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**DEVELOPMENT OF A HOMEOWNER DECISION-
MAKING FRAMEWORK FOR AGEING RESIDENTIAL
BUILDING RENOVATION**

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**Development of a Homeowner Decision-making Framework
for Ageing Residential Building Renovation**

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A thesis submitted in partial fulfilment of the requirement for the degree
of Doctor of Philosophy

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Certificate of originality

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Abstract

Ageing residential buildings face multiple challenges, including deterioration, degraded infrastructure and low energy efficiency. These issues not only undermine the safety and functionality of the buildings but also adversely affect residents' quality of life. Homeowners are key stakeholders in residential renovation projects and their perspectives play a crucial role in ensuring rational and effective renovation choices, which ultimately determine the success of residential renovation initiatives.

Understanding homeowners' perspectives is critical for successful decision-making in residential building renovation. However, previous studies have predominately focused on environmental impacts or cost-effectiveness of the residential renovation. Limited research has examined decision-making metrics that adequately incorporate homeowners' preferences. To address this gap, the present study aims to develop an index model for assessing homeowners' preferences in ageing residential building renovation and investigate the variations of homeowners' importance perceptions across different demographic and socioeconomic groups.

This study employs a multi-stage methodological framework to achieve seven research objectives. To fulfil the first objective, a scientometric analysis and qualitative literature review were conducted to examine existing research on performance assessment in residential building renovation. This revealed a critical research gap: prior studies had

largely overlooked homeowner priorities in residential renovation. In achieving the second objective, a combination of systematic literature review and expert interviews identified 33 potential performance indicators relevant to homeowners in housing renovation contexts. The fulfillment of the third objective involved a questionnaire survey to gather data on homeowners' demographic and socioeconomic characteristics, as well as their perceptions regarding the importance of the performance indicators. This survey identified 24 key performance indicators. Among these indicators, "building lifespan", "seismic resistance capability" and "gas pipeline quality" emerged as the most critical. In fulfilling the fourth objective, factor analysis was employed to categorize the 24 indicators into six clusters: (1) safety and health, (2) indoor comfort, (3) facility and infrastructure, (4) environmental protection and living environment, (5) structure and planning, and (6) social and sustainability. Using fuzzy synthetic evaluation, the fifth objective developed an index model, with the weightings of indicators and clusters, membership functions, and criticality indices determined.

In delivering the sixth objective, the variations in the importance rating of the 33 performance indicators among different demographic and socioeconomic groups were analyzed using mean ranking analysis, intraclass correlation coefficients, and Kruskal-Wallis tests with post-hoc Dunn's test. The findings reveal that, overall, the mean importance ratings of the performance indicators are consistent across different demographic and socioeconomic subgroups, and "building lifespan" was rated by most subgroups as the most important indicator. Nevertheless, significant variations in the

perceived importance of several indicators existed among different subgroups: men prioritize prestige and status more than women; the elderly place greater importance on both indoor natural daylighting and public lighting; homeowners with secondary education levels show stronger preferences for acoustic comfort than less-educated counterparts; lower-income residents value green and social spaces more; small families are more concerned with residential density; and homeowners with shorter residence care more about fire safety. The underlying reasons for these variations were further examined through in-depth interviews. In achieving the final objective, the study analyzed the renovation policy transitions and synthesized these findings into practical policy implications and strategies for residential renovation.

This study makes multifaceted contributions, offering significant insights into the field of residential building renovation by developing an index model that enhances the planning, design, and implementation of ageing dwelling renovations. Additionally, it provides empirical evidence to support tailored policies and regulations that account for the diverse motivations and priorities of homeowners across different demographic and socioeconomic backgrounds. Such targeted approaches not only improve the effectiveness of renovation projects but also promote more sustainable urban renewal practices.

Publications arising from the thesis

Journal publications:

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Chapter 1: Introduction

1.1 Background

1.1.1 The increasing ageing residential building stock

The post-World War II construction boom, driven by rapid urban expansion and population growth, has resulted in a continuously expanding inventory of ageing buildings globally (Jensen and Maslesa, 2015). This phenomenon is particularly evident in numerous cities which have experienced prolonged urbanization histories (Ritchie and Roser, 2018), where intensive buildings have been constructed throughout their growth phases (Li and Yao, 2009). Following multiple decades of urban development, the aggregate built environment has reached unprecedented amount, with recent estimation indicating that the global collective floor area of buildings has surpassed 252.7 billion square meters (IEA, 2023).

As these buildings have undergone prolonged periods of continuous utilization and operational stresses, the building stock in numerous urban contexts has progressively turned ageing (Jensen and Maslesa, 2015). The ageing of buildings refers to the physical deterioration that occurs following their original construction. This process presents both technical and managerial challenges—such as material degradation, system

obsolescence, and declining performance—often resulting in non-compliance with contemporary structural, safety, or energy codes.

The concurrent processes of accelerated urbanization patterns and sustained demographic increases in metropolitan regions worldwide have necessitated the large-scale development of residential buildings to accommodate urban populations. Within this context, ageing housings, which constitute a significant portion of urban buildings and serve as the primary living spaces for millions of residents, represent a crucial category for renovation efforts (Su and Zhang, 2016).

The global inventory of ageing building stock has been experiencing consistent and rapid growth across various geographical contexts and economic regions, with residential housing constituting a substantial and increasingly prominent component of this worldwide phenomenon. Empirical data from multiple literature demonstrate this accelerating trend. The United States housing market provides a particularly illustrative case, where longitudinal analysis reveals that the proportion of residential units exceeding 53 years of service life increased significantly from 29% of total housing stock in 2012 to 35% by 2022 (Zhao, 2024). The situation appears even more pronounced in high-density urban environments, as evidenced by Xu (2024) that approximately 19% of residential housings had surpassed the critical 50-year threshold—a benchmark widely recognized as the general life expectancy of reinforced concrete structures.

1.1.2 Multidimensional challenges confronting ageing residential building stocks

The progressive ageing of global housing stocks presents multifaceted challenges that manifest across physical, functional, and environmental dimensions. Extensive research indicated that ageing residential structures commonly experience simultaneous deterioration processes, including deterioration, degraded infrastructure and low energy efficiency (Balaras et al., 2005; Hu et al., 2024; Li et al., 2021). Unlike public or industrial buildings that primarily serve functional purposes, residential buildings are intimately related to people's daily lives and activities. The status of dwellings is not merely associated with the cities' appearance and development but also closely impacts residents' living standards and well-being.

The maintenance expenditures for ageing residential buildings create various challenges for both cities and residents (Baldwin, 2006). The maintenance costs for ageing buildings are much higher than new buildings (Bullen and Love, 2011). Energy performance represents another critical concern, as thermal insulation materials in older buildings frequently degrade over time, leading to substantial energy inefficiencies that require comprehensive retrofitting solutions (Castleton et al., 2010). Furthermore, ageing buildings can bring health risks to occupants. Since water pipelines become corroded over time, heavy metal ions and pathogenic microorganisms will occur and

contaminate the water (Li et al., 2022). Beyond these three primary concerns, ageing residential buildings exhibit a range of secondary yet equally consequential issues that collectively contribute to their declining performance. Of particular concern are the safety risks associated with ageing elevator systems, which frequently fail to meet contemporary safety standards and often experience mechanical failures due to prolonged usage (Feng et al., 2020). Acoustic performance represents another significant challenge, as poor sound insulation in older buildings result in inadequate noise attenuation between dwelling units, substantially compromising residential privacy and comfort (Oh, 2014). Furthermore, the widespread presence of antiquated electrical wiring system (Lai et al., 2006) poses both fire hazards and operational limitations, particularly in meeting modern power demands.

These compounding deficiencies create a multifaceted problem set that extends beyond mere physical deterioration. The cumulative effect significantly impairs both the structural integrity and operational functionality of residential buildings, while simultaneously creating substandard living conditions that adversely affect occupants' quality of life. Mitigating these impending threats necessitates prompt and effective solutions.

1.1.3 Critical necessities for residential building renovation

As residential buildings deteriorate over time, their capability to meet modern safety, health, resident well-being, accessibility and sustainability standards diminishes, heightening the urgent need for comprehensive renovations initiatives to address these critical issues (Jensen and Maslesa, 2015). This necessity is reflected in various national policies worldwide. According to the Ministry of Housing and Urban-Rural Development of China (2024), the objective of urban renewal is to enhance urban livability, resilience and intelligence, thereby improving residents' comfort, security and well-being. Furthermore, urban renewal acts as a crucial catalyst for stimulating investment and employment and serves as a pivotal strategy for advancing high-quality urban development. Recognizing the magnitude of the urban ageing problems and the significant benefits of renewal, the Chinese government has allocated substantial resources to this endeavor. Recent official statistics from The Central People's Government of the People's Republic of China (2024) reveal the remarkable scale of this undertaking, indicating that over 60,000 urban renewal projects were implemented nationwide in 2024, with investments totaling approximately 2.9 trillion Chinese Yuan (CNY).

Similarly, in the European context, France has also demonstrated a significant commitment to urban renewal through the New National Urban Renewal Program (NPNRU), which has an allocated budget of 14 billion Euro. The program's objective

is the renovation of 448 neighborhoods by 2030 and has already improved living conditions for three million residents (OECD, 2025). The European Commission launched the Renovation Wave, a strategy targeting the renovation of 35 million buildings by 2030 to at least double the EU's annual energy renovation rate (European Commission, 2021). These coordinated efforts across different governance levels highlight the global recognition of building renovation as an essential component of sustainable urban development.

The strategic renovation of ageing residential properties represents a comprehensive and sustainable approach for addressing the multifaceted challenges posed by deteriorating building stocks. Tackling the ageing challenges is urgent for sustaining urban development and contributes significantly to the fulfilment of the United Nations Sustainable Development Goals (SDGs) of the United Nations (2015), including: SDG 3 (Good Health and Well-being), which includes target 3.4 to “reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being”; SDG 7 (affordable and clean energy), specifically target 7.3 “by 2030, double the global rate of improvement in energy efficiency; SDG 11 (Sustainable Cities and Communities), specifically target 11.1 that aims to “ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums”; and SDG 13 (climate action), which contains target 13.2 “integrate climate change measures into national policies, strategies and planning”.

Residential building renovation has become an indispensable strategy for cities addressing ageing building stocks while pursuing sustainable development objectives.

1.1.4 The important role of homeowners in residential renovation

The success of building renovation projects necessitates complex coordination among multiple stakeholders. These projects typically engage a diverse actors including policymakers, investors, homeowners, developers, and construction contractors (Rose et al., 2021). Among these stakeholders, homeowners play a vital role in determining the success of renovation initiatives. The critical importance of homeowners arises from three fundamental factors:

- (1) Decision-making authority: As the primary occupants and legal owners, homeowners possess veto power over renovation proposals (The National People's Congress of China, 2020), making their consent an absolute prerequisite for project commencement.
- (2) Smooth execution: homeowner cooperation are critical for smooth implementation, as homeowner's resistance can results in delays, increased costs, or project failures (Olander and Landin, 2005).
- (3) Long-term sustainability: Since the ultimate goal of renovations is to enhance residents' quality of life and well-being (Ministry of Housing and Urban-Rural Development of China, 2024), the long-term success of building renovations is

inherently tied to homeowner satisfaction.

1.1.5 The interdependence between homeowner preferences and renovation success

Homeowners' preferences and the success of housing renovation are deeply intertwined. Since individuals spend a significant portion of time at home, the quality of the residential environment is crucial to their overall well-being (Taherkhani and Aziminezhad, 2023). As primary occupants, residents naturally develop specific expectations and aspirations regarding enhanced quality-of-life standards in their residential environments. Housing renovation projects which fail to adequately incorporate multifaceted homeowner considerations frequently encounter significant implementation barriers, including formal opposition during approval processes, non-cooperation during construction phases, and post-renovation dissatisfaction—all of which can substantially delay project, increase operational costs, and ultimately compromise the intended outcomes of the renovation.

Conversely, when examining the fundamental objectives of residential renewal programs through the policy lens established by the Ministry of Housing and Urban-Rural Development of China (2024), it becomes evident that successful renovation outcomes must be evaluated not merely through technical or economic metrics (e.g. energy efficiency, cost-effectiveness), but also through their capacity to fulfil residents'

expectations and enhance subjective well-being indicators. Consequently, fulfilling these expectations becomes paramount for project success. A thorough investigation of homeowner priorities would consequently serve dual purposes: increasing project renovation efficacy while simultaneously enhancing occupant benefits and satisfaction.

1.1.6 The Complexity in aligning and conflicting homeowner priorities with stakeholders

The multifaceted nature of renovation decision-making processes is fundamentally shaped by the divergent, and often competing, interests of various stakeholders, coupled with the essential yet challenging requirement for achieving consensus (Chen et al., 2020). Within this complex dynamic, homeowners' preferences and priorities frequently demonstrate both alignments and conflicts when examined in relation to the objectives pursued by other key stakeholders. An example of alignment can be observed that homeowners' desires for a healthier living environment are in line with government's goal of good health and well-being (SDG 3) (World Health Organization, 2018). However, such priorities may conflict with developers' primary operational objective of maximizing profit (Chou et al., 2023). According to Geva and Rosen (2018), developers have perceived the negotiation and execution of a renovation project with homeowners as the riskiest part. Balancing the needs of homeowners and the interests of other stakeholders has become a pressing challenge prompt to be addressed.

1.2 Research gaps and motivations

1.2.1 Performance indicators for homeowner priorities in renovation

Key performance indicators (KPIs) serves as valuable tools for monitoring renovation project progress, guiding decision-making, and ensuring projects achieve their intended goals and impacts (Al Dakheel et al., 2020). The selection of appropriate indicators enhances the scientific rigor and effectiveness of renovation decisions, thereby optimizing project success. Numerous studies have been conducted to investigate building performance indicators. Ho et al. (2021) identified 19 key indicators for comprehensive evaluation of building retrofits, categorizing them into economic, environmental, health/safety, and user perspective. McGinley et al. (2022) developed an integrated assessment framework for energy-efficient residential retrofits using economic, social, and environmental indicators. Al Dakheel et al. (2020) emphasized that quantifying building energy performance through the development and application of KPIs was crucial for achieving smart building objectives in both new and existing buildings. Through a comprehensive literature review of smart building indicators, the researchers systematically identified and compiled 36 critical indicators. Liu et al. (2022) systematically reviewed 47 publications and identified 689 variables across seven categories that influence homeowner decision-making in energy retrofits. However, performance indicators representing concerns of homeowners in housing renovation have not been thoroughly investigated.

1.2.2 Towards holistic performance evaluation metrics: incorporating homeowner perspectives in housing renovation decision-making

Refurbishment and redevelopment represent two distinct approaches for building renovation. Refurbishment primarily involves the maintenance, repair and retrofitting of existing buildings (Vilches et al., 2017), whereas redevelopment entails the demolition of old buildings and the construction of new ones (Zhao, 2022). Extensive research has been conducted to compare these two renovation options in order to facilitate decision-making. In a systematic review by Schwartz et al. (2018), the Life Cycle Carbon Footprint (LCCF) was identified as a key metric for assessing the environmental performance of refurbished versus newly constructed buildings. Their findings indicated that while many refurbishments exhibited lower LCCF than most new constructions, some newly built buildings outperformed refurbished ones. Therefore, a definitive preference between the two options could not be conclusively determined based on the available evidence. In a subsequent study by Schwartz et al. (2022), the comparison was expanded to include both LCCF and Life Cycle Cost (LCC) as evaluative criteria. The results indicated that optimal refurbishment models generally outperformed redevelopment in terms of these two criteria. Nevertheless, decisions regarding the two renovation options should not rely solely on environmental or economic considerations. Instead, they should involve a broader discussion that considers the multifaceted nature of the issue, including cultural and social dimensions.

Power (2008) highlighted significant social, economic, and environmental benefits of refurbishment over demolition and redevelopment, such as reduced transportation costs, decreased landfill waste, enhanced material reutilization, and the preservation of community infrastructure and local neighborhoods. Gaspar and Santos (2015) estimated that the costs of the two strategies were similar, leading them to prioritize environmental impact as the decision criterion. Their findings also concluded that refurbishment is a more sustainable approach than reconstruction due to its lower material use, demolition waste and embodied energy consumption.

These studies have predominantly utilized methodologies such as life cycle assessment, Pareto models analysis and simulation based on cases in specific regions to evaluate the environmental or economic performances of refurbishment vs. redevelopment. Metrics including life cycle carbon emissions, embodied energy and life cycle costs are commonly used to inform decision-making. While these metrics provide valuable insights into environmental impacts and cost-effectiveness, they fail to capture the full spectrum of considerations that matter to homeowners. Key motivations and objectives of homeowners, such as improving comfort levels, also play a significant role in shaping homeowners' renovation choices (Friege and Chappin, 2014). However, these factors have often been overlooked in the decision-making framework in prior studies (Ortiz et al., 2020). Furthermore, those studies made comparisons and decisions without considering the weights of the evaluation criteria or a rigorous decision-making framework. Such deficiencies create a gap in research, and the decision-makers are in

lack of a reliable tool and sufficient information to fully assess the trade-offs between the benefits and drawbacks of residential renovation. This may eventually result in project failures and homeowner dissatisfaction.

