep retrofits for Australia's real estate sector. ID09 described: "*Australian homeowners move every seven years, so spacing retrofit steps every two to four years, ideally three, makes sense as deep retrofits aren't always guaranteed within that short timeframe*". These three-year retrofit steps align with the Australian Building Codes Board (ABCB)'s review cycles, ensuring retrofitting remains in sync with regulatory updates. Major renovations, accounting for over 30% of the floor area, must comply with current codes, creating more opportunities for retrofitting. Overall, academia supports flexible yet shorter retrofit cycles, taking into account technological progress, climate responsiveness, and market dynamics.

Collectively, *all three sectors* showed varying yet complementary perspectives on retrofit timing. Industry and policy experts advocate for longer cycles (approximately ten years), aligning with homeowner budgets, regulatory frameworks, and Australian real estate cycles, which typically span from 10 to 20 years (Fawcett, 2014; KPMG, 2022). Academia suggests shorter adaptive cycles (3–5 years) driven by rapid technological advancements and climate variability, although acknowledging these cycles may surpass current regulatory and market readiness. Nonetheless, shorter cycles might suit rental properties with typical two to three-year leases (KPMG, 2022), encouraging landlords to regularly improve energy efficiency. Ultimately, legally mandated 10-year retrofitting cycles with retrofit steps every three years, aligned with the real estate market, incentives, and regulations, create homeowner-friendly retrofit frameworks. Comprehensive building simulations, however, remain essential to refine these adaptive policies in response to Australia's evolving climate and housing conditions.

*Element 02: Packaging.* Industry experts emphasise that retrofit packages should be tailored to the specific conditions of individual homes, taking into account homeowner affordability and the acceptable level of disruption. Limited historical records of previous upgrades due to the absence of structured Building Renovation Passports (BRPs) [2] in Australia complicate creating these packages. Practitioners, therefore, rely primarily on NatHERS ratings. As ID01 explained: "*We always do a NatHERS energy rating on existing homes during renovations to identify the best measures that add value without making unnecessary changes*". However, NatHERS evaluates architectural features rather than existing conditions, limiting its practical applicability (Vender, 2024).

Cost constraints strongly influence package design, prompting industry professionals to favour low-cost, high-impact, and easy-to-apply measures, such as roof insulation, air sealing, or appliance upgrades. More invasive interventions, such as wall and floor insulation, often coincide with essential maintenance tasks like weatherboard replacement or window repairs to minimise disruption. Additionally, Industry professionals highlight the necessity of considering functional interdependencies between retrofit measures. For instance, wall insulation, air sealing, and window upgrades collectively enhance thermal performance, while insulation or window upgrades alone do not provide significant benefits. However, retrofit packages designed around current conditions may become less effective due to changing climate demands. Thus, flexibility is crucial to maintain long-term energy efficiency and occupant comfort. Overall, industry experts recommend pragmatic and adaptable retrofit packages, which balance existing home conditions, affordability, planned refurbishments, technological interdependencies, and climate responsiveness.

*Policy experts* recommend standard retrofit packages tailored specifically for owner-occupied and rental dwellings to avoid piecemeal upgrades. They highlight that BRPs, although currently absent in Australia, are essential for recording retrofit histories and guiding

cost-effective future upgrades. Hence, experts strongly recommend legislatively mandated BRPs to guide retrofit packaging. They emphasise balancing operational savings and embodied carbon since retrofitting decreases operational energy but increases embodied carbon. They further recommend aligning retrofit packages with global climate targets, such as the Paris Agreement [3], in order to achieve net-zero emissions by 2050. Technological dependencies significantly influence package design. ID11 added: “. . . *If you do insulation and draft-proofing together, you can reduce the size of the HVAC equipment . . .* “. Overall, policy experts advocate for structured, standardised, and tenure-specific retrofit packages regulated through clear incentives, system compatibility, and climate goals.

*Academic experts* recommend a hybrid approach, combining tailored, data-driven assessments with standardised retrofit packages. This strategy accommodates individual building characteristics and broader market dynamics. Academics explained market dynamics: for example, if triple glazing becomes the standard in new homes, increased demand will lower its cost, making it more affordable for retrofits (ID02). Tailored audits ensure retrofit measures complement each other effectively, preventing common pitfalls such as lock-in effects. For instance, installing double glazing without adequate window sealing significantly reduces the measure’s effectiveness.