1.2.3 How demographic and socioeconomic factors shape variations in homeowner renovation priorities

A notable volume of research has investigated how demographic and socioeconomic characteristics affect individuals' interactions with the built environment. Nielsen et al. (2021) discovered that a high socioeconomic status could lead to increased housing-related emissions, as desirable public amenities were often situated in neighborhoods with large homes. Conversely, higher income levels could facilitate the reduction of greenhouse gas emissions through housing initiatives that require significant initial investments, such as home retrofits and the installation of residential solar panels. Pinto et al. (2021) observed that older and wealthier individuals were more likely to utilize urban parks. Fan et al. (2022) identified that the socioeconomic attributes of a community influenced the likelihood of pipe failures. Reames (2016) found that lower urban residential heating energy efficiency was associated with lower educational level and income. Demographic and socioeconomic factors can significantly shape homeowners' behaviors and perceptions, with their priorities varying according to different demographic and socioeconomic characteristics. Therefore, when determining key indicators for decision-making or policy formulation, it is crucial to consider these

disparities to ensure accuracy and relevance to local residential communities.

Nonetheless, there remains a gap in the examination of these disparities.

1.2.4 Research motivation

The primary motivation underlying this research is to address the gap in existing decision-making models for renovating ageing residential buildings, which have largely overlooked homeowners' preferences. Prior decision-making models predominantly focused on energy performance and environmental impact, often neglecting residents' concerns and priorities. As a result, renovation projects may fail to meet residents' actual needs and low homeowner participation heightens the risk of project delays or failures. This study therefore aims to incorporate homeowners' preferences into the residential building renovation decision-making, thereby enhancing their cooperation and satisfaction, as well as improving the overall success and long-term sustainability of renovation projects.

1.3 Research questions

The comprehensive analysis of existing literature reveals several significant research gaps that necessitate further investigation, prompting the formulation of the following critical research questions:

1. What research trends and gaps are in the field of performance evaluation of residential buildings?
2. What performance indicators potentially hold substantive relevance and importance for homeowners within the Chinese ageing housing renovation context?
3. How do homeowners perceive and prioritize the relative importance of various performance indicators in residential building renovation projects?
4. What is the underlying dimensional structure of the KPIs that homeowners use to evaluate ageing building renovations?
5. Which components and indicators emerge as the most significant for constructing an index model?
6. How do homeowner preferences for housing renovation vary across different demographic and socioeconomic groups?
7. How can the study's findings be applied to enhance decision-making processes and outcomes in ageing building renovation projects?

1.4 Research objectives

This research study was primarily designed to establish a comprehensive decision-making framework that systematically integrates KPIs reflecting residents' priorities and concerns in ageing residential building renovation. Through this approach, the study seeks to enhance both homeowner satisfaction and project success. To accomplish this aim, the study pursues the following sequential research objectives:

1. Conduct a systematic literature review to analyze existing studies on the performance evaluation of residential buildings, identify current trends and key knowledge gaps in the field.
2. Identify the full spectrum of performance indicators that demonstrate substantive relevance to homeowners during residential renovation processes, drawing upon both established metrics and newly emerging priorities.
3. Assess the importance ratings assigned to various indicators by homeowners and determine the most critical KPIs that warrant inclusion in the decision-making framework.
4. Unveil the underlying dimensional components of the KPIs through factor analysis.
5. Develop a weighted index model for homeowner residential building renovation decision-making.
6. Statistically examine the variations of importance ratings among different demographic and socioeconomic groups of homeowners.
7. Formulate evidence-based policy recommendations and implementation strategies by integrating the existing policy context with the empirical findings of this thesis.

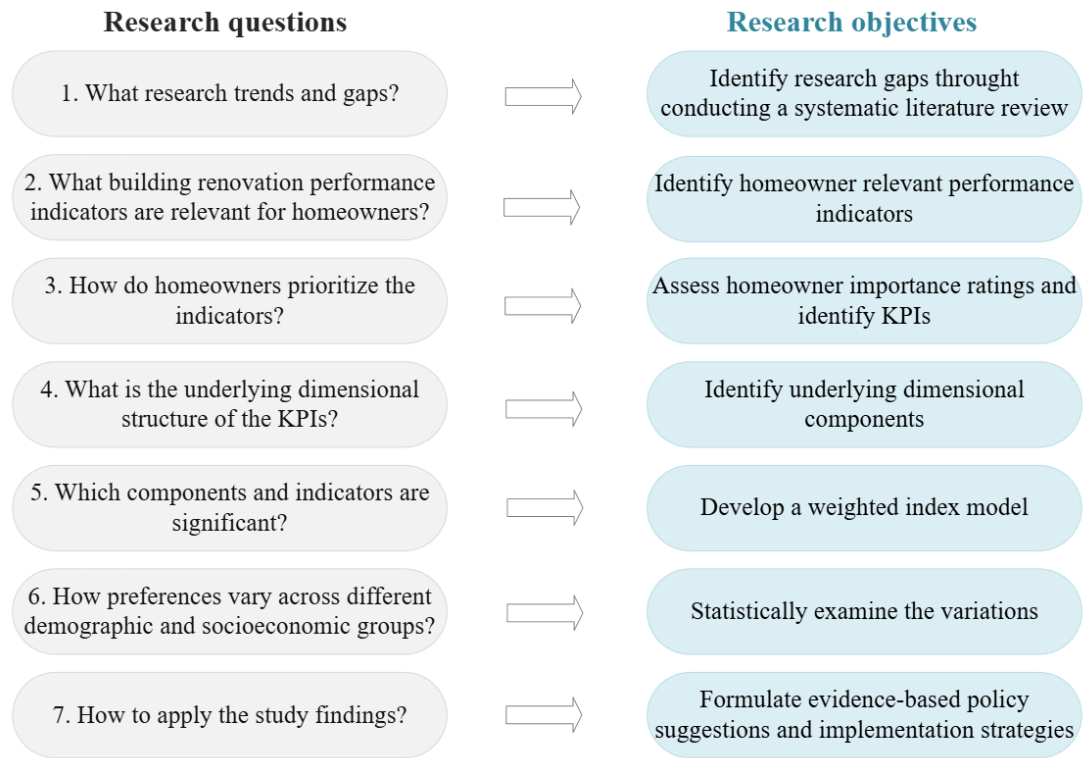


Figure 1.1 Research questions and objectives.

1.5 Research significance

The index model developed serves as a guiding framework for decision-making in residential renovation, facilitating consensus among stakeholders. By incorporating a comprehensive set of metrics that reflect homeowner preferences into the decision-making process, stakeholders can better understand trade-offs and synergies. This transparent and inclusive approach helps bridge differing interests, enabling collaborative identification of solutions that balance competing priorities and achieve mutually acceptable outcomes. Besides, it contributes to informed policymaking and the design and implementation of renovation projects that align with the needs of homeowners across diverse demographic and socioeconomic contexts. Furthermore,

the model supports the development of communication strategies that highlight renovation benefits most valued by homeowners, thereby gaining more valuable support and cooperations from residents. By using the identified KPIs as reference and applying the methodology outlined in this study, the index model can also be tailored to reflect regional variations in homeowner preferences, enhancing its applicability and utility for decision-makers across global urban contexts.

This study also advances research on decision-making in residential building renovation by addressing the gap in understanding variations in homeowners' renovation priorities across different demographic and socioeconomic groups. Besides, it provides practical implications for policymakers and urban planners, suggesting that policies and regulations should be tailored to accommodate the diverse motivations and priorities of various demographic and socioeconomic features. Furthermore, the study can inform more targeted and effective communication strategies, ensuring that renovation initiatives resonate with diverse homeowner groups. Lastly, the study contributes to the development of more sustainable and effective urban housing renovation solutions, which not only improve the quality of housing but also enhance the overall well-being and satisfaction of different resident groups.

1.6 Structure of the thesis

This thesis comprises eight chapters. Chapter 1 presents the background and rationale for the research topic, identifying gaps in existing literature concerning decision-making for ageing residential buildings, particularly in relation to homeowners' preferences. Based on these gaps, the research questions are formulated, followed by the corresponding objectives designed to address them. Additionally, the significance of the study is outlined.

Chapter 2 presents a systematic literature review on the performance assessment of residential building renovation. With a hybrid review approach adopted, relevant literature was examined in three stages. In stage 1, literature retrieved from Scopus was screened for their relevance to the study topic. In stage 2, bibliographic data of the shortlisted literature underwent scientometric analyses by the VOSviewer software. Finally, an in-depth qualitative review was made on the key literature. The review reveals current study trends, research hotspots, and prominent contributors within the field, while also identifying critical research gaps in the performance assessment of building renovation. These recommended directions for further investigation not only address current knowledge deficiencies in the field but also served as the fundamental rationale for selecting the specific research focus of this thesis.

Chapter 3 presents a comprehensive methodological framework for the study, beginning with a rigorous approach to identify and consolidate homeowner performance indicators through systematic literature review and expert validation. An importance perception survey was then conducted, followed by normalization process to develop a refined shortlist of KPIs. Factor analysis (FA) was employed to examine underlying dimensions, while a robust index model was developed with fuzzy synthetic evaluation (FSE) and subjected to rigorous validation procedures. Finally, statistical analyses, including mean ranking analysis, intraclass correlation coefficient and the Kruskal-Wallis test followed by post-hoc Dunn's test, were implemented to investigate variations in homeowners' importance perceptions across different demographic and socioeconomic groups.

Chapter 4 presents the establishment of 33 performance indicators derived from systematic literature review and expert interviews, including their definitions, sources, and expert rationales for both included and excluded indicators. The study then examines the demographic and socioeconomic profile of survey respondents. Finally, the chapter verifies data reliability through Cronbach's alpha test, confirming the internal consistency of the importance ratings dataset and its appropriateness for subsequent model development and statistical analyses.

Chapter 5 begins with the identification results of 24 KPIs through normalization techniques, which are subsequently classified into six distinct clusters via FA. To

quantify these preferences systematically, the study employs FSE to assign weighted values to each indicator and cluster, thereby developing an empirically grounded index model. Expert validation confirms the model's practical applicability, demonstrating high ratings for both its rationality and replicability. The subsequent discussion highlights the differential prioritization of factors, particularly emphasizing homeowners' predominant concern.

Chapter 6 examines variations in homeowners' residential renovation priorities across demographic and socioeconomic subgroups, addressing a critical gap in existing research. This chapter analyses importance ratings of 33 building performance indicators through statistical techniques—including mean ranking analysis, intraclass correlation coefficients, and Kruskal-Wallis tests with post-hoc Dunn's tests—to identify significant disparities in prioritization patterns. Complementing quantitative findings, qualitative interviews explore underlying reasons for observed differences. Together, these methods provide empirical evidence to guide equitable policymaking and tailored renovation strategies that account for diverse homeowner needs. The chapter ultimately advances understanding of how demographic and socioeconomic factors shape housing improvement preferences, offering actionable insights for inclusive urban renewal.

Chapter 7 is organized into two main sections to provide a comprehensive analysis of China's urban renovation policy evolution and to offer practical recommendations for

future residential renovation strategies. In the first section, the historical transition of national urban renovation policies was traced and the challenges encountered during this policy shift were discussed. The second section presents evidence-based recommendations for residential renovation policies and strategies, drawing on empirical findings regarding residents' priorities and the policy context. By aligning policy frameworks with these insights, the chapter aims to guide policymakers in developing more effective, equitable, and sustainable urban renewal initiatives.

Chapter 8 serves as the concluding section of the research, systematically summarizing the study's key findings, contributions, limitations and suggesting future research directions. The chapter begins with a brief introduction that outlines the chapter's structure. Section 8.2 comprehensively addresses the fulfilment of each research objective and synthesizes the key findings. The subsequent section 8.3 highlights the study's multidimensional contributions to both academic knowledge and practical applications in residential renovation. Finally, the chapter concludes with section 8.4, which discusses the research limitations and proposes directions for future studies.

Chapter 2: Literature review and research gap identification

2.1 Introduction

Proper assessment of renovations can help decision-makers choose the most effective method for attaining the SDGs, minimizing economic and environmental costs while maximizing benefits of renovation projects. Given the importance of performance evaluation on residential building renovation, extensive studies have been conducted over the years. A comprehensive review of these assessment works can be beneficial for recognizing any research gaps, thus signposting future development and advancement of performance assessment of residential building renovation. However, there is an absence of study that offers a full picture of the assessment works and reveals the research hotspots and gaps in this domain. To address this gap, this chapter is conducted to systematically review extant literature in the field of performance assessment of residential building renovation.

Reported in Section 2.2 is the detailed processes and methods adopted for reviewing the literature. Section 2.3 shows a scientometric analysis conducted to quantify and visualize the literature publication trend, major research areas, knowledge sources, and global collaborations within the domain of performance assessment of residential building renovation. Based on the scientometric analysis followed by a qualitative content analysis of the shortlisted literature, main research hotspots were identified and

reviewed, as shown in Section 2.4. In Section 2.5, the research gaps are revealed and the future directions for bridging these gaps are recommended. Section 2.6 summarizes the main findings and implications of the review. Finally, in Section 2.7, the specific research direction was selected for conducting the following empirical studies in this thesis.

2.2 Review methods

A hybrid review approach was adopted, which comprises a scientometric analysis and a qualitative review. This approach has been adopted by extensive studies and was found effective in identifying the research hotspots and gaps within a research domain (Adegoriola et al., 2021; Martinez et al., 2019; Peiris et al., 2023). Scientometric analysis is a review method that scientifically and technologically analyses the literature being studied (Hood and Wilson, 2001). Unlike traditional reviews which often inherit subjectivity, scientometric analysis can objectively map the research areas of the field under investigation (Zhong et al., 2019). Using this method, this review is able to objectively unveil the trend and recent state of literature outputs in the research domain and find research hotspots by visualizing relevant networks. A qualitative review can provide a deeper and more detailed analysis of important literature. By using the hybrid approach, this review can identify research gaps more objectively and at the same time, provide an in-depth understanding of existing scientific studies in the area of performance assessment of residential building renovation. A flowchart of the review

processes is depicted in Figure 2.1; further explanations of the steps taken are detailed in the ensuing sub-sections.

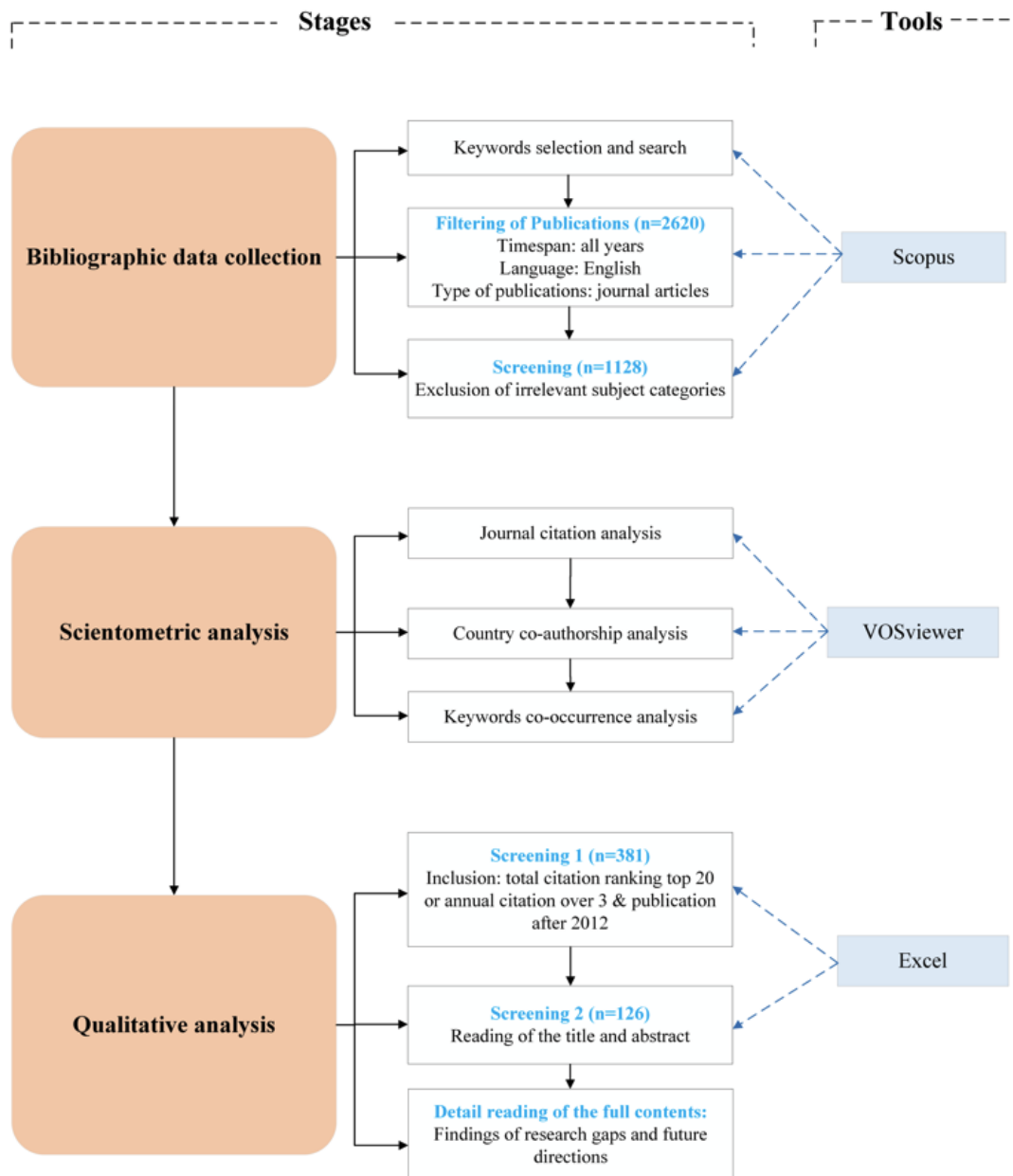


Figure 2.1 Flowchart of the review processes.

2.2.1 Bibliographic data collection

This review collected the data for the bibliographic analysis from Scopus, a database covering broader and more recent sources of academic literature compared to other databases such as Web of Science (Salihu et al., 2022). Three groups of keywords germane to the scope of this review study, covering the lead keywords (“renovation”, “assessment” and “residential buildings”) and their synonyms (including different word forms such as noun and verb), were combined in the search of the literature in Scopus, as shown in Table 2.1. These three sets of keywords were selected because they represent the essential themes in the performance assessment of residential building renovation. Their use ensures that the literature review closely aligns with the study’s central and foundational scope. Between the groups, “AND” was used to restrict the search results with a focus on the research domain of performance assessment of residential building renovation. The timespan was set to “all years” in order to observe the evolution of these studies over the years. Then, the language was limited to English and the type of publications was confined to journal articles. As a result, a total of 2620 papers were found. After excluding publications that belong to irrelevant subject categories (e.g. Medicine, Biochemistry, and Nursing), the number of publications was reduced to 1127. Bibliographic information including titles, keywords, abstracts, authors and affiliations, citations, countries, publishers, and publication years of these 1127 publications were exported from Scopus, forming the dataset for the subsequent scientometric analysis.

Table 2.1 Groups of keywords.

Group No.	Keywords
1	“Refurbishment” OR “Refurbish” OR “Reusing” OR “Reuse” OR “Renovation” OR “Renovate” OR “Retrofitting” OR “Retrofit” OR “Rehabilitation” OR “Rehabilitate” OR “Redevelopment” OR “Redevelop” OR “Replacement” OR “Replace” OR “Rebuilding” OR “Rebuild” OR “Reconstruction” OR “Reconstruct” OR “Regeneration” OR “Regenerate” OR “Demolition” OR “Demolish” OR “Renewal”
2	“Assessment” OR “Assess” OR “Evaluate” OR “Evaluation” OR “Grading” OR “Performance” OR “Evaluation-criteria” OR “Decision making” OR “Measurement” OR “Measure”
3	“Residential-buildings” OR “Family-house” OR “Dwelling” OR “Condominium” OR “Apartment” OR “Flat” OR “Dormitory”

2.2.2 Scientometric techniques

Science mapping is a method for analyzing and visualizing the research domain (Chen, 2017). VOSviewer, which is a science mapping software that provides abundant functions including network visualization and clustering (Salihu et al., 2022), was used to conduct scientometric analysis and map literature networks. For science mapping, this study utilized scientometric techniques including journal citation analysis, country co-authorship analysis, and keywords co-occurrence analysis. Journal citation analysis is a tool for analyzing the contribution of each journal in the research domain and journals’ collaboration network. Country co-authorship analysis helps in recognizing the country with the most research outputs and countries’ collaboration status in the research domain. Keywords co-occurrence analysis can objectively present the main

research area (Darko et al., 2019). To accomplish the scientometric analysis, two steps were conducted using VOSviewer. The first step extracted literature data from Scopus and uploaded it to VOSviewer. The second step comprised calculation, visualization, and analysis of the co-occurrence of keywords, scientific collaboration network of countries, and contribution and network of journals.

2.2.3 Qualitative analysis

Following the scientometric analysis, a qualitative analysis of mainstream articles was conducted to gain an in-depth understanding of the main research areas in the field of performance assessment of residential building renovation. Since the keyword co-occurrence maps only cover authors' keywords, some important information reported in the retrieved articles might not be fully reflected. Through a manual scrutiny of the articles' entire contents, the in-depth qualitative review can reveal any important information not identified from the keyword co-occurrence analysis.

For this review, the method for choosing the core articles was modified based on the approach of Yang et al. (2022). First, publications with total citations ranking top 5% were selected, as they were the most influential studies. Second, since it takes time for publications to accumulate citations, recent articles may rank low in total citations (Goyal et al., 2021). Therefore, the remaining papers published within the recent ten years with annual average citations of 3 or above were shortlisted as mainstream articles.

381 publications were shortlisted by refining the publication time and number of citations. Then, a further screening of the title and abstract of these 381 papers was conducted to refine the most significant publications in the final qualitative review. The full text of each shortlisted article underwent a manual content analysis where the article's main theme was identified, followed by an in-depth review of its contents. With the aid of keyword co-occurrence analysis, the articles were grouped into categorized research areas. Then, the research gaps were unveiled and future research paths for bridging the gaps were recommended.

2.3 Scientometric analysis

2.3.1 Publication trend of the literature

The initial literature search conducted in the Scopus database yielded a collection of 1,127 relevant articles, all of which were subsequently included in the scope of Scientometric analysis. Figure 2.2 demonstrates the number of papers published every year in the field of residential building renovation performance assessment. Since publishing the first article in this research domain in 1979, generally the rising trend of publications has continued and the growth of publications has accelerated over the past twenty years. This sustained increase in publication frequency serves as a strong indicator that this research domain is attracting increasing academic research interest. Notably, the analysis shows that approximately 51% of the total articles were published

within the last five years (2018 to October 2022). This confirms the continued importance and the pressing research needs in the assessment of residential building renovation projects.

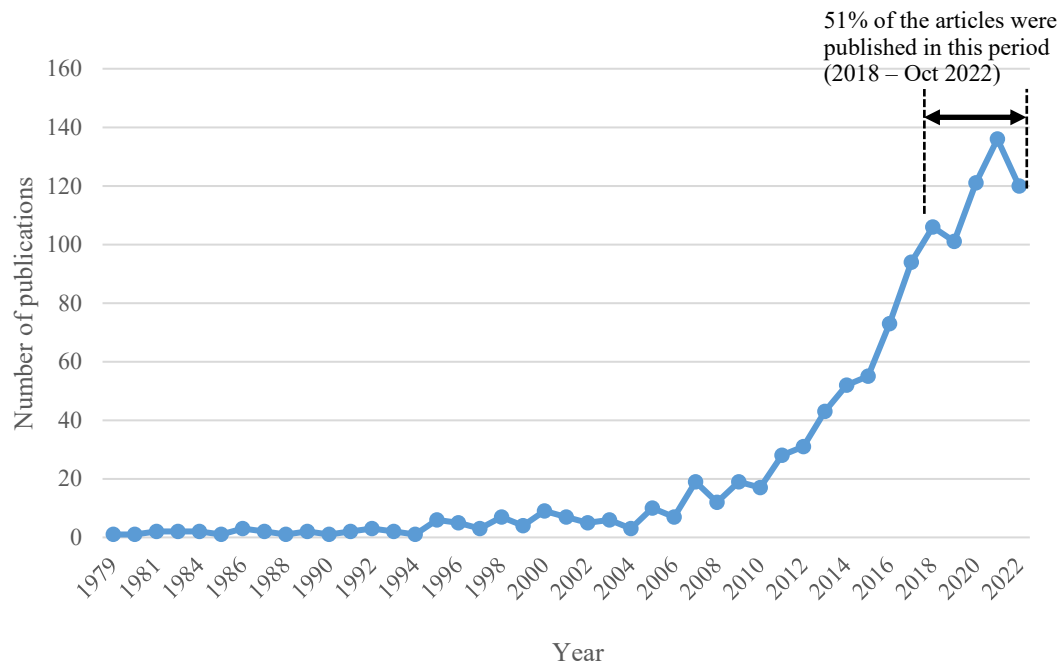


Figure 2.2 Number of publications per year from 1979 to October 2022.

2.3.2 Scientific collaboration network of publication sources

In analyzing the publication sources of the literature dataset, the minimum number of articles published in a journal was set to the default value of 5 and the minimum number of citations of a source was set to 20 (Adegoriola et al., 2021). A total of 32 journals out of all 419 journal sources were shortlisted after meeting the conditions. Figure 2.3 illustrates the leading journals that published articles within the field of performance assessment of residential building renovation. These journals were grouped into seven

clusters, represented by seven different colors in this figure. The sizes of the nodes and the labels indicate the number of papers published by the corresponding journals. The link between journals represents the mutual citations between them, indicating the strength of the relationship between the concerned journals.

As shown in Figure 2.3, the size of the node of the *Energy and Buildings* journal is the biggest, demonstrating its largest number of papers published in the research domain. With a total of 150 papers published in this research area, *Energy and Buildings* recorded an average of 30.2 citations per publication. Specialized in energy use and efficiency in buildings, this journal also covers research areas such as energy efficiency improvement measures, evaluation and control of indoor thermal and lighting systems, and building's total performance and intelligent buildings, all of which being related to the present study.

Two other popular publication sources, the *Sustainability* journal and the *Building and Environment* journal, ranked respectively second and third by total number of publications. The number of publications in *Sustainability* is 68, which is just below the number of publications in *Energy and Buildings*. However, *Sustainability* only ranked seventh in terms of total citations. The average number of citations of *Sustainability* was low (8.4 citations) compared to the other journals such as *Energy and Buildings* (30.2 citations), *Building and Environment* (42.1 citations), and *Energy Policy* (45.3 citations). In contrast, some journals published a small number of articles but generate

high citations; for instance, *Applied Energy* published a total of 17 papers in this research domain with the average citations reaching 51.1. This difference may be ascribed to factors such as high popularity and reachability of those highly cited journals while the *Sustainability* journal covers various topics related to sustainable development, with its scope not confining to the present study's research domain. The results illustrate that the assessment works on existing residential buildings were mainly published in journals with themes focusing on the energy and environment aspects. Other journals with themes closely related to the overall performance of residential building renovations such as economic, social, occupants' health, and safety hardly publish papers or receive high citations in this research domain, showing insufficient attention and neglections of the research field in these journals.

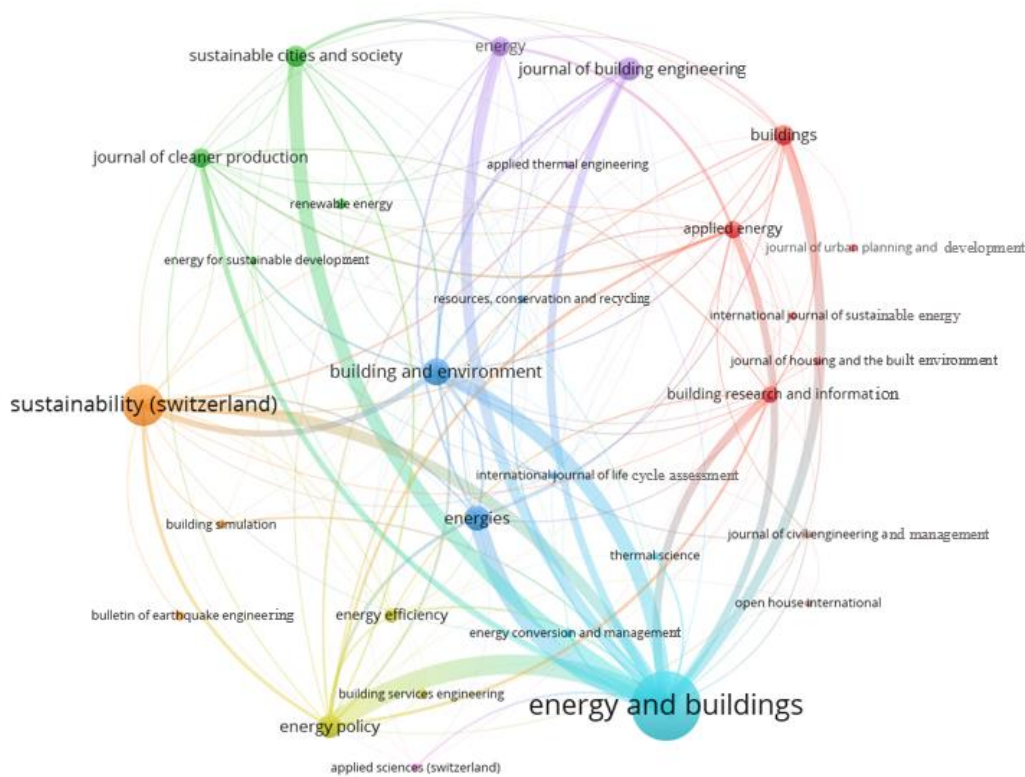


Figure 2.3 Mapping of main journal sources.

2.3.3 Country co-authorship analysis

Analyzing the cooperation network of countries can provide support for identifying which country pays more attention to the research area (Darko et al., 2019). After importing the bibliographic data into VOSviewer, the type of analysis was set to “co-authorship”, the unit of analysis was set to “countries”, and the “fractional counting” was chosen as the counting method. Both the “minimum number of documents of a country” and “minimum number of citations of a country” were set as VOSviewer’s default values (5 and 0 respectively). Ultimately, 45 out of the total 87 countries were included in the network, as shown in Figure 2.4. Based on the analysis of the network between countries, the following findings were obtained.

The size of the nodes represents the influential levels of countries, the larger the node, the more research work was fulfilled in the research domain by the country. As shown in Figure 2.4, the United Kingdom (UK), the United States (US), China, and Italy were the top four countries each publishing more than 100 articles, indicating that they are the core regions that produce a significant volume of assessment studies on residential building renovation. There are two reasons for the leading positions of these four countries in the research domain. First, the UK and the US have track records in scientific research and inventions. Over the past few decades, China has grown remarkably in scientific research. The massive expansion of research in these countries have enabled numerous researchers to generate plentiful building renovation

assessment studies. Second, since the bulk of residential building stock in these countries turns ageing, they are under more pressure to deal with the associated problems. In these countries, renovation projects are popular because they can bring along a range of benefits. For instance, optimizing the energy performance of residential buildings through renovations can help these countries achieve SDG 7 (affordable and clean energy) and meet the imminent target of carbon neutrality.

The link strength indicates the closeness level of the collaboration between two countries in the research domain. A total of 201 links and 259 link strengths were formed in Figure 2.4. Amongst these links, only the strengths of four links exceeded the value of 5. Sorted by link strength, the collaboration between China and the US (8.33), China and Hong Kong (7.83), China and Australia (6.67), UK and France (5.50) were the strongest. Although China did not generate the most research output in the research domain of this study, its collaborations with other countries were the strongest. In contrast, the number of scientific works (140) created in the UK was the highest, whereas UK's collaboration with other countries was weak compared to China. Only France collaborates with the UK with a link strength of over 5. The result shows an overall weak linkage between countries, indicating that previous studies in the research domain lack global cooperation. To improve the performance of residential buildings through renovation, in the future, global collaborations should be promoted to exchange knowledge and international experiences.