Academics also propose clearly communicating the health and comfort benefits of retrofit packages alongside energy savings to enhance homeowner engagement. ID09 noted: “*The retrofitting roadmap shouldn’t just detail what needs to be done at each step, but it also needs to show the value of doing it, such as fewer heatstroke cases, less pressure on emergency services, and better comfort for residents.*” Improved health outcomes and reduced morbidity due to extreme temperatures strongly encourage homeowners to retrofit. Overall, academia recommends a hybrid approach integrating bespoke, data-driven assessments with standardised retrofit packages, considering technological dependencies and long-term compatibility.

Across *all sectors*, there is a consensus on the significance of retrofit packages for improving residential energy efficiency in Australia, though each group emphasises different strategies. Industry professionals favour site-specific retrofit packages tailored to existing home conditions, affordability, acceptable disruption levels, and planned maintenance routines. Policy experts, conversely, advocate for standardised, tenure-specific packages, supported by mandated BRPs, regulations, clear incentives, and climate goals. Academia suggests a hybrid approach, integrating structured standardisation with tailored audits, emphasising the clear communication of broader health and comfort benefits. All sectors recognise that technological interdependencies are crucial when designing retrofitting packages. In summary, standardisation benefits common measures such as insulation and glazing, while detailed audits remain necessary for complex systems, including HVAC, heat pumps, and SHW systems, to ensure compatibility, efficiency, and long-term resilience.

*Element 03: Sequencing.* *Industry experts* acknowledge that Australia’s lack of a standardised retrofitting roadmap leads to inconsistent sequencing and limits the effectiveness of retrofitting. While broadly supporting a fabric-first approach which prioritises envelope improvements, experts advocate for flexibility to accommodate homeowner preferences and budgets. In certain scenarios, HVAC upgrades precede envelope upgrades due to immediate benefits, although this often results in oversized, inefficient systems.

Thus, experts propose a structured, flexible three-step sequence. The first step targets simple, low-cost and high-impact measures (“*low-hanging fruits*” (ID05)), such as sealing gaps, blocking unused fireplaces, and roof insulation, delivering quick, tangible benefits without substantial investment. ID04 summarised this as the “*Keep It Simple, Keep It Stupid (KISS)*” principle, suggesting straightforward upgrades like hydronic ceiling systems, which yield 30–40% immediate energy savings. The second step targets more complex and costly improvements, such as wall insulation and double glazing, focused on rooms that experience significant energy losses. These targeted interventions, which can be identified through NatHERS assessments and Scorecard analyses, significantly improve building performance

despite short-term disruptions. The third step integrates advanced technologies, including high-efficiency HVAC, heat pumps, solar systems, automated controls, and real-time energy monitoring. Emerging innovations, such as carbon-capturing paint, can further enhance indoor air quality and reduce emissions. Overall, Industry experts recommend a structured yet adaptable sequence, starting with low-cost measures, progressing to targeted envelope upgrades, and concluding with advanced technology integration for sustained efficiency.

*Policy experts* also recommend a structured retrofit sequence that adheres to the fabric-first approach to prevent lock-in effects. Currently, Australian assessment tools, such as the National Scorecard, provide retrofit measures without a clear sequencing guide, leaving the sequence to homeowners' discretion, which results in fragmented outcomes. Therefore, experts suggest policy-driven guidelines for sequencing.

Policy experts propose a structured four-step sequence ("*Big 4*" (ID11)) specifically for heating-dominated climates. Step one involves basic insulation to improve thermal efficiency. The second step focuses on thorough draft-proofing, significantly reducing energy losses. These two steps adhere to the fabric-first approach. The third step introduces efficient reverse-cycle HVAC systems, while the final step includes installing heat pump hot water systems to optimise overall energy efficiency and sustainability. Overall, policy experts advocate for a structured sequence: (1) envelope insulation, (2) draft-proofing, (3) HVAC upgrades, and (4) heat pump installations, aiming to minimise lock-in effects and enhance long-term efficiency.

*Academic experts* support a clearly defined retrofit sequence, which takes into account effectiveness, technical compatibility, and ease of implementation. They recommend a structured three-step sequence. The initial step prioritises cost-effective insulation and draft-proofing measures, immediately improving thermal performance and comfort, while preparing the building for subsequent upgrades. The second step involves comprehensive window improvements, which include sealing leaks, adjusting window openings, and upgrading glazing. ID09 added: "... windows can offer a mix of benefits, like better thermal comfort, improved ventilation, and good natural daylight." These initial two steps integrate complementary measures to maximise retrofit effectiveness. The final step involves upgrading centralised HVAC systems, leveraging reduced thermal demands from previous envelope improvements.