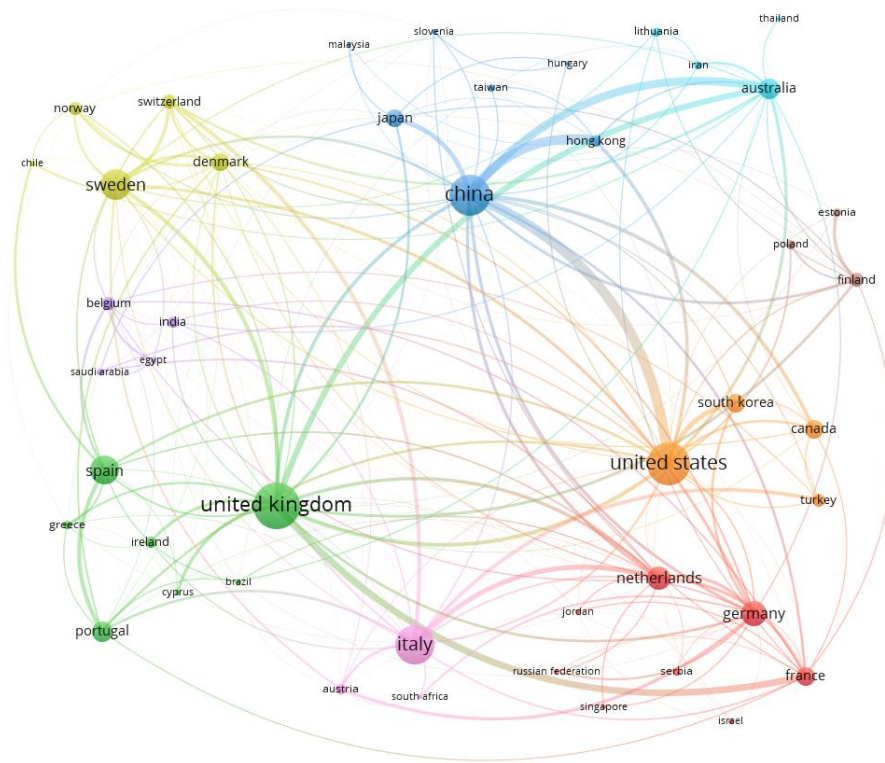


Figure 2.4 Mapping of cooperation networks between countries.

Figure 2.5 illustrates the average publication time of the research works in different countries. The average publication year of the US is around 2011, which is the oldest, followed by that (around 2015) of countries such as the UK and Sweden. The average publication years of China, Spain, and South Korea are more recent - around 2018. This indicates that the US was a pioneer in this research field while researchers in countries such as the UK and China soon recognized the importance of conducting performance evaluations on residential building renovation and then accumulated plenty of research outputs in this domain.

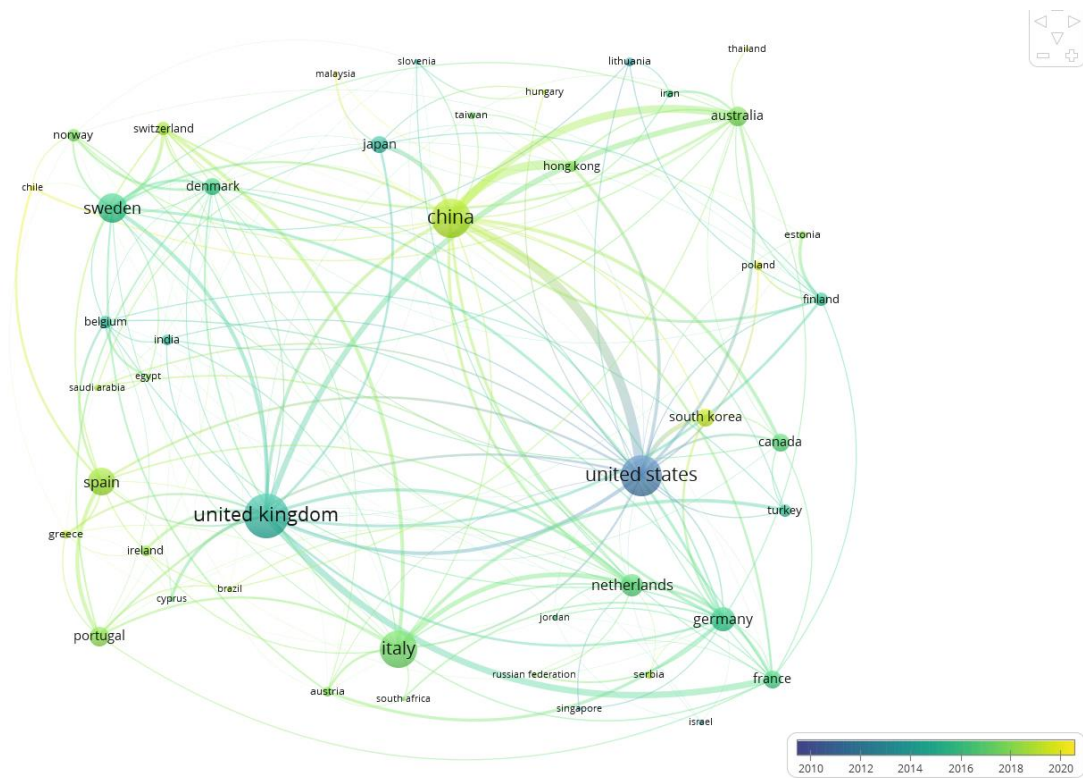


Figure 2.5 Occurrence time of publications in different countries.

2.3.4 Keyword co-occurrence analysis

Mapping the co-occurrence of keywords can distinctly and objectively present the hotspots of the research domain and how different research topics are associated (Darko et al., 2019). Therefore, the keywords occurrence analysis was conducted. A total of 3471 author keywords were retrieved from the dataset using the co-occurrence analysis and the fractional counting method. The minimum number of occurrences of a keyword was set as the system default value of 5, resulting in a total of 119 keywords. By manually removing repeated synonyms (e.g. retrofit and retrofitting) and several general terms, a keywords network was obtained, as shown in Figure 2.6. The network comprises 81 nodes and 385 links. The size of the node and circle is positively related

to the occurrence frequency of each keyword in the research domain (Salihu et al., 2022). The thickness of the connecting line indicates the strength of the link between each pair of keywords, which was calculated by counting the number of publications in which the two keywords occur together (Van Eck and Waltman, 2020). The strength of the linkage has a positive correlation with the thickness of the connecting line. Besides, the 13 colors represent the 13 different clusters of closely related keywords.

As shown in Figure 2.6, energy efficiency (132 occurrences), retrofit (79 occurrences), renovation (43 occurrences), energy retrofit (39 occurrences), sustainability (28 occurrences), thermal comfort (28 occurrences), energy performance (27 occurrences), refurbishment (24 occurrences), life cycle assessment (23 occurrences), energy renovation (21 occurrences), and climate change (18 occurrences) are keywords ranking top ten by frequency of occurrence, representing the main topics in the research domain of this study. The dominance of these keywords reflects that past researchers were inclined to focus on studying energy retrofits and the performance indicators were mainly about energy efficiency, sustainability, thermal comfort, and climate change. The popular assessment tool used by these studies was life cycle assessment (LCA).

The associations between energy efficiency and renovation measures are the strongest, suggesting the prevalent use of energy efficiency in the performance assessment of residential building renovations. Furthermore, as Figure 2.7 demonstrates, the average occurrence times of energy retrofits and thermal comfort are within the past five years,

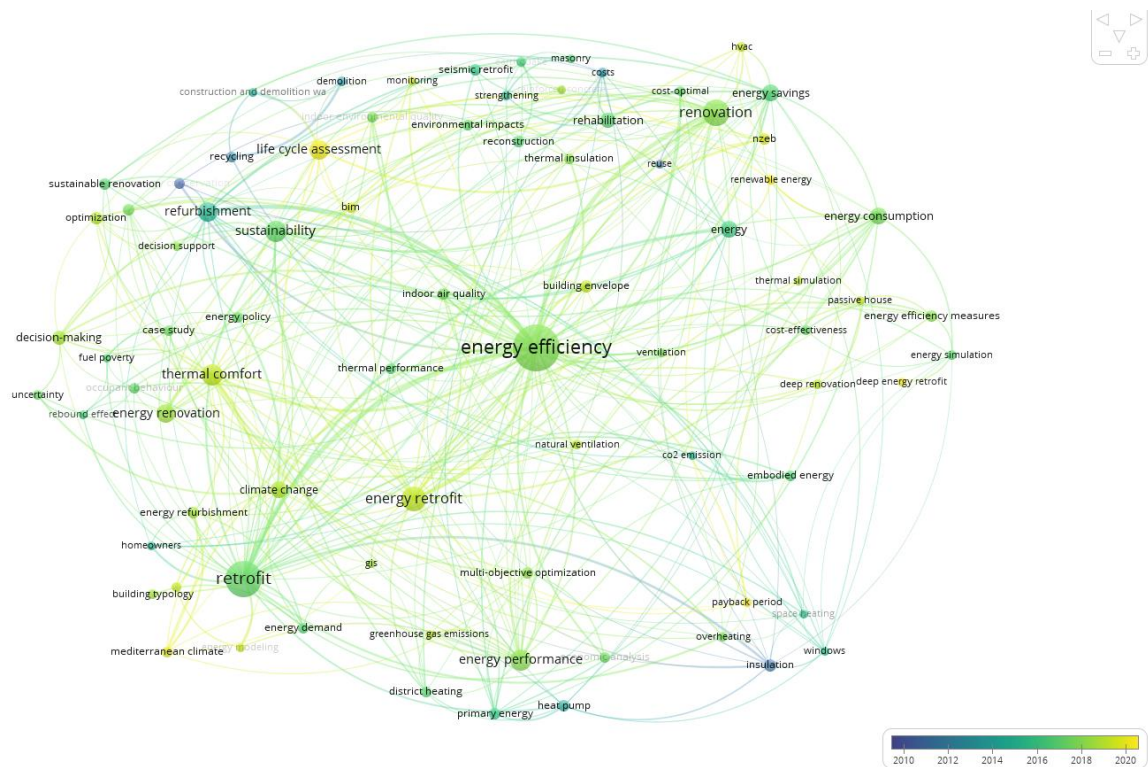


Figure 2.7 Average occurrence time of keywords.

2.4 Research hotspots

Based on the main research topics found by the above keyword co-occurrence analysis and the in-depth review of the mainstream articles, four research hotspots were revealed, including energy retrofit and energy efficiency assessment, life cycle assessment and sustainability, thermal comfort and other housing quality assessments, and decision-making criteria and methods. The ensuing sub-sections highlight and review the key findings reported in the articles of each hotspot. Table 2.2 summarizes and groups the articles covered by the in-depth review.

Table 2.2 Articles covered in the in-depth review

No.	Research hotspots	Articles reviewed
1	Energy retrofit and energy efficiency assessment	Hong et al. (2006); Ballarini et al. (2017); Saikia et al. (2020); Akgüç and Yılmaz (2022); Thomsen et al. (2016); Eicker et al. (2015); Ouyang et al. (2009); Amstalden et al. (2007); Asadi et al. (2012); Kolaitis et al. (2013); Dodoo et al. (2017); Ahmed and Asif (2020); Moran et al. (2020); Niemelä et al. (2017)
2	Life cycle assessment and sustainability	Raluy et al. (2006); Amoruso et al. (2022); Shirazi and Ashuri (2020); Ramírez-Villegas et al. (2019); Berg and Fuglseth (2018); Wrålsen et al. (2018); Rodrigues and Freire (2021); Dauletbek and Zhou (2022); Wang et al. (2018); Feng et al. (2020); Zhang et al. (2021); Moschetti and Brattebø (2017); Pombo et al. (2016); Amoruso and Schuetze (2022); Oregi et al. (2017)
3	Thermal comfort and other housing quality assessments	Lai and Yik (2009); Noris et al. (2013); Vakalis et al. (2021); Tuck et al. (2020); Földváry et al. (2017); Thomsen et al. (2016)
4	Decision-making criteria and methods	Jaggs and Palmer (2000); Kamari et al. (2018); Amorocho and Hartmann (2022); McGinley et al. (2022); Chen et al. (2020); Alba-Rodríguez et al. (2017); Pombo et al. (2016); Chandrasekaran and Dvarionienė (2022)

2.4.1 Energy retrofit and energy efficiency assessment

Since buildings consume the major share of the world's total energy (Lu and Lai, 2019; Norouzi et al., 2021), it is of paramount importance to improve the energy performance of existing buildings through retrofitting (Ho et al., 2021; Sing et al., 2021). As shown

in the keywords co-occurrence network, energy efficiency assessments of both ordinary renovation and energy retrofit have attracted immense concerns over the years. Extensive studies have been conducted to assess the effectiveness of certain techniques or methods in saving energy through retrofitting buildings. These energy-saving-oriented approaches can be categorized into passive measures and active measures. The passive method indicates retrofit measures that achieve energy savings by reducing energy loss and energy demand, such as enhancing thermal resistance by renovating the building envelope and improving glazing systems (Kerdan et al., 2016; Spanodimitriou et al., 2022). Building envelope and insulation retrofitting are widely acknowledged as effective methods to reduce fuel consumption for space heating (Ballarini et al., 2017; Hong et al., 2006); particularly, solid wall insulation saves more energy compared to cavity wall insulation (Dowson et al., 2012). Also, energy savings can be achieved by replacing building facilities or components such as doors and windows (Chandrasekaran and Dvarionienė, 2022). The energy saving effect of some passive energy retrofit methods can be high – as Saikia et al. (2020) demonstrated, 33.5% of heat gain and 9.2 kWh/day of electricity in a single housing unit in India could be reduced by a multi-retrofit envelope.

Active energy retrofit represents the adoption of technologies to save energy by improving energy efficiency. Several studies have proved the effectiveness of active retrofits in saving energy. A decentralized heat recovery ventilator system combined with the demand-controlled ventilation strategy could save up to 39% of the energy

(Akgüç and Yılmaz, 2022). Thomsen et al. (2016) found that the energy use and cost of heating could be reduced by 31% through the installation of a PV system. Akgüç and Yılmaz (2022) supported that the utilization of photovoltaics is cost-optimum. With decreases in energy consumption, generally, the corresponding energy cost could be reduced. However, Eicker et al. (2015) found that the cost and energy effectiveness is associated with the geographical latitude of a building's location. In the northern region, insulation retrofit performed better than renewable technology in saving energy while the cost of insulation is higher.

Energy saving is always associated with economic factors such as cost, profitability, and payback period (Amstalden et al., 2007; Asadi et al., 2012; Ballarini et al., 2017; Dodoo et al., 2017; Kolaitis et al., 2013; Ouyang et al., 2009). When conducting assessments on the implementation of building renovation, the potential of energy savings and the economic costs should be considered altogether. For instance, building envelope refurbishment was found to have satisfactory performance in saving energy; in areas dominated by heating season, thermal insulation measures became cost-effective owing to the substantial energy reduction (Ballarini et al., 2017). Also, higher energy price was one of the most crucial factors for attracting investments in energy-efficient retrofitting projects of existing residential buildings (Amstalden et al., 2007; Ouyang et al., 2009). An energy retrofit would be implemented when the economic value of the expected energy saving exceeds the investment into the retrofit. Sometimes, even if an energy retrofit could generate extraordinary performance in energy saving, it

may not be feasible to implement the retrofit without financial incentives. For example, the deep energy retrofit could decrease energy consumption by 60%, but the payback period could be up to 25 years (Ahmed and Asif, 2020). Financial incentives, therefore, are essential for making deep energy retrofitting feasible (Moran et al., 2020; Niemelä et al., 2017). Without sufficient financial incentives, only shallow retrofits of homes are economically feasible (Ahmed and Asif, 2020). But if the decision-making of retrofitting is purely based on cost-effectiveness, it is hard to imagine how energy retrofitting could be widely adopted.

2.4.2 Life cycle assessment and sustainability

Extensive studies have shown their concerns about quantifying the environmental impacts generated by building construction or refurbishment. LCA is a powerful tool that helps assess the environmental impacts associated with different life cycle stages within a product or system (Raluy et al., 2006). As the above review findings corroborate, LCA has become increasingly popular in recent years for evaluating the environmental impacts of residential building renovations. LCA could help identify the renovation components with the lowest carbon emissions (Amoruso et al., 2022) and select low-emission options for construction and retrofit measures (Shirazi and Ashuri, 2020). Using the LCA method, Ramírez-Villegas et al. (2019) found that the investigated building materials and construction processes generate the most environmental impacts. Berg and Fuglseth (2018) argued that building materials and

the use phase of buildings' life cycle are mainly responsible for life cycle greenhouse gas emissions, thus older buildings should be refurbished instead of being replaced by new building constructions. Wrålsen et al. (2018) also found that the renovation of existing buildings could bring considerable life cycle environmental benefits. Despite the strong power of LCA in dealing with environmental problems, the application of the LCA method is constrained by the challenge of collecting and processing voluminous and intensive data of complex building systems and components (Rodrigues and Freire, 2021).

BIM is a process using digital modelling to manage the information through the life cycle of a building (Poljanšek, 2017). It provides information for design, construction development, and building performance evaluations (Bu et al., 2015) and data on the material use and energy use for building construction, operation, and demolition for LCA (Wang et al., 2018). The integration of BIM and LCA enables the minimization of the embodied energy and the environmental impacts of buildings (Dauletbek and Zhou, 2022). Therefore, in numerous studies, BIM was coupled with LCA to analyze the life cycle environmental impacts of buildings. Based on an integrated BIM-LCA approach, Feng et al. (2020) identified that the embodied emissions brought by the investigated reconstruction were five to six times higher than refurbishment. Hence, they recommended the adoption of renovation instead of reconstruction. Wang et al. (2018) found that the recycling of metal waste contributed significantly more reduction to environmental impacts in comparison to masonry wastes, in spite of the metals' low

weight. In addition, on-site recycling was found to have better carbon reduction potential than factory recycling and landfill.

If residential building renovations are only considered from the perspective of environmental impacts, economic burdens will be brought to their house owners (Zhang et al., 2021). To embrace both environmental and economic considerations, LCA has been combined with life cycle costing (LCC) in numerous residential building innovation assessment studies. As Moschetti and Brattebø (2017) highlighted, in building energy renovation, it is important to balance the trade-off between environmental and economic costs. Pombo et al. (2016) combined LCA and LCC to quantify environmental impacts in monetary values; incorporated with Pareto optimization, preferred strategies for the renovation of existing buildings could be selected. Amoruso and Schuetze (2022) also identified that sustainable building renovation should possess attractive and profitable potential. They proposed that additional floor space expanded through building renovation could be sold or rented to make the renovation project profitable. Oregi et al. (2017) found that both the economic and environmental impacts of the transport stage and end-of-life phase in building energy retrofitting were minor. For building energy refurbishments, more attention should be given to their production, maintenance and replacement phases, given their significant environmental and economic importance.

2.4.3 Thermal comfort and other housing quality assessments

Housing quality standard improvement is one of the most vital objectives of renovating ageing residential buildings. Concerning different factors that influence residents' living qualities, assessment studies have considered a wide variety of attributes such as thermal comfort, indoor air quality, noise, and humidity (Afful et al., 2021; Lai and Yik, 2009). The renovation measures for old residential buildings can bring plenty of benefits to living quality improvements. Thomsen et al. (2016) found that after implementing energy retrofit measures such as new facades, windows, insulation, and photovoltaic installation, the satisfaction rate of temperature, air quality, noise, draught, and indoor climate has been largely increased despite a slight reduction of satisfaction with daylight. Noris et al. (2013) also found that a holistic enhancement of conditions such as comfort, humidity, concentrations of CO₂, and particles resulted from retrofits.

Among the various environmental quality attributes, indoor air quality, ventilation, and thermal comfort have attracted tremendous attention, as shown in Figure 2.6. Vakalis et al. (2021) found that mechanical retrofits of multi-unit residential buildings may save energy and carbon but failed to improve thermal comfort. To effectively improve the thermal comfort of residential buildings in tropical countries such as Malaysia, natural ventilation can be adopted by retrofitting affordable high-density polyethylene (HDPE) nets as roof covers (Tuck et al., 2020). As for indoor air quality after renovation, the results of several studies were negative. Földvary et al. (2017) found that energy

renovation was negatively associated with indoor air quality. Both CO₂ concentrations and formaldehyde (CH₂O) concentrations were considerably higher and air exchange rates were significantly lower in the renovated buildings. Awad and Jung (2021) also found that the average CO₂ and TVOC & CH₂O in several houses, after renovations, failed to meet the World Health Organization's indoor air quality standards. Such poor performance in indoor air quality was due to the replacement of finishing materials. In principle, ventilation can be an effective approach for reducing the adverse effects of renovation on indoor air quality (Földváry et al., 2017; Goodarzi et al., 2023). This kind of ventilation improvement is resulted from the drop in indoor pollutants; for this purpose, continuous mechanical ventilation systems should be installed to ensure the enhancement of indoor air quality (Noris et al., 2013).

2.4.4 Decision-making criteria and methods

Before implementing refurbishment measures for old buildings or demolishing such buildings followed by redeveloping new buildings, multiple factors have to be considered in order to optimize the eventual building performance and the requirements of different stakeholders (Zhuang et al., 2019). The assessment studies serve as scientific references for making rational decisions on residential building renovation projects. This kind of decision making is a complex process as various factors should be taken into consideration (Amorocho and Hartmann, 2022).

To balance the needs of different stakeholders and select optimal options for maximizing the benefits of residential renovation, numerous studies have attempted to develop some decision-making frameworks. A wide variety of decision-making methods have been adopted to build the framework. Multi-criteria decision-making (MCDM) methods such as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy Analytic Hierarchy Process (AHP) and Pareto optimization have been widely adopted. For instance, Amorocho and Hartmann (2022) developed an MCDM framework and integrated a pairwise comparison method with TOPSIS to investigate the standpoints of different stakeholders and the performances of various renovation options. Kamari et al. (2018) developed a hybrid Decision Support System (DSS) that involves renovation indicators including energy consumption, investment cost, and thermal indoor comfort. Besides measuring the trade-off between the criteria by the Pareto-front method, the optimal renovation options were selected through MCDM-based rating methods. The Fuzzy AHP tool, which can be used to set a decision process comprising both qualitative and quantitative elements, was adopted in that study. In the research work of Pombo et al. (2016), Pareto optimization was applied to select the retrofitting solutions with low life cycle environmental impact and financial cost.

In developing decision-making frameworks for residential building renovation, the use of holistic criteria is the basis. Some studies have tried to identify appropriate criteria for building the framework. According to Chandrasekaran and Dvarionienė (2022), the

renovation of residential buildings needs different approaches to reduce energy use and increase buildings' safety, comfort, value, and life span. Jaggs and Palmer (2000) developed a decision-making methodology concerning energy performance, indoor environmental quality, and initial cost. In the study of McGinley et al. (2022), an integrated framework constituted by KPIs including economic, social and environmental was used to assess retrofitting work. Using a metric of weighting factors, Chen et al. (2020) considered key criteria including primary energy reduction, global costs, payback period, carbon emission reduction, and social aspects to represent various stakeholders' views on the selected retrofit combination packages. Alba-Rodríguez et al. (2017) proposed a model that compared the economic and environmental impacts of demolition and new construction against the counterparts of repair and retrofit. By building the model using the two aspects of criteria, they recommended rehabilitation rather than replacing existing buildings with newly constructed buildings. All in all, these studies on identifying comprehensive performance assessment criteria provide opportunities to build more rational decision-making models for selecting optimized renovation options for residential buildings.

2.5 Research gaps and future directions

Through the keyword co-occurrence analysis and the in-depth qualitative review, four hotspots of the research domain were identified. First, a plethora of studies paid attention to energy efficiency and economic assessments of passive energy retrofit

methods, which corroborate the findings in the keyword co-occurrence analysis that keywords including energy efficiency and energy retrofit occurred frequently in this research domain. What was also found in the in-depth review was the close connection between energy retrofit and economic factors. Although keywords related to economic assessments appeared less frequently in the keyword co-occurrence analysis results, economic factors were found frequently exist in the contents of articles, revealing the popularity of economic and financial issues in the research domain. Second, the in-depth qualitative review proves the findings shown in the keyword co-occurrence analysis that LCA is commonly used in the performance assessment of residential building renovation. Also, the detailed review of the articles' contents identified other important assessment tools such as BIM and LCC. Third, the qualitative review revealed that thermal comfort has drawn significant attention and that other housing quality indicators such as indoor air quality and ventilation were widely studied. Last, decision-making, which was not distinctly shown in the keyword co-occurrence map, was found to be prevalent in the contents of the reviewed publications.

Based on the scientometric analysis and qualitative review, five research gaps in performance assessment of residential building renovation were identified. Corresponding to these gaps, future research directions are suggested, as depicted in Figure 2.8. Details of the research gaps and the future directions are elaborated in the following.

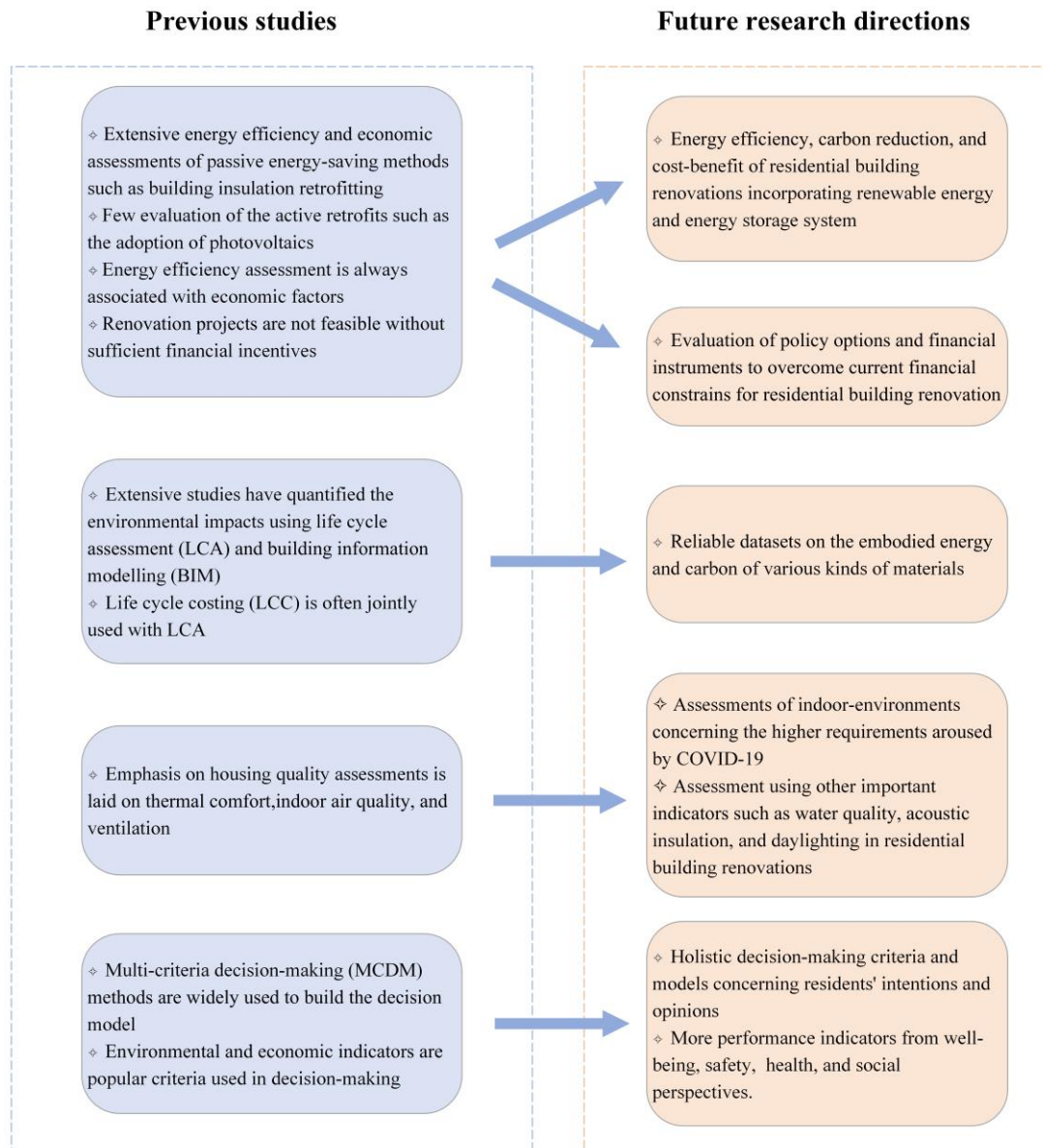


Figure 2.8 Future research directions.

Firstly, as the above findings reveal, passive energy-saving measures like building envelope retrofit can significantly reduce energy use in residential buildings. However, the energy consumption for daily building operations remains to be large and still needs to be improved. Although several studies have investigated the use of photovoltaics as an active energy-saving measure in residential building retrofits, the evaluation of

renewable energy use in residential building renovation is limited as few studies have considered integrating renewable energy technology in building retrofitting (Fina et al., 2019). To improve energy efficiency as well as reduce the associated carbon emissions (Lu and Lai, 2020), the adoption of renewable energy in building renewal warrants further exploration. Additionally, the evaluation of energy storage systems in renovating residential buildings is lacking. Assessing energy efficiency, carbon reduction, and cost-benefit of renewable energy applications and energy storage systems in residential building renovations can provide support for choosing appropriate technologies and measures, thereby helping reach energy self-sufficiency, reduce the dependence on fossil fuels, and promote the sustainable development of the building sector.

Secondly, energy retrofit usually requires a large amount of investment. As the above finding shows, without sufficient financial incentives, renovation projects that fall short in cost benefits are economically infeasible and thus seldom implemented. However, despite the lack of cost-effectiveness, some renovation projects are still desirable because they can generate benefits such as improvements in well-being and sustainability, even though such intangible merits are not readily quantifiable. Therefore, befitting policy instruments for energy retrofit are needed. Having identified the limited studies that investigated the impacts of green retrofit policies (GRPs) on the application of green retrofit technologies (GRTs), Tan et al. (2021) analyzed the relationship between GRPs and GRTs, serving as references for the local government

to develop future policies for promoting green retrofit of ageing residential buildings in Hong Kong. On the basis of financial risk and return, Ahlrichs et al. (2020) adopted the Pareto analysis to evaluate political instruments for the investment in building retrofits. They found that insurance was more effective than subsidies in promoting building retrofits. In addition, the misaligning of interests between the property owner and tenant, which is a significant barrier impeding the development of sustainable renovation of residential buildings in Europe, can be overcome by applying proper policy instruments. Ástmarsson et al. (2013) investigated the effectiveness of tools such as energy performance contracting and energy labelling in addressing the proprietor and tenant dilemma. They found that integrating different tools including legislative transitions, financial incentives and better information dissemination can overcome the dilemma in Denmark. All these studies demonstrate that effective policy or financial instruments are essential for enabling the realization of residential building renovation projects. With the economic recession in the post-COVID period (Asif et al., 2022), finance for renovation projects turns harder and constrains the development of renovation projects. Assessing the effectiveness of previous and potential financial tools and policy incentives for renovation become increasingly important. An eligible financial tool or policy incentive should not only promote the development of renovation projects for individual buildings but also generate benefits to boost the economy at large. Therefore, future studies should put more emphasis on evaluating and selecting appropriate policies or financial instruments to promote energy retrofit and other residential building renovation measures.

Thirdly, as the above findings show, the use of the LCA method is limited by the lack of large data on complex building systems and components. Chen et al. (2022) also pointed out that evaluating the embodied energy and carbon of building materials is challenging due to the lack of reliable data. In particular, comprehensive embodied energy and carbon data of recycled building materials are lacking. To identify cost-effective materials and technologies for renovation and hence evaluation of carbon reduction potential (Zheng and Lai, 2018), proper quantification of carbon emissions is essential. To meet the increasing need of accurate quantification of carbon emissions in residential building renovation, future studies need to strive for establishing reliable datasets of embodied energy and carbon of materials and technologies for residential building renovation projects. Carbon quantification methods such as LCA, process analysis, input-output analysis, or hybrid analysis should be utilized in connection with recognized standards to evaluate the carbon footprint of renovation materials and technologies (Chen et al., 2022).

Fourthly, housing quality assessments were mainly focused on thermal comfort, air quality, and ventilation. Studies incorporating the assessment of these criteria for the indoor environmental quality demand consequent upon the COVID-19 outbreak remain limited. Better ventilation and indoor air quality are essential to prevent the fast sprawling of the COVID-19 virus (Noorimotlagh et al., 2021). The assessment of ventilation and air quality meeting the higher standards for COVID-19 virus prevention,

which can help identify effective indoor environment improvement methods to reduce the infection rate of COVID-19, requires more research to be undertaken (Law et al., 2021). Other important aspects of housing quality such as water quality, noise and daylighting, which are crucial to residents' living experiences, should also be assessed. In aged residential buildings, deteriorated metallic water pipes may generate harmful metal ions. For buildings with thin walls and a lack of soundproof glasses, residents are vulnerable to noise nuisance from neighbors or noise pollution from road traffic. The daylighting of old buildings located in urban villages is extremely poor due to the dense distribution of buildings (Pan and Du, 2020). These severe problems were largely overlooked by previous assessment studies. To optimize the overall housing conditions, more housing quality indicators, such as those assessed under various practical building rating tools (Ascione et al., 2022), should be included in future research on performance assessment of residential building renovation.