Academic experts caution against premature HVAC installations, highlighting the risks of oversizing and inefficiency of the post-envelope upgrades. Additionally, academia emphasises communicating the broader benefits of each step, including reduced heatstroke cases, lower emergency service burdens, and reduced morbidity during extreme temperatures, to motivate homeowner participation. Overall, academia strongly supports structured sequencing: starting with low-cost insulation, proceeding with window improvements and finalising with efficient HVAC upgrades, carefully avoiding lock-in effects and clearly outlining holistic benefits.

*All sectors collectively* support structured sequencing, but vary in terms of flexibility, rationale, and recommended steps. Industry and academia propose three-step sequences, whereas policy suggests a four-step approach. All agree on beginning with low-cost, high-impact improvements, although the policy prioritises insulation (step 1) before draft-proofing (step 2) as insulation minimises air leakage across most of the envelope, reducing the need for extensive draft-proofing. However, industry and academia prioritise draft-proofing in step 1 due to its affordability, ease of implementation, and immediate thermal comfort. Step two emphasises substantial building envelope upgrades, where Industry advocates for insulation and double glazing. Advanced system integration characterises the final step across all sectors: Industry and academia focus on high-efficiency HVAC systems, heat pumps, and renewable systems combined with smart technology, whereas policy favours sequencing efficient HVAC systems before heat pumps, aligning with climate targets. Overall, integrating policy-driven structure, industry flexibility, and academic precision yields a three-step sequence: (1) initial basic envelope improvements (insulation, draft-proofing), (2) targeted envelope upgrades (wall insulation, double glazing), and (3) advanced technologies (efficient HVAC systems, renewables), enhancing long-term climate resilience.

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*Examining the compatibility of expert recommendations with the current policy directions*

The policy analysis reveals that, although no current Australian policies explicitly mandate stepwise retrofitting, 31 federal and state programs implicitly support its implementation, albeit with varying degrees of support across different regions. [Table 4](#) summarises expert recommendations on key elements of stepwise retrofitting, while [Table 5](#) evaluates their compatibility with existing Australian policy directions.

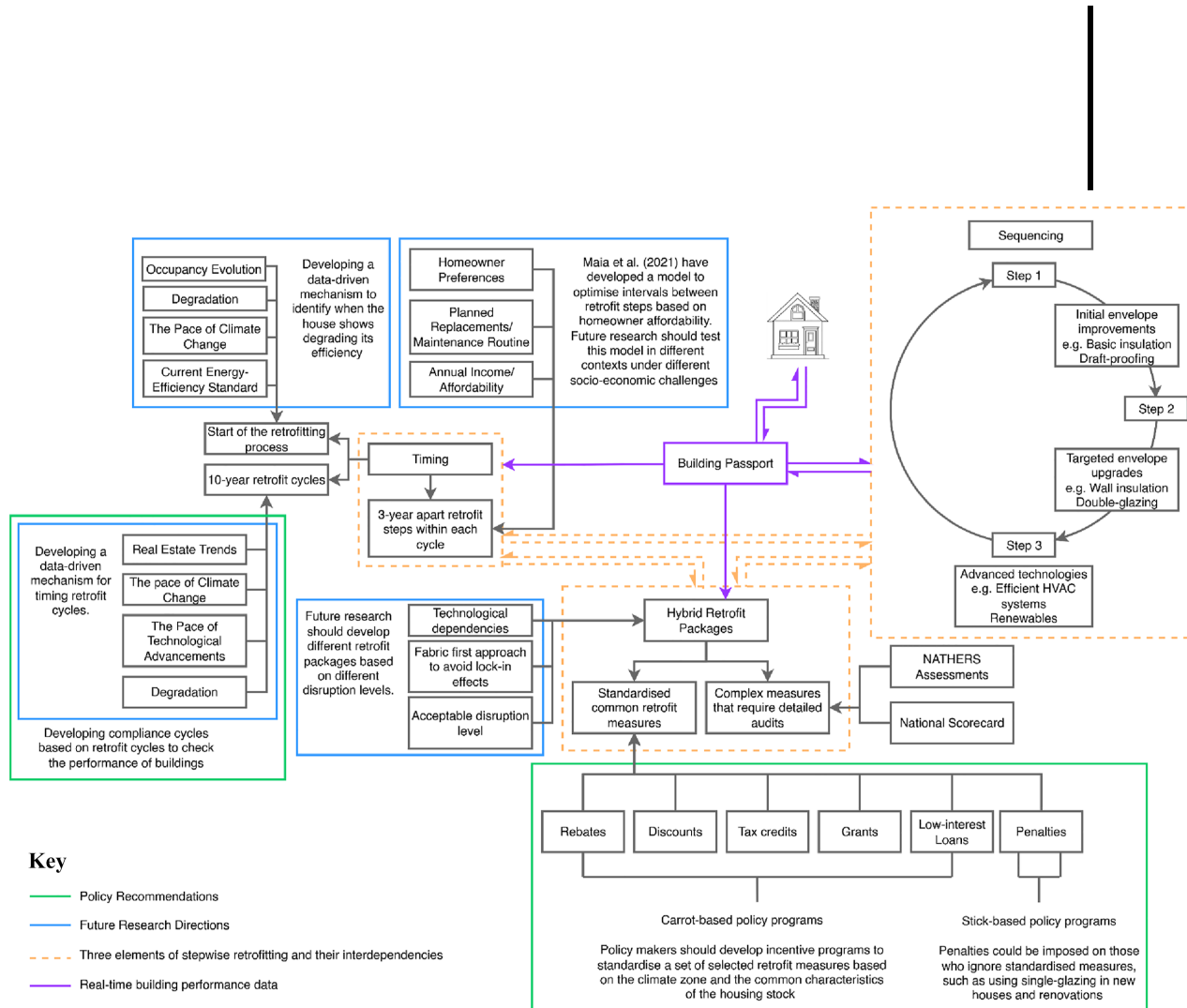
*Element 01: Timing.* Current policies reviewed offer very limited positive support for timing. For instance, EED might implicitly support retrofitting before property turnover, aligning somewhat with the expert recommendation to consider real estate cycles. However, no reviewed policy defines the timing for retrofit intervals or cycles. Decisions on timing remain largely at homeowners' discretion, influenced indirectly by available incentives or rebate cycles, creating a significant gap between policy guidance and expert recommendations.