Lastly, residents are important stakeholders in residential building renovation but their real needs for housing improvements were largely neglected in previous studies. Decisions on renovation measures must gain permission from homeowners of old residential buildings. In many cases, dilemmas such as interest conflicts between different stakeholders (e.g. landlord, tenants, and governments) are complex issues that prohibit the renovation of ageing residential buildings (Liu et al., 2020). Without a proper evaluation of residents' attitudes toward the renovation measures, biased or arbitrary decisions may occur. For example, in choosing whether to refurbish or

reconstruct an old building, the government may consider a lower cost of refurbishment and the exemption of resident relocation while the residents affected may like to receive compensation for acquiring brand-new building units in the vicinity with better quality and longer life expectancy. Therefore, if not including residents' opinions, the government may make a renovation decision that deviates from the real need of residents. Holistic decision-making models should be developed to appropriately incorporate residents' attitudes for making an optimized decision.

Most of the previous assessment schemes on building renovation only considered the environmental impact or energy aspect. Few have considered other elements such as social factors (Kamaruzzaman et al., 2018). Additionally, occupants' health, well-being, and safety were overlooked. For instance, installations of elevators for old residential buildings are prevalent renewal projects in China (Dai et al., 2022), which is closely related to occupants' well-being and can affect their renovation decisions. In some regions with earthquakes, reinforcement of the structure of ageing residential buildings is attached to great importance by residents. However, energy performance has become the priority of most studies as energy saving and carbon neutrality are highly demanded by countries across the world. While the importance of energy savings should not be ignored, other development goals such as improving people's well-being, safety, health, and social need should also be given sufficient attention.

The above research gaps and the corresponding recommendations for future research

are critical to the prospect of residential building renovation projects. As shown in Figure 2.8, by incorporating renewable energy and energy storage systems, evaluating and selecting policy options and financial incentives, building reliable embodied energy and carbon datasets, assessing water quality, acoustic insulation, and daylighting, holistic decision-making models concerning residents' intentions and including safety, health, well-being, and social indicators, the obstacles that prohibit the sustainable development of residential building renovation projects would be overcome.

2.6 Summary

Given the mounting importance of improving the conditions of ageing residential buildings, renovation measures are in strong need. Appropriate assessments of renovation measures can assist in reaching a more effective decision-making, bringing renovation technology breakthroughs, and enabling better services for occupants. However, there is an absence of review that offers a full picture of these assessment works. Previous research efforts made in this domain remain fragmented. In addressing the research question of this study (i.e. what are the research hotspots and gaps in performance assessment of residential building renovation?), a systematic review of existing literature was conducted. Through the above scientometric analysis and qualitative review of the extant literature, this review has identified four research hotspots and unveiled the research gaps in residential building renovation assessment.

As discovered, the research domain of residential building renovation assessment has attracted notably rising attention in the recent decade and particularly more new studies have emerged in countries such as China and Spain. Within the research domain, energy efficiency, thermal comfort, sustainability, and LCA have been the most popular topics. In assessing energy efficiency, passive energy-saving methods such as building insulation retrofitting attracted the majority of attention. Insufficient financial incentives were found to be prominent obstacles to implementing energy retrofit projects. To promote the sustainability of residential building renovations, extensive studies quantified the environmental impacts using popular tools such as LCA, BIM, and LCC. In housing quality assessments, the focus was mainly on thermal comfort, indoor air quality, and ventilation performance. With regard to developing decision-making frameworks for residential building renovation, MCDM methods (including TOPSIS, Fuzzy AHP and Pareto optimization) and environmental and economic indicators are tools/criteria that are commonly used.

After revealing the research gaps, corresponding research directions for enhancing the performance of residential building renovation have been formulated, namely, (1) incorporating renewable energy and energy storage systems in energy retrofits assessments; (2) evaluating and selecting policy and financial incentives to overcome the renovation obstacles and relieve the economy recession in the post-COVID era; (3) establishing reliable embodied energy and carbon datasets for LCA; (4) assessing indoor environment concerning the new need for COVID-19 prevention and

incorporating more indicators such as water quality, acoustic insulation, and daylighting into living quality assessment; and (5) developing holistic decision-making models that embrace residents' intentions as well as safety, health, well-being and social indicators.

The implications of this review are two-fold. First, the above proposed research directions can serve as guidance for future studies to perfect the performance assessment method or process for residential building renovation. Second, concomitant research outcomes would offer insights for building renovation stakeholders, including property owners, building professionals and building residents. Performance assessment methods, when improved based on such future research, will help decision-makers in evaluating the performance of building renovation. Government bodies and policymakers, too, would benefit from being more able to identify effective policy/financial incentives to address the challenges that constrain the implementation of renovation projects for the ageing residential building stock.

2.7 Topic chosen for the thesis from the systematic literature review

As detailed in Section 2.4.4 and Section 2.5, previous studies demonstrated a narrow decision-making perspective: existing decision-making models and frameworks predominantly focused on indicators such as economic cost, payback period, energy savings, and carbon emissions. There is a lack of attention to social and well-being factors that may be concerned by homeowners. These gaps revealed an incomplete

decision-making framework in residential building renovation.

Having recognized homeowners as pivotal stakeholders whose participation is indispensable for the successful renovation of ageing residential buildings and acknowledged the urgent need to integrate their preferences into renovation initiatives, this study seeks to develop a holistic homeowner decision-making framework for ageing residential building renovations. Inspired by the gaps found in the literature review, this study moves beyond purely economic or technical considerations. The proposed framework integrates multidimensional indicators to better reflect homeowners' priorities. By systematically addressing the gaps, this research aims to enhance resident satisfaction and acceptance rates for residential renovation initiatives. Ultimately, by aligning renovation strategies with homeowner needs, this study contributes to more effective, sustainable, and socially supported urban regeneration, facilitating smoother project implementation and long-term housing quality improvements.

Chapter 3: Methodology

3.1 Introduction

This chapter demonstrates the methodological framework employed in this research. The presentation systematically details each component of the research design, including rigorous approach adopted for homeowner performance indicator identification and consolidation, an importance perception survey of homeowners to identify priority renovation indicators, methods for developing a shortlist of KPIs, FA techniques to examine underlying dimensions, a robust index model development approach incorporating validation procedures, and statistical analyses to investigate the variations of homeowners' importance perceptions of indicators across different demographic and socioeconomic groups.

3.2 Overview of the research process

This study utilized multiple methods to achieve the research objectives. These methods included a systematic literature review, expert interviews, a questionnaire survey, FA and FSE, a validation survey, and a series of statistical analyses. Figure 3.1 illustrates the overall research process.

In the first stage, indicators potentially representing the critical concerns of

homeowners in ageing residential building renovation were identified and extracted from existing literature. Subsequently, these indicators were presented in expert interviews. The experts were facilitated to evaluate their relevance and comprehensiveness as well as suggest exclusions and supplements.

In the second stage, a questionnaire survey was conducted to collect the demographic and socioeconomic information of homeowner participants and ask homeowners to assess the importance of each indicator. After obtaining the survey dataset, the reliability of it was tested using Cronbach's Alpha.

In the third stage, the index model was developed. First, normalization was utilized to shortlist KPIs. Subsequently, FA was applied to group indicators into clusters. Then, the FSE method was employed to construct the homeowner index model for ageing residential buildings. This stage concluded with a thorough validation phase.

In the fourth stage, to examine variations in the importance perceptions of the indicators across demographic and socioeconomic subgroups, a mixed-methods analytical approach was implemented. Initially, the mean ranking analysis was conducted to rank the mean importance ratings of the indicators in each subgroup. Then Intraclass Correlation Coefficient (ICC) was adopted to evaluate whether the mean importance ratings of the 33 indicators are consistent across different subgroups. Afterwards, Kruskal-Wallis test was used to identify statistically significant variations among

different subgroups. Post-hoc Dunn's Test with Bonferroni correction was applied after significant Kruskal-Wallis test results. To complement these quantitative findings and provide deeper contextual understanding, qualitative interviews were conducted to explore the underlying reasons for observed disparities, thereby offering a more nuanced interpretation of the quantitative results.

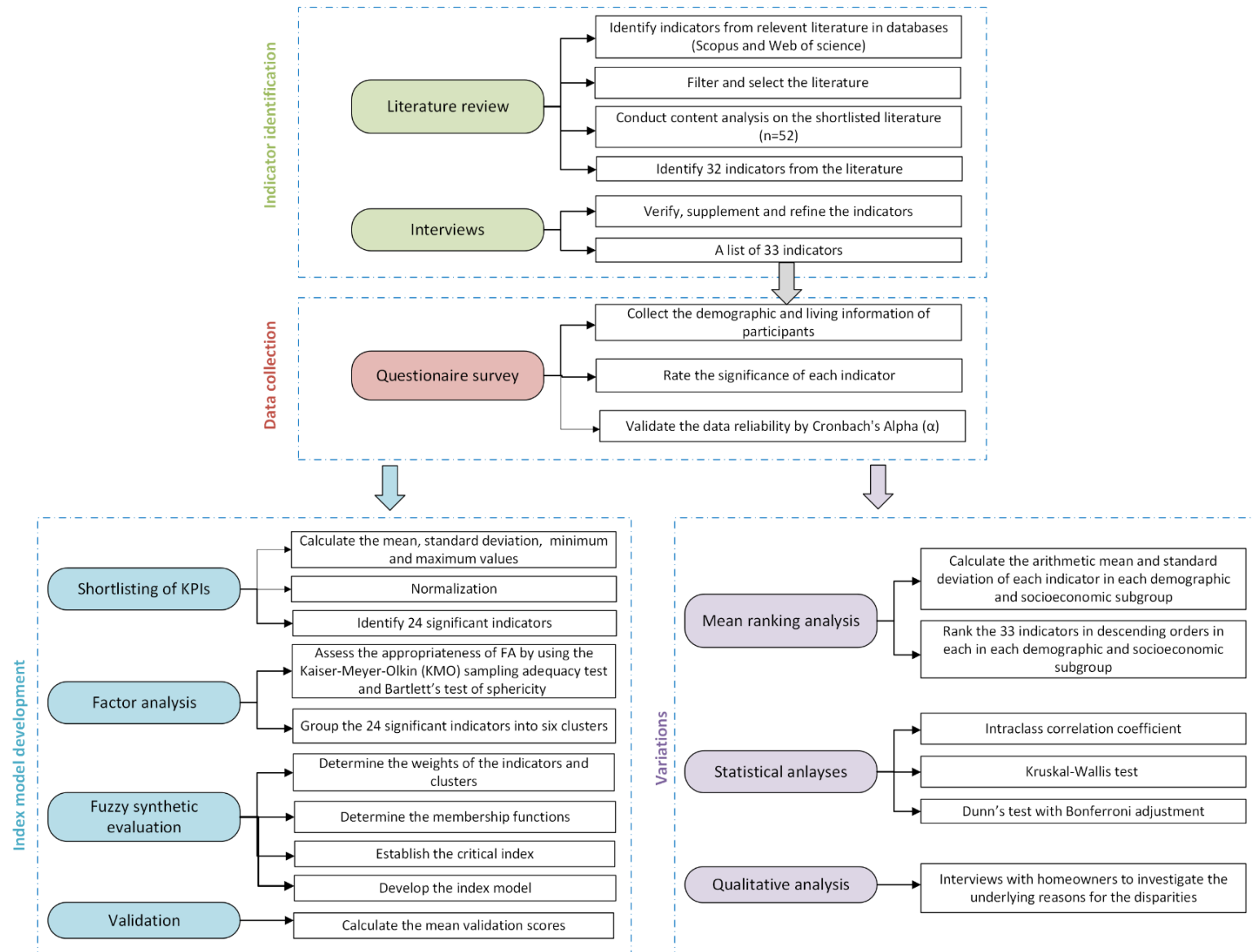


Figure 3.1 Overall research process.

3.3 Performance indicator identification

This study adopted a rigorous mixed-methods approach to identify and validate performance indicators pertinent to homeowners in residential building renovation projects. The research methodology commenced with a comprehensive systematic literature review to establish an initial set of performance indicators derived from existing scholarly work. Building upon this foundational phase, the study then incorporated semi-structured interviews with domain experts to critically evaluate, refine, and adjust the identified indicators. This dual-phase methodological design ensured both academic grounding through the literature review and practical relevance through expert validation, thereby enhancing the robustness and applicability of the final set of performance indicators for residential renovation assessment.

3.3.1 Performance indicator selection from literature

To identify potential performance indicators representing homeowners' preferences in the decision-making of ageing residential buildings renovation in extant literature, this study employed the systematic review method. Systematic review is a review method that employs explicit and systematic approaches to gather and synthesize findings from studies that address a clearly defined question (Page et al., 2021). Systematic review method—Preferred Reporting Items for Systematic Reviews and Meta-Analyses

(PRISMA), which has been adopted by numerous studies (Lu and Lai, 2020), was employed in this study. Adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021), the initial extraction of indicators from the literature was accomplished through four steps:

- Step 1: In the first step, a literature search was conducted utilizing keyword searches in major academic databases including Scopus and Web of Science. Three groups of keywords, including “residential building”, “renovation” and “Indicator”, were combined to search for relevant publications in databases. This search yielded a total of 447 publications, comprising journal articles, conference proceedings, and books (316 from Scopus and 131 from Web of Science).
- Step 2: By restricting the language to English, excluding irrelevant research fields (e.g., physics and astronomy, agricultural and biological sciences, chemical engineering) and removing duplicates, the list was narrowed down to 307 publications.
- Step 3: In the third step, the titles and abstracts of the 307 publications were carefully reviewed to identify literature pertinent to indicator identification. Consequently, 52 publications were selected for detailed review of their contents
- Step 4: After thoroughly reading the full texts of these 52 publications, 32 indicators

deemed potentially significant for homeowners in decision-making regarding residential renovation were extracted.

3.3.2 Semi-structured interviews for indicator validation and supplementation

Subsequently, as a qualitative interview approach suggested by prior studies for refining the performance indicators (Rincón-Moreno et al., 2021), semi-structured interviews were utilized to evaluate the applicability and adaptability of the 32 indicators, as well as to recommend the removal of certain indicators and the inclusion of new ones. In this study, purposive sampling was utilized to recruit participants with expertise in residential building renovation or homeowner-related activities, and the sample size was determined based on the principle of data saturation. Purposive sampling is a sampling method in which specific characteristics are identified to align with the study's objectives (Andrade, 2021; Palinkas et al., 2015). This approach involves selecting individuals or groups who have significant knowledge or experience related to the phenomenon being investigated (Palinkas et al., 2015). Saturation refers to the point in data collection and analysis when additional information results in little or no changes to the codebook. Data saturation is often achieved within the first twelve interviews (Guest et al., 2006). Patton (2014) also suggested that, in the context of expert interviews, a sample size of 5 to 15 participants may be sufficient to reach data

saturation. Therefore, a panel of eleven experts with extensive professional experience in residential renovation and homeowner-related matters participated in the interviews.

This study conducted 11 interviews with experts with significant experience, including three construction project managers, three homeowner representatives, two civil engineers, two facility managers, and a property manager. Their professional backgrounds are shown in Table 3.1. Semi-structured interviews were conducted at convenient times of the experts, and each interview took around 1 to 1.5 hours to complete. At the outset of each interview, the purpose and objectives of the study were clearly explained to the interviewee, followed by asking about the interviewee's personal particulars including work experience. Then, interviewees were presented with the meanings of the 32 indicators. Afterwards, interviewees were asked to assess the applicability of each indicator in terms of their relevance and significance for homeowners, and to suggest any additional indicators considered necessary.

Table 3.1 Backgrounds of experts.

Role	Experiences
Construction project manager	Construction project manager 1 holds approximately 30 years of experience in construction project management and currently serves as Chief Project Manager at a leading Chinese construction enterprise. Construction project manager 2 has over 25 years of practical experience and successfully delivered more than 20 construction projects. Construction project manager 3 has over 15 years of experience.
Homeowner representative	The three homeowner representatives selected for this study each possess substantial professional experience exceeding five years in resident advocacy and housing renovation matters. Their expertise encompasses three key domains: (1) systematic collection and analysis of resident feedback, (2) comprehensive understanding of occupant renovation preferences and requirements, and (3) formal representation of resident interests in consultations with building professionals, including facility managers and renovation practitioners.
Civil engineer	Civil engineer 1 is a China-certified senior engineer with approximately four decades of professional experience in civil engineering practice. Currently serving as director of the design institute at a prestigious Chinese university. Civil engineer 2 is a certified engineering professional in China with over a decade of practical experience in civil engineering design and project execution.
Facility manager	Facility manager 1 is an experienced professional with a decade of specialized work in residential community facility management. Facility manager 2 has over eight years of specialized experience maintaining pre-2000 housing stock.
Property manager	The property manager possesses over seven years of specialized experience managing pre-2000 residential communities in China.

The expert interviews yielded significant refinements to the initial indicator framework:

11 of those indicators identified from the initial literature review were excluded, while

12 new indicators suggested by the experts were added. Ultimately, a final list of 33 performance indicators was determined.