*Element 02: Packaging.* Most existing policy programs provide moderate support for packaging through monetary incentives, mandatory standards, and advisory services. Incentives, such as rebates, discounts, tax credits, grants, or low-interest loans, enhance affordability and improve the uptake of specific retrofit measures, contributing to standardised retrofit packages. The Gas Substitution Roadmap further supports this by outlining retrofit packages for replacing gas appliances and disconnecting gas lines. Minimum energy efficiency standards establish baseline packages for rental homes. Therefore, incentives and mandatory standards support the standardisation of retrofit measures, a part of the hybrid packaging. Advisory programs, such as the Sustainable Home Advice Program (SHAP) and the Residential Efficiency Scorecard, though limited to a few states (e.g. ACT and Victoria), provide tailored guidance and audits, supporting the detailed assessment component of the expert-recommended hybrid approach.

*Element 03: Sequencing.* Existing policies provide limited support for sequencing primarily through advisory programs that guide homeowners in prioritising retrofit measures. Minimum energy efficiency standards implicitly support initial sequencing steps by prioritising foundational envelope improvements and appliance upgrades. Advisory services, such as SHAP, also offer limited sequencing guidance but are restricted geographically (ACT). Without structured sequencing guidelines, homeowners risk selecting retrofit measures independently, which can potentially lead to suboptimal sequences and lock-in effects.

Although existing policies implicitly encourage stepwise retrofitting, explicit strategic coordination is essential to fully realise its potential. Consequently, an application framework (see [Figure 4](#)) was developed based on insights gained from Phases 1 and 2 to enhance stepwise retrofitting implementation. This framework integrates the three core elements of stepwise retrofitting, illustrating their interconnections and relationship with real-time building performance. Timing sets when interventions occur. Packaging bundles retrofit measures. Sequencing assigns these packages to discrete steps. The Building Renovation Passport (BRP) presents Building Performance Data (BPD) as measured through sensors under real-time interactions between occupants and the building. BPD assists in Post-Occupancy Evaluation (POE) after each retrofit step. The following connections can be seen within the framework.

- (1) *Timing* → *Packaging*: Timing constraints shape the most suitable bundle of standard measures based on the subsidies that are accessible in the market.
- (2) *Timing* → *Sequencing*: Timing specifies when each step should be implemented.
- (3) *Packaging* → *Sequencing*: Packaging indicates appropriate bundles for retrofit steps and their priority levels.
- (4) *Packaging* → *Timing (feedback)*: Accessible subsidies/financial incentives reduce net costs and can shorten intervals to the next step.



**Figure 4.** An application framework for stepwise retrofitting. Note: A clear version of the framework is attached in [Appendix 3](#). The interconnections are elaborated on in the text. Source: Developed by authors

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- (5) *Sequencing* → *Timing and Packaging (feedback)*: Delays or skipped steps trigger updates to timing and repackaging.
  - (6) *BRP* → *Timing and Packaging (feedback)*: Post-step performance data inform refinements to subsequent timing and packaging.
  - (7) *BRP* → *Sequencing (feedback)*: Real-time building performance data informs delays or non-implementation against the plan and updates step status for rescheduling or reprioritisation.
  - (8) *Sequencing* → *BRP*: Sequencing notifies building occupants when to implement each step and which measures should be implemented, through BRP, and informs any updates to the building model, such as new u-values, air-tightness, HVAC sizing, after each retrofit step.
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This framework serves as a practical tool to guide decision-makers, practitioners, and homeowners through a structured retrofit process. Furthermore, the framework provides a foundation for future validation through case studies and energy simulations, informs policy development aimed at promoting stepwise retrofitting and guides smart home developers.

## Discussions

*Element 01: Timing.* This study recommends legislated ten-year cycles with retrofit steps, spaced every three years. However, timing cycles should take into account property turnover rates, climate adaptation, technological advancements, and degradation, while considering affordability, replacements, and homeowner preferences to define intervals between steps (Fawcett, 2014; KPMG, 2022). In practice, sale/lease events accelerate retrofit steps to leverage the marketing opportunity. Finance can also speed up the subsequent retrofit steps; for instance, accessible subsidies can lower net costs and shorten the intervals. While current Australian policies provide limited guidance on retrofit timing, the proposed Home Energy Ratings Disclosure Framework (HERDF) may encourage upgrades before sales and rentals, typically occurring every 12–20 years in Australia (KPMG, 2022). These medium-term cycles align with international recommendations, such as PAS 2035s 15-year cycle for retrofitting UK housing stock (Bennadji et al., 2022) and Thorpe's (2010) 10–15-year timeline. Similarly, Maia et al. (2021) developed a 15-year cycle with three interim retrofit steps for the European residential sector. Conversely, academia recommends shorter intervals (3–5 years), aligning with international examples such as Washington, DC's five-year mandated compliance cycles for rapid efficiency and sustained climate resilience (Bergfeld et al., 2021). This study further recommends a BRP, which offers a valuable tool for streamlining timing decisions for retrofitting. The BRP logs planned steps and streams Building Performance Data (BPD). POE guided by BPD after each retrofit step justifies advancing or deferring the next retrofit step. Nonetheless, accelerated cycles enhance learning and resilience but necessitate increased coordination capacity, whereas extended cycles correspond with property events yet potentially impede decarbonisation progress unless punctuated by interim assessments. Since occupants encounter multiple shorter disruptions during stepwise retrofitting, the process requires meticulous change management and communication strategies at each stage.

*Element 02: Packaging.* This study, for the first time in research, advocates for a hybrid approach, including (1) standardisation of common measures like glazing and insulation, and (2) detailed audits for complex systems like HVAC, heat pumps, and SHW to ensure compatibility and avoid lock-in effects. Most of the current Australian policies, such as monetary incentives, implicitly promote bundling common retrofit measures, resulting in the standardisation of these measures. This hybrid approach further aligns with Maia et al. (2023), who highlighted that complex retrofit measures require detailed analysis for maximum efficiency and compatibility. They further emphasised the importance of bundling closely related measures such as facade insulation, window replacement, and roof design into a single

package to prevent thermal bridging and ensure airtightness. Although standardisation delivers scale and equity, over-standardisation can overlook occupant realities. Hence, this study proposes validation gates, such as audits and POE through BPD and BRPs, between steps, and dynamic re-packaging if materials, prices, or measured performance shift. Furthermore, defining retrofit packages as stock-keeping units [4], along with a fixed scope of work, bill of quantities, defined crew roles, eligible rebates, and quality/warranty terms, enables one-stop shops [5] and contractors to coordinate crew scheduling, procurement, and accountability across successive steps (Kolesnikova, 2016).

*Element 03: Sequencing.* The study developed a three-step retrofit sequence integrating policy structure, industry flexibility, and academic insights: (1) low-cost initial envelope improvements; (2) targeted upgrades such as wall insulation and double glazing; and (3) advanced technologies for long-term resilience. Limited policy support exists in Australia for sequencing retrofit packages, which is restricted to a one-stop-shop advisory support in the ACT and several mandatory energy-efficiency measures that serve as the initial step of a stepwise approach. The proposed structured sequence prevents lock-in effects by prioritising envelope enhancements before HVAC upgrades, aligning with established practices recommended by Maia *et al.* (2023) and PAS2035's fabric-first strategy (Bennadji *et al.*, 2022). Two practical provocations sharpen decision-making in this case: first, early HVAC replacements must anticipate future envelope gains to avoid oversizing; second, accounting for grid decarbonisation trajectories can alter the order of steps in high-cooling-demand regions. Finally, behavioural signals, such as over-reliance on HVAC, can justify bringing forward shading/ventilation steps before equipment upgrades to maintain comfort. Although the proposed sequence is staged, Armstrong *et al.* (2024) outlined a similar three-tiered framework (quick fix, modest, and climate-ready) based on retrofitting intensity. "Quick fix" mostly aligns with Step 1, "modest" merges Steps 1 and 2, and "climate-ready" includes all three. Each level in Armstrong *et al.*'s (2024) framework involves installing a standalone space conditioning heat pump and is designed as a single-step retrofit rather than as part of a stepwise process.