3.4 Importance data collection

3.4.1 Questionnaire survey

Based on the final list of 33 indicators, a questionnaire was devised and subsequently distributed to inhabitants residing in multi-story residential buildings aged over 20 years and located in Sichuan, China. The selection of a 20-year age threshold for dwellings is informed by the Chinese residential renovation policy context (State Council of the People's Republic of China, 2020). The survey has been approved by the PolyU Ethical Review for Teaching/Research Involving Human Subjects (Reference Number: HSEARS20230317006). The questionnaire comprises two sections. The first section gathered respondents' demographic and living information such as age and length of residency. In the second section, the respondents were asked to rate the importance of each of the 33 indicators using a five-point scale (1= extremely unimportant; 2 = unimportant; 3 = neutral; 4 = important; 5 = extremely important).

Non-probability sampling methods, including purposive sampling and snowball sampling, were employed for the questionnaire survey. These two techniques were

utilized in the survey to ensure the inclusion of participants aligning with the study objective and to increase the sample size (Biernacki and Waldorf, 1981; Campbell et al., 2020). Purposive sampling is widely used in research to identify and select cases that are rich in information and relevant to the phenomenon being studied (Palinkas et al., 2015). This method was chosen to ensure that the sample closely aligns with the research aim and objectives, thereby enhancing the study's rigor and the trustworthiness of the data and findings (Campbell et al., 2020). Snowball sampling is a technique that expands the study sample through referrals from individuals who know others with the characteristics of interest (Biernacki and Waldorf, 1981). This method is commonly employed to increase the sample size of homeowners, as evidenced in previous studies (De Wilde, 2019; Horne et al., 2021).

The strength of purposive sampling lies in its ability to identify information-rich cases for in-depth analysis (Nyimbili and Nyimbili, 2024; Suri, 2011). Unlike probability-based sampling, purposive sampling selects participants based on predefined criteria subject to the study purpose, expecting participants to contribute unique and valuable insights (Etikan et al., 2016). Furthermore, as noted by Klar and Leeper (2019), purposive sampling does not employ upon a probability-based survey design for respondent selection, thereby it has no design-based claim to representativeness within a given population. Using purposive sampling, the goal of this study was not statistical generalizability but to select information rich in cases for in-depth analysis that align

with the research objectives. Participants were selected based on predefined traits critical to ensure alignment with the research objectives, specifically targeting homeowners residing in ageing multi-story residential buildings over 20 years old. Given the non-random nature of purposive sampling, the resulting sample was not representative of the broader population. Consistent with prior studies employing small sample sizes for non-parametric tests (Lai et al., 2022; Rześny-Cieplińska et al., 2021), the research sample was not representative due to the use of non-random, purposive sampling; however, this approach is appropriate given the exploratory nature of the study.

To achieve comprehensive population coverage, particularly among internet hard-to-reach demographic groups (e.g., elderly individuals and low-income populations), while ensuring rigorous data quality standards and questionnaire reliability, this study conducted a series of face-to-face and paper-based surveys in residential buildings aged over 20 years. Face-to-face surveys offer several methodological advantages. First, researchers can verify participant eligibility in person, reducing the risk of fraudulent or mismatched responses (Bryman, 2016). Second, this approach facilitates access to hard-to-reach populations, including individuals with limited literacy skills or internet access. Researchers can read questions to participants who experience reading difficulties, thereby promoting inclusive participation (Heerwegh and Loosveldt, 2008). Additionally, face-to-face surveys can yield higher-quality data than web-based surveys

(Heerwegh, 2009). Given the constraint of the time, budget and resources available for this study, during the survey period, over 150 residents were approached in person. After excluding non-homeowner residents, renters and incomplete responses, a total of 94 valid questionnaires from the targeted respondents were taken for the following statistical analyses.

The demographic and socioeconomic characteristics of survey respondents were compared with national statistics to portray homeowners in ageing residential communities. The country's gender distribution, educational attainment levels and income data were sourced from the China Statistical Yearbook (National Bureau of Statistics of China, 2024). National age structure statistics were obtained from World Population Prospects 2024 (United Nations), while family size distributions were derived from the National Bureau of Statistics of China (2024).

3.4.2 Reliability test

The reliability of the collected importance rating data from the survey was assessed through the computation of Cronbach's Alpha (α). Cronbach's alpha, developed by Lee Cronbach, is a measure used to assess the internal consistency of a test or scale (Tavakol and Dennick, 2011), a pivotal procedure that should be conducted prior to employing a test for research or examination to validate its reliability (Tavakol and Dennick, 2011).

This reliability test method has been employed in numerous studies to evaluate the applicability, reliability and consistency of variables and datasets derived from questionnaire surveys (Ameyaw and Chan, 2015; Lai et al., 2022). A value exceeding 0.7 is generally deemed acceptable (Taber, 2018). Hence, this study used the Cronbach's alpha coefficient to assess the reliability and internal consistency of the importance ratings for the 33 indicators obtained from the homeowner questionnaire survey. According to the study of Cronbach (1951), Cronbach's alpha is calculated using Equation (1).

$$\alpha = \frac{k}{k-1} \left(1 - \frac{\sum_{i=1}^k \sigma_i^2}{\sigma_t^2} \right) \quad (1)$$

where k is the number of indicators, σ_i^2 represents the variance of the i th indicator, and σ_t^2 denotes the variance of each homeowner respondent's total scores of 33 indicators.

3.5 Index model development

3.5.1 Shortlist of key importance indicators

The mean, standard deviation, as well as the minimum and maximum values of the importance ratings of the 33 indicators in the questionnaire dataset, were computed

utilizing SPSS version 27. The mean values were applied for the ranking of the importance of the 33 indicators. Afterwards, the normalization technique represented by Equation (2) was applied to identify the crucial indicators. The normalization formula is a mathematical expression utilized to standardize data to a common range, aiding in the evaluation of the relative importance of each indicator in comparison to others. A normalization value equal to or exceeding 0.50 was considered significant (Chan et al., 2018).

$$X_{normalized} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (2)$$

where $X_{normalized}$ is the normalized value, X indicates the original value, X_{max} represents the maximum value, and X_{min} refers to the minimum value.

3.5.2 Factor analysis

FA was conducted using SPSS version 27 to categorize the indicators into different clusters. FA is a statistical method used to consolidate measurable and observable variables into a smaller set of latent variables that are unobservable and with common variance, which is referred to as dimensionality reduction (Yong and Pearce, 2013). This method helps to unveil the factors underlying the indicators that influence homeowners' decision-making in ageing residential building renovations. Before

conducting the FA, two tests were performed to determine the appropriateness of the data for FA, including the Kaiser-Meyer-Olkin (KMO) sampling adequacy test and Bartlett's test of sphericity (Shrestha, 2021; Williams et al., 2010). A higher KMO value ranging from 0.5 to 1 signifies the more appropriateness of FA, while a lower value below 0.5 suggests inadequacy (Shrestha, 2021). Bartlett's test was utilized to verify whether the initial correlation matrix is an identity matrix, which indicates that the variables exhibit no correlation (Shrestha, 2021). A significance level below 0.05 indicates a suitability for FA (Shrestha, 2021; Williams et al., 2010).

3.5.3 Fuzzy synthetic evaluation

FSE, a modelling approach grounded in fuzzy set theory, is designed to quantify multiple evaluations and attributes (Osei-Kyei and Chan, 2017). As noted by Xu et al. (2010), FSE is utilized for multi-criteria decision-making (MCDM), offering a comprehensive evaluation of an object in relation to an objective within a fuzzy decision environment that involves numerous factors. For most MCDM models, it is crucial to assign appropriate weights to criteria, which can be achieved through various methods such as goal programming, the Analytic Hierarchy Process (AHP), the weighted score method, VIKOR and TOPSIS (Odu, 2019). According to Osei-Kyei and Chan (2017), FSE offers a distinct advantage over traditional weighting methods by effectively objectifying and managing the subjective judgments inherent in human

decision-making processes. FSE has been widely applied in diverse research domains to evaluate MCDM problems, including building management (Adegoriola et al., 2024), risk assessment (Ameyaw and Chan, 2015; Xu et al., 2010; Xu et al., 2010) and digital technology (Ameyaw et al., 2017; Chen et al., 2023). Given its ability to handle complex and subjective evaluations, FSE was adopted in this study to quantify the significance of both individual indicators and their respective clusters. The steps taken for using FSE are outlined below (Adegoriola et al., 2024; Ameyaw and Chan, 2015; Chen et al., 2023; Xu et al., 2010; Xu et al., 2010):

1. Create the fundamental set of indicators as: $\Pi = \{IN_1, IN_2, IN_3 \dots IN_i\}$, where IN_i denotes the i_{th} indicator.
2. Establish the set of grading scale alternatives to assess the significance levels of indicators. In this study, a five-point scale was utilized. Hence, the set can be represented as a vector $S = [s_1, s_2, s_3, s_4, s_5]$, where s_1 = extremely unimportant, s_2 = unimportant, s_3 = neutral, s_4 = important, and s_5 = extremely important.
3. Calculate the weight assigned to each indicator, represented by the vector $W = [w_1, w_2, w_3 \dots w_i]$ using Equation (3), where w_i indicates the weighting of the indicator i within a cluster, q denotes the quantity of indicators in a cluster, and M_i represents the mean value of indicator i .

$$w_i = \frac{M_i}{\sum_{i=1}^q M_i} \quad (3)$$

4. Compute the weight of each cluster through Equation (4), where W_c signifies the weighting of the cluster c , M_c is the sum of mean values of all indicators in cluster c , and n denotes the total number of clusters.

$$W_c = \frac{M_c}{\sum_{c=1}^n M_c} \quad (4)$$

5. Define the membership function $MF_i = \{a_{i1}, a_{i2}, a_{i3}, a_{i4}, a_{i5}\}$, where a_{il} is the percentage of the number of grading s_l in the total number of gradings received by indicator i .
6. Determine the fuzzy evaluation matrix $A = [a_{ij}]_{m \times n}$, where a_{ij} is the fuzzy membership item of indicator i to grade j , m is the number of indicators, and n is the number of grading scales (which equals 5).
7. Develop the final evaluation matrix by incorporating the weighting vector W and fuzzy evaluation matrix A using Equation (5), where $\circ$ indicates the fuzzy composition operator.

$$E = W \circ A \quad (5)$$

8. Obtain the critical index CI by normalizing matrix E using Equation (6), where E is the final evaluation matrix and S_n is the n th values of the five-point scale.

$$CI = \sum_{n=1}^5 E \times S_n \quad (6)$$

9. Calculate the coefficients for the index model using Equation (7), where $COEF_c$ is the coefficient of clusters and CI_c is the critical index of clusters.

$$COEF_c = \frac{CI_c}{\sum_{c=1}^6 CI_c} \quad (7)$$

3.5.4 Validation of the index model

To ensure the practical applicability of the index model, the validation was conducted through consultations with professionals. Twelve experts in residential building renovation in China participated in this validation survey. They included four homeowner representatives, three building construction project managers, two civil engineers, two facility managers, and one property manager. Each of these 12 experts has a minimum of five years of experience in residential building renovation projects or in representing homeowners' perspectives. With reference to the validation questions in the study of Adegioriola et al. (2024), five parameters were established to validate the robustness, practical applicability and replicability of the index model. These experts were asked to evaluate the index model developed in this study by assigning scores on a scale from 0 (lowest level) to 10 (highest level) to each of the five parameters under

validation.

3.6 Variations among different demographic and socioeconomic groups

3.6.1 Mean ranking analysis

The arithmetic means and standard deviations of the importance scores of each indicator were calculated across different respondent groups. Indicators with higher importance scores and lower standard deviations were ranked higher. This method was chosen because it effectively represents central tendency and is widely-used to assess the significance of a list of indicators (Ameyaw and Chan, 2015). The analysis was conducted for both the overall group of respondents and within 18 demographic and socioeconomic subgroups.

3.6.2 Intraclass correlation coefficient

This study utilized the intraclass correlation coefficient (ICC) to examine whether the mean importance ratings of the 33 indicators are consistent across different subgroups of homeowners. ICC is a widely-used statistical model for assessing variation among two or more raters evaluating the same group of subjects (Koo and Li, 2016). This

method was chosen because it supports assessments by three or more raters and is suitable for analyzing ordinal data (Gisev et al., 2013). This study measures the degree of agreement among two or more group raters, who are representative of a larger population with similar characteristics. Therefore, following the guidelines of Koo and Li (2016), the 2-way random-effects model with absolute agreement and multiple raters/measurements were selected. Based on the 95% confidence interval of the ICC estimate, values below 0.5 indicate poor interrater reliability, values between 0.75 and 0.9 suggest good reliability, and values greater than 0.90 denote excellent reliability (Koo and Li, 2016). A significance level of 5% was chosen for this analysis and the ICC was calculated using Equations (8) and (9).

$$M_{ij} = \frac{\sum_{n=1}^n R_{ij}}{n} \quad (8)$$

where i represents the i^{th} subgroup, j is the j^{th} indicator, M_{ij} is the mean importance ratings of indicator j in subgroup i , n refers to the number of respondents in subgroup i , and R_{ij} represents the importance rating of indicator j in subgroup i .

$$ICC_f = \frac{MS_R - MS_E}{MS_R + \frac{MS_C - MS_E}{m}} \quad (9)$$

where ICC_f indicates the intraclass correlation coefficient of subgroups under factor f , MS_R is the mean square for rows, MS_E is the mean square for error, MS_C

represents the mean square for columns, and m is the number of indicators.

3.6.3 Kruskal-Wallis test

This study employed the Kruskal-Wallis test to examine whether different independent groups of respondents are identical when precepting the importance ratings of each indicator. The Kruskal-Wallis test, a non-parametric test for comparing samples from two or more groups of independent observations was selected as it is exempted from the normal distribution requirement and can be used for ordinal data (Anderson et al., 2020; Filipiak et al., 2013; McKight and Najab, 2010). The significance level for the Kruskal-Wallis test was set at 0.05. A p-value below 0.05 indicates a statistically significant difference in the importance ratings of the indicator among the different respondent groups being compared. The calculation of the Kruskal-Wallis test statistics H (Hecke, 2012) is shown in Equation (10).

$$H = \left[\frac{12}{N_T(N_T+1)} \sum_{i=1}^g \frac{R_i^2}{n_i} \right] - 3(N_T + 1) \quad (10)$$

where N_T indicates the sum of the numbers of observations in all subgroups, i is the subgroup, g is the number of subgroups, n_i refers to the sample size of subgroup i , and R_i represents the sum of ranks in subgroup i .

3.6.4 Dunn's test

After the Kruskal-Wallis tests, pairwise comparisons were conducted on the respondent groups where significant differences were found. For this purpose, the post-hoc Dunn's test with Bonferroni correction was used to determine whether specific pairs of groups differed significantly in the importance ratings of the performance indicator under investigation. Dunn's test is a non-parametric post-hoc test employed following a significant Kruskal-Wallis result to identify pairwise differences between groups (Agbangba et al., 2024). Since conducting multiple statistical comparisons increases the risk of Type I errors, it is necessary to apply the Bonferroni correction to adjust the p-values (Valaskova et al., 2021). Using the Bonferroni correction, the calculated p-value is multiplied by the number of statistical comparisons being performed. If the Bonferroni adjusted p-value remains below the significance threshold of $\alpha = 0.05$, this indicates that the observed difference between the two groups is statistically significant (Wilson, 2019). According to Dunn (1964), the calculation of Dunn's test statistics is by Equation (11).

$$z_{ij} = \frac{\bar{R}_i - \bar{R}_j}{\sqrt{\frac{N(N+1)}{12} \left(\frac{1}{n_i} + \frac{1}{n_j} \right)}} \quad (11)$$

where $\bar{R}_i$ and $\bar{R}_j$ refer to the mean ranks for group i and j , n_i and n_j indicate the sample sizes of group i and j , and N is the total sample size.

3.6.5 Interviews with homeowners

This study employed an explanatory sequential mixed-methods design to integrate quantitative survey findings with qualitative analyses. Initially, the Kruskal-Wallis test was applied to the quantitative survey data to identify indicators exhibiting significant differences across various demographic and socioeconomic groups. The results of this analysis informed the subsequent qualitative phase by highlighting key indicators that warranted further exploration. Accordingly, in-depth interviews were conducted to elucidate the underlying reasons for the observed differences and to provide comparative insights. Through this approach, the qualitative data served to explain and contextualize the quantitative findings, particularly regarding why certain groups assigned different importance to indicators with significant Kruskal-Wallis test results.