## Conclusions and implications

The concluding remarks, including their theoretical and practical applications and implications for the applicability of stepwise retrofitting, are discussed below.

*Theory.* The study offers a structured foundation for retrofit timing, packaging, and sequencing, based on the perspectives of 11 experts, as well as an analysis of 31 Australian policy programs (see Tables 4 and 5). This study is the first to propose a sequence for stepwise retrofitting, prioritising "low-hanging fruit", to motivate households by offering increased comfort and lower energy bills from initial low-cost options, unlike existing studies for Europe and the USA that discuss different retrofit packages but not their sequence. This study presents a first-of-its-kind application framework for stepwise retrofitting, providing a skeleton for smart home researchers to build upon (see Figure 4). This framework can be scaled from single homes to housing stocks.

*Practice.* The findings provide actionable insights for industry practitioners and homeowners. Industry practitioners can adopt the proposed hybrid approach to design cost-effective retrofit packages, while also exploiting available subsidies. Practitioners can further leverage the proposed sequencing approach to attract prospective clients with constrained budgets by elucidating various retrofit pathways that necessitate minimal initial investment. One-stop shops can treat packages as stock-keeping units to coordinate crews and procurement across steps. Homeowners and industry practitioners can gain a basic understanding of stepwise retrofitting through Table 4 and Figure 4, enabling them to make informed decisions. This understanding will help reduce energy poverty among low-income households. For social housing and rentals, the framework can be applied at a property group level, aligning with scheduled maintenance and tenancy changes, while also utilising bulk

procurement. Additionally, the application framework provides strategies for smart home builders to develop digital twins that simulate and notify occupants about retrofit steps.

*Policy.* Policymakers can refer to [Table 5](#) and [Figure 4](#) in setting regulations on retrofit timing and packaging and proposing potential policy programmes for financial incentives and advisory services. Policymakers are encouraged to assess real estate cycles and market dynamics before defining compliance timelines. The hybrid packaging approach guides policymakers to determine which retrofit measures should be standardised through regulatory mechanisms. The study further emphasises to policymakers the significance of establishing BRPs due to their pivotal role in the stepwise retrofitting approach, while framing the stepwise approach as a flexible and attractive means to mobilise private investments for retrofitting.

*Research.* While the research focuses specifically on owner-occupied residential buildings within Australia, its methodology can be adapted for international use and extended to various building types. Given that the study is constrained by its dependence on expert perspectives and policy analysis, future research should incorporate on-site details of stepwise retrofitting projects through case studies once the concept is industrialised. Future studies should focus on developing digital twins to expand the application framework (see [Figure 4](#)) for smart homes. Critical success factors should be developed for assessing the quality of stepwise retrofitting projects. Considering Australia's diverse climate, case studies using building simulations should evaluate variations in core elements of stepwise retrofitting across different climate conditions and building typologies. Future research should investigate packaging retrofit measures under varying levels of disruption. A data-driven mechanism should be developed to identify when a new house shows a decline in its efficiency for initiating the retrofitting process. Future phases of this study will develop this data-driven mechanism and will evaluate performance outcomes under different climate conditions using simulation-based case studies.

### **Acknowledgments**

Expert interviews were conducted in accordance with the ethics approval granted by the University's Human Ethics Advisory Group and their ethical guidelines (Ref No.: SEBE-2023-79). During the preparation of this work, the author(s) used Grammarly in order to proofread and make grammar corrections. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

(The Appendix follows overleaf)

**Table A1.** The selected policy programs related to retrofitting residential buildings in Australia

Federal/State government	Policy programs
Federal	Home Energy Ratings Disclosure Framework
Victoria (VIC)	Solar Homes Program Victorian Energy Upgrades program Residential Efficiency Scorecard Gas Substitution Roadmap Minimum energy efficiency standards in rentals Energy Efficiency in Social Housing Program White Certificates for Retailer Energy Productivity White Certificates for Peak Demand Reduction
South Australia (SA)	APY Lands Energy Efficiency Retrofit Pilot Retailer Energy Productivity Scheme Social Housing Energy Efficiency Program Residential Efficiency Scorecard
Northern Territory (NT)	NT Homelands and Housing NT Social Housing Energy Performance Initiative Residential Efficiency Scorecard
Australian Capital Territory (ACT)	Sustainable Household Scheme Home Energy Support Program Energy Efficiency Improvement Scheme Sustainable Home Advice Program The Integrated Energy Plan 2024–2030 Minimum energy efficiency standards for rental homes Energy Efficiency in Social Housing Program Residential Efficiency Scorecard
New South Wales (NSW)	Energy Savings Scheme Peak Demand Reduction Scheme NSW Social Housing Energy Performance Initiative Residential Efficiency Scorecard
Western Australia (WA)	Esperance Energy Transition Package (closed) Energy Ahead WA Social Housing Energy Performance Initiative Residential Efficiency Scorecard
Queensland (QLD)	Social Housing Energy Performance Initiative Home Energy Saving Rebates Residential Efficiency Scorecard
Tasmania (TAS)	Tasmania's Energy Saver Loan Scheme Homes Tasmania Energy Efficiency Program Residential Efficiency Scorecard
<b>Source(s):</b> Developed by authors	

**Table A2.** Implicit policy influence on stepwise retrofitting implementation in Australia

Policy program	Implicit impact on stepwise retrofitting	Element	References
Home energy ratings disclosure framework (Federal)	This program requires disclosing energy ratings for rentals and sales, thereby increasing demand for energy-efficient homes. This encourages single-step retrofitting before selling energy-inefficient homes and stepwise retrofitting for rental dwellings, but lacks guidance for any element of stepwise retrofitting	–	<a href="#">Australian Government (2024)</a>
Minimum energy efficiency standards in rentals (VIC, ACT)	This legislation mandates basic energy efficiency for rental homes (e.g. a mandatory minimum 2-star heater for the living area in Victoria) and thus identifies a retrofit package for the first mandatory retrofit step. This provides a common baseline from which landlords can pursue further upgrades over time	Packaging and sequencing	<a href="#">EECA (2025)</a>
Gas substitution roadmap from 2024 to 2030 (VIC, ACT, WA)	This program accelerates the replacement of gas appliances with electric alternatives and the removal of gas connections. These measures form the initial steps of a retrofitting cycle for those who use gas	Packaging and sequencing	<a href="#">DEECA (2022)</a>
Grants for energy efficiency in social housing (All states)	This program funds extensive upgrades, thereby encouraging single-step deep retrofitting for the old social housing between 2024 and 2029. However, these upgrades form the initial steps in a retrofit cycle, while subsequent steps involve advanced technologies	Packaging and sequencing	<a href="#">DCCEEW (2025)</a>
Grant for urgent repairs (NT)	This program funds urgent repairs and maintenance, implicitly forming initial retrofit packages	Packaging and sequencing	<a href="#">AHURI (2024)</a>
Loans (TAS, ACT)	These programs offer no-interest or low-interest loans for specific retrofit measures (e.g. solar panels), creating a retrofit package	Packaging	<a href="#">Brighte (2025)</a>
Rebates for low-income households (ACT, WA)	These programs offer rebates to low-income households for installing energy upgrades, creating a retrofit package	Packaging	<a href="#">Government of Western Australia (2025)</a>
Rebates (VIC, QLD)	These programs offer rebates for specific retrofit measures, including solar panels, batteries, and energy-efficient appliances, which make up a retrofit package	Packaging	<a href="#">Queensland Government (2024)</a>

*(continued)*

Table A2. Continued

Policy program	Implicit impact on stepwise retrofitting	Element	References
Retailer energy productivity scheme, or White certificates (SA, ACT, NSW, VIC)	This program sets energy productivity targets for obligated retailers, who offer incentives to promote selected energy retrofit measures, creating a retrofit package	Packaging	<a href="#">ecovantage (2025)</a>
Peak demand reduction scheme, or White certificates (NSW, VIC)	This program sets peak demand reduction targets for obligated retailers, who offer incentives to promote selected retrofit measures, creating a retrofit package	Packaging	<a href="#">ecovantage (2025)</a>
Energy efficiency in indigenous communities (SA)	This program focuses on a single-step approach; however, the data and experience gathered can inform retrofit packages	Packaging	University of SA (2023)
Residential Efficiency Scorecard (All states)	This program provides tailored ratings and retrofit guidance, aiding package selection and evaluating energy performance after each retrofit step	Packaging	<a href="#">State Government of Victoria (2024)</a>
Sustainable Home Advice Program (ACT)	This one-stop shop program guides ACT residents on how to reduce energy use and upgrade homes, supporting package selection and sequencing	Packaging and sequencing	<a href="#">ACT Government (2021)</a>

**Note(s):** Abbreviations indicate the eight states and territories in Australia  
**Source(s):** Developed by authors

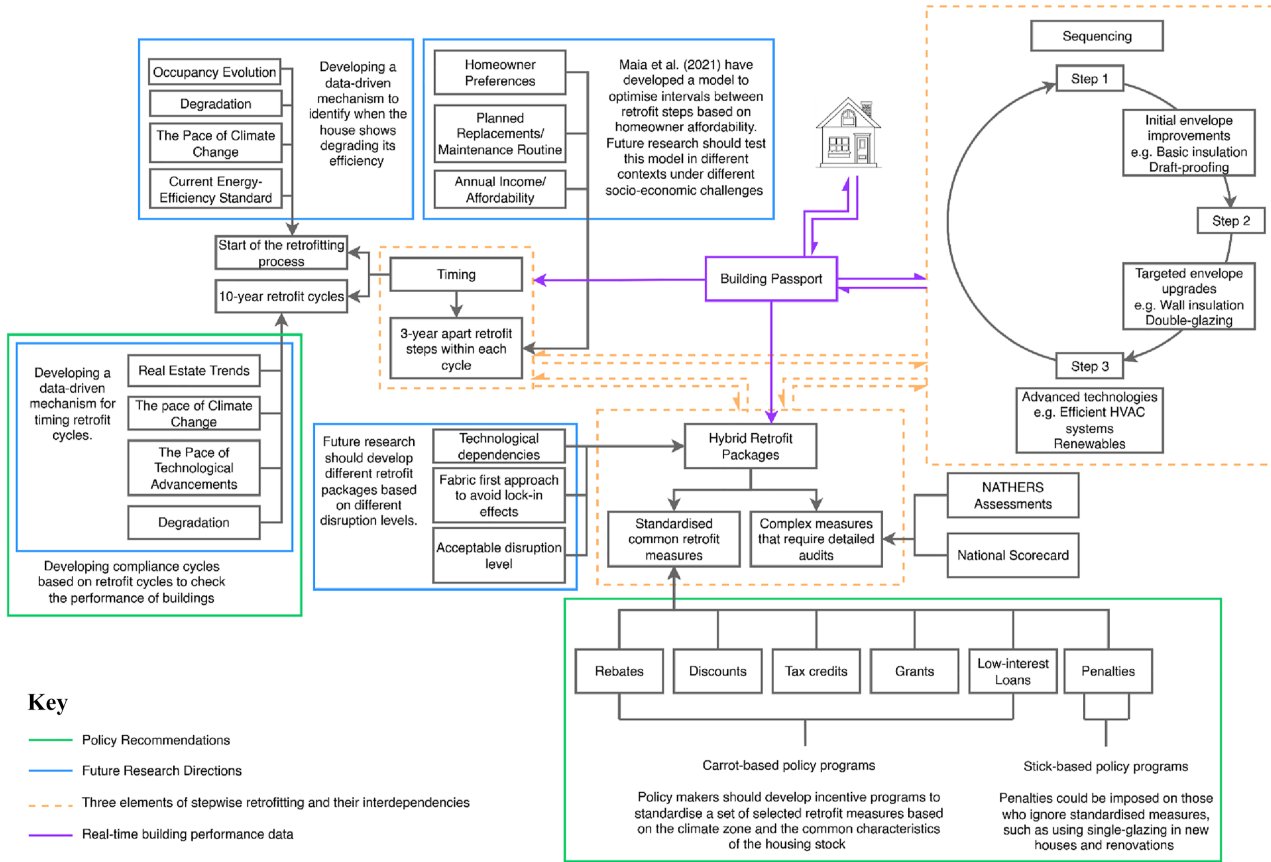


Figure A1. A clear version of Figure 4

**Notes**

1. Restumping involves replacing or resetting a building's foundation stumps.
2. A BRP is a data platform hosting all building data from design to demolition.
3. Paris Agreement aims to limit global warming to 1.5 °C above pre-industrial levels.
4. A stock-keeping unit is a distinct part number whose production, storage and flows are planned and controlled independently across the network.
5. A one-stop shop is an integrated service that simplifies renovation by coordinating support, assessments, contractors, financing, and admin through a single provider.

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