Mixed-methods research benefit from the strengths of both qualitative and quantitative methodologies by integrating these approaches within a single study, thereby enhancing the breadth and depth of understanding of the research (Greene et al., 1989; Johnson et al., 2007). It provides better insights than qualitative or quantitative approaches alone (Palinkas et al., 2015; Wisdom et al., 2012). According to Wisdom et al. (2012), mixed-methods research is particularly effective for analyzing results requiring additional explanation and generalizing exploratory findings. The integration of qualitative analysis complements quantitative findings by elaborating, enhancing, or clarifying the

results from quantitative analysis. Through in-depth interviews with homeowner respondents, this study is able to unveil the underlying reasons for the discrepancies identified in the statistical analysis, thereby enhancing the depth of the study. The qualitative data compensate for the limited statistical representativeness inherent in purposive sampling by yielding richer, more nuanced insights into the phenomenon under investigation.

Qualitative data were collected to investigate the underlying reasons for disparities among different groups of homeowners in their perceptions of various indicators. Eight participants were involved in in-depth semi-structured interviews, a number considered adequate to achieve data saturation (Patton, 2002). These participants were selected from homeowners who had previously participated in a questionnaire survey, ensuring representation from all 18 subgroups. Each interview lasted approximately one to two hours. During the interviews, participants were presented with the indicators that had demonstrated statistically significant differences in the Kruskal-Wallis test. Then, they were asked to articulate the rationale behind their assessments of the importance of these indicators and to discuss the underlying reasons for the differing perceptions of importance among their respective subgroups compared to others. The interviews were conducted face-to-face, and participants' responses were documented through written notes. Subsequently, a thematic analysis was undertaken to identify and synthesize the key insights emerging from the interview data (Akhter, 2022; Riger and Sigurvinsdottir,

2016), thereby providing a deeper understanding of the reasons behind the observed subgroup differences in indicator importance.

Chapter 4: Performance indicators and survey respondents

4.1 Introduction

Through a mixed-methods approach combining systematic literature review and expert interviews, 33 performance indicators potentially concerned by homeowners in ageing residential building renovations were identified. Following this identification phase, a questionnaire survey of 94 homeowners was conducted to assess the perceived importance of these indicators, with the reliability of the resulting importance rating dataset validated through Cronbach's α analysis.

4.2 Performance indicators identified

The systematic literature review initially identified 32 performance indicators relevant to homeowners' decision-making processes regarding ageing residential building renovations. Following expert interviews, 11 indicators collected from literature were considered non-essential and eliminated, while 12 additional indicators were incorporated based on professional recommendations, resulting in a refined set of 33 validated performance indicators. The final indicator list, including detailed definitions and source references, is presented in Table 4.1 and visually summarized in Figure 4.1, while Table 4.2 documents the excluded indicators along with their original sources.

Table 4.1 Identified list of indicators.

Code	Indicators	Sources
IN01	Carbon reduction in the operation stage	(Belpoliti and Bizzarri, 2015; Chen et al., 2020; Daniel and Ghiaus, 2023; Li et al., 2022; McGinley et al., 2022; Risholt et al., 2013; Wang et al., 2022)
IN02	Energy saving in renovated buildings	(Amorocho and Hartmann, 2022; Belpoliti and Bizzarri, 2015; Daniel and Ghiaus, 2023; Galante and Pasetti, 2012; Kadrić et al., 2022; McGinley et al., 2022; Risholt et al., 2013; Zhao et al., 2009)
IN03	Water consumption saved in renovated buildings	(Amorocho and Hartmann, 2022; Juan et al., 2009; Liu and Ping, 2012)
IN04	Costs and expenditures related to the maintenance of building systems and common areas	(Amorocho and Hartmann, 2022)
IN05	Changes in house prices induced by renovation	(Amorocho and Hartmann, 2022; Bisello, 2020; Liu et al., 2022)
IN06	Changes in rentals prompted by the renovation of the dwelling	(Amorocho and Hartmann, 2022)
IN07	Satisfaction with the indoor air quality	(Amorocho and Hartmann, 2022; Beldean-Galea et al., 2020; Broderick et al., 2017; Chen et al., 2020; Juan et al., 2009; Risholt et al., 2013)
IN08	Satisfaction with the building's indoor thermal environment	(Amorocho and Hartmann, 2022; Broderick et al., 2017; Chen et al., 2020; Flamant et al., 2022; Földváry et al., 2015; Juan et al., 2009; Ortiz et al., 2016; Ortiz et al., 2020; Risholt et al., 2013; Serrano-Jiménez et al., 2020)
IN09	Satisfaction with the building's acoustic insulation quality	(Amorocho and Hartmann, 2022; Juan et al., 2009; Liu et al., 2022)
IN10	Satisfaction degree with lighting in the public space of the dwelling	(Acre and Wyckmans, 2014)
IN11	Number of EV charging piles available per resident	(Apostolopoulos et al., 2022)

IN12	The aesthetics of the façade and its surroundings	(Amorocho and Hartmann, 2022; Chen et al., 2020; Risholt et al., 2013)
IN13	The ratio of housing units to the land area occupied by a building	(Acre and Wyckmans, 2014)
IN14	The building's fire safety level	(Juan et al., 2009)
IN15	The building's capacity to withstand and resist forces generated by seismic activity	(Pohoryles et al., 2020)
IN16	The layout and quality of electric wire	(Juan et al., 2009)
IN17	New life experiences and lifestyles	(Liu et al., 2022)
IN18	Residents' perceptions of the social status and prestige conferred by their dwellings	(Liu et al., 2022)
IN19	The total time necessary to complete the renovation	(Amorocho and Hartmann, 2022; Liu et al., 2022; Serrano-Jiménez et al., 2021)
IN20	Disturbances to occupants in renovation process	(Chen et al., 2020)
IN21	Perception of privacy given a specific building spacing	(Acre and Wyckmans, 2014; Mesthrige and Cheung, 2020)
IN22	The ratio of green cover to the land area occupied by the building	Added via interviews
IN23	The lifespan of the building	Added via interviews
IN24	Indoor natural daylighting	Added via interviews
IN25	The standard of the renovated building's tap water quality	Added via interviews
IN26	The ratio of elevators to housing units	Added via interviews
IN27	Residents' satisfaction degree with the renovated building's waterproof quality	Added via interviews
IN28	The potential risk of sewer blockage	Added via interviews
IN29	The ratio of parking spaces to housing units	Added via interviews
IN30	The durability and quality of gas pipelines	Added via interviews
IN31	Pathways designed for emergency evacuation	Added via interviews
IN32	Anti-theft facilities and surveillance coverage	Added via interviews
IN33	The ratio of social space to housing units	Added via interviews

Table 4.2 Removed indicators by expert interviews.

NO.	Indicators	Definition	Sources
1.	Renewable energy	Electricity production capacity of installed renewable energy equipment in buildings	(Amorocho and Hartmann, 2022)
2.	Energy poverty	Proportion of annual energy cost in annual income	(Amorocho and Hartmann, 2022; Bisello, 2020; McGinley et al., 2022)
3.	Radioactivity of building materials	Radioactive intensity of materials used for renovation	(Juan et al., 2009)
4.	Humidity	Indoor moisture content in the air	(Földváry et al., 2015; Serrano-Jiménez et al., 2020; Touceda et al., 2018; Zavadskas et al., 2009)
5.	Convenient walkway	Convenient and barrier-free pedestrian access	(Mesthrige and Cheung, 2020)
6.	Emergency and rescue facilities	Number of emergency and rescue facilities to the households	(Juan et al., 2009)
7.	Flood prevention	Drainage and waterlogging control capacity	(Amini and Memari, 2021)
8.	Structure safety	Level of resisting the forces and loads	(Juan et al., 2009)
9.	Relocation	Whether homeowners can access to their homes during renovation process	(Serrano-Jiménez et al., 2021)
10.	Sense of identity	Improvement of the recognition of surroundings	(Bisello, 2020)
11.	Attractiveness and public image	Public's view toward the attractiveness of the dwelling	(Acre and Wyckmans, 2014)

Performance indicators identified from literature			Performance indicators added through expert interviews	
IN01. Carbon reduction	IN08. Indoor thermal comfort	IN15. Seismic resistance ability	IN22. Green space	IN28. Sewer blockage risk
IN02. Energy saving	IN09. Acoustic comfort	IN16. Electric wire layout	IN23. Building lifespan	IN29. Parking spot
IN03. Water saving	IN10. Public lighting	IN17. New lifestyle	IN24. Indoor natural daylighting	IN30. Gas pipeline safety
IN04. Maintenance cost	IN11. EV charging pile	IN18. Prestige and status	IN25. Water quality	IN31. Escapeway
IN05. House value increment	IN12. Aesthetics	IN19. Construction duration	IN26. Elevator	IN32. Anti-theft and monitoring
IN06. Rental	IN13. Residential density	IN20. Renovation disturbance	IN27. Waterproof	IN33. Social space
IN07. Indoor air quality	IN14. Fire safety	IN21. Privacy		

Figure 4.1 Summary of 33 indicators.

The expert interviews revealed several critical insights regarding performance indicators for residential renovation projects. Experts consistently recommended removing “renewable energy” as an essential indicator, noting that homeowners typically lack sufficient understanding of its benefits in building applications. In contrast, experts emphasized the significance of “green space” improvements, particularly in ageing residential complexes where such spaces are often inadequate. This recommendation aligns with existing research demonstrating green space’s positive correlation with mental and physical health outcomes, including reduced mortality rates, lower heart rates, and decreased violence. More green space can generate positive impacts on improving people’s attention, mood, and physical activities, as well as enhanced attention, emotional well-being and physical activity levels (Kondo et al., 2018). Furthermore, experts identified “lifespan” as a potentially important performance indicator. A longer lifespan not only reflects superior

construction quality and reduced annual embodied energy/carbon (Zhu et al., 2022) but also guarantees residential stability and preserves community relationships, making it a likely priority for homeowners when selecting renovation options.

The experts recommended excluding “energy poverty” from the performance indicators, arguing that this issue has limited relevance for most urban residents in China. However, Wang et al. (2015) indicated that energy availability was poor in the middle region of the Yangtze River, while Lin and Wang (2020) further demonstrated that central China exhibits the nation’s highest energy poverty rates. Although these findings suggest energy poverty remains a critical concern for residents in these specific regions, the expert panel ultimately excluded this indicator from the final list, prioritizing indicators with broader applicability across China’s urban residential sector.

The inclusion of “water quality” as a performance indicator addresses a critical gap in existing residential renovation research, as this factor has been frequently overlooked despite its significant health implications. Experts emphasize that ageing water infrastructure in older dwellings—particularly deteriorating pipes and equipment—often leads to contamination through the leaching of heavy metal ions and proliferation of pathogenic microorganisms (Li et al., 2022). Strategic renovation interventions involving modern water systems with durable materials can substantially improve water quality outcomes. “Indoor natural daylighting” emerges as another vital indicator, especially in densely configured older buildings characterized by limited floor-to-

ceiling heights, small windows, and compromised privacy conditions. According to Jozsef et al. (2009), enhanced daylight exposure is associated with lower infarction rates. Also, Acre and Wyckmans (2014) regarded privacy as a determinant of spatial quality, the improvement of which could increase residents' wellbeing, thereby was paid great attention by residents in redeveloped dwellings (Mesthrige and Cheung, 2020).

The inclusion of “elevator” as a performance indicator addresses a critical oversight in prior refurbishment research, particularly relevant to China's ageing housing stock. According to the experts, many older residential buildings either completely lack elevators (common in multi-story stair-access dwellings) or maintain outdated elevator systems requiring urgent upgrades. This infrastructure deficiency creates substantial mobility challenges, especially for elderly residents—a growing demographic particularly vulnerable to knee osteoarthritis (Iijima et al., 2020), for whom stair climbing and heavy lifting pose significant physical burdens. Experts further identified inadequate parking infrastructure as another critical deficiency in ageing residential buildings, particularly highlighting the shortage of both conventional parking spaces and electric vehicle (EV) charging facilities—a growing concern given rapid EV adoption rates. These parking limitations frequently generate neighborhood conflicts and accessibility challenges in older communities, necessitating urgent intervention. Strategic refurbishment or redevelopment projects present a valuable opportunity to address these issues through spatial reconfiguration and modernization of parking

facilities, which not only resolves immediate functional problems but also enhances property appeal to homeowners by accommodating contemporary mobility needs.

The experts emphasized that “gas pipeline” warrants particular attention as a critical performance indicator, citing numerous recent gas explosion incidents attributable to ageing infrastructure that have heightened resident awareness of pipeline safety. They also indicated the critical importance of “social space”, particularly for facilitating culturally significant communal activities such as mahjong, square dancing, and card games that are deeply embedded in Chinese residential life. This consideration holds special relevance for retired elderly populations, for whom the shared spaces in their dwellings often serve as primary venues for social interaction and community engagement. The experts’ recommendation aligns with the study by Kamaruzzaman et al. (2016), which demonstrates that well-designed public amenities such as refreshment places, recreational facilities and meeting spaces are essential for enhancing a building’s social functionality and contribute to residents’ quality of life. These experts underscore the necessity of incorporating adequate social spaces in residential renovation projects to support the psychosocial wellbeing of ageing residential residents.

4.3 Demographic and socioeconomic characteristics of survey respondents

Table 4.3 presents the demographic and socioeconomic characteristics of the homeowner participants in the questionnaire survey. Among the 94 homeowners surveyed, 57.4% were female and 42.6% were male. The age distribution reveals that the majority of respondents were middle-aged and elderly individuals, with only one-third falling under the age of 45. This demographic distribution aligns with the findings of Li et al. (2021) that the majority of occupants in ageing residential buildings are the older generation. In terms of educational level, 9.6% of the respondents had attained a college-level education, while the majority completed education at the middle school level.

Regarding the annual income, approximately three-quarters of the homeowners earned less than the average annual per capita income level (CNY 49,283) of urban residents in China (NBSC, 2023). Family size distribution indicates a predominance of two to three person households, with diminishing representation in both smaller and larger household configurations. The per capita living space metrics demonstrate that 42.6% of respondents occupying sub-30m² spaces. Overall, a significant proportion of respondents had resided in their current dwellings for more than 20 years. The remarkable longevity of residence (≥ 20 years: 77.7%) indicates profound place attachment within the sample population. These demographic and socioeconomic

backgrounds may influence homeowners' consideration in renovation decision-making.

For instance, according to Poortinga et al. (2004), higher education levels of homeowners are associated with lower energy use. Educational attainment and high income are closely linked to environmental awareness and the propensity to engage in pro-environmental behavior (Ogunbode and Arnold, 2012; Vassileva and Campillo, 2014).

Table 4.3 Respondents' demographic and socioeconomic information.

Characteristics	N	%
<i>Gender</i>		
Female	54	57.4%
Male	40	42.6%
<i>Age (years)</i>		
18–44	32	34.0%
45–59	39	41.5%
60 or above	23	24.5%
<i>Education level</i>		
Primary school or below	9	9.6%
Middle school	76	80.8%
College or above	9	9.6%
<i>Annual income per capita (CNY)</i>		
< 20,000	12	12.8%
20,000–30,000	16	17.0%
30,000–50,000	42	44.7%
50,000–90,000	21	22.3%
≥ 90,000	3	3.2%
<i>Family size</i>		
1	5	5.3%
2	32	34.0%
3	34	36.2%
4	16	17.0%
≥ 5	7	7.5%
<i>Per capita living space (m²)</i>		
< 30	40	42.6%
30–50	38	40.4%
≥ 50	16	17.0%
<i>Residence period in present dwelling (years)</i>		
< 10	7	7.4%
10–20	14	14.9%
≥ 20	73	77.7%

4.4 Reliability test results

Prior to conducting statistical analyses, a comprehensive reliability assessment was performed to evaluate the internal consistency and measurement reliability of the importance ratings assigned to the 33 indicators within the survey data. Cronbach's Alpha (α) was employed as the method for this evaluation. This test is commonly used as a metric to determine the internal consistency and reliability of datasets intended for subsequent analyses. Cronbach's alpha values range from 0 to 1, with a value of 0.7 or higher indicating acceptable internal consistency (Taber, 2018). In this study, the overall Cronbach's Alpha value for the survey dataset is 0.915, indicating that the importance ratings of the 33 indicators in the survey exhibit high internal consistency and reliability. This rigorous reliability assessment represents a critical preliminary step in ensuring the soundness of the dataset before proceeding with more analytical procedures.

4.5 Summary

This chapter began with a systematic literature review identifying 32 initial indicators, which were subsequently refined through expert interviews—resulting in the removal of 11 non-essential indicators and addition of 12 new ones, yielding a final set of 33 validated performance indicators. The expert validation process provided critical insights, particularly emphasizing the importance of homeowner indicators like “green space”, “building lifespan”, “water quality”, “indoor natural daylighting”, and “social

space”, while excluding less universally applicable metrics such as “renewable energy” and “energy poverty”.

A survey of 94 homeowners in ageing residential communities revealed key demographic characteristics: predominantly middle-aged and elderly residents (66.0% aged 45+), with limited higher education (9.6% college-educated) and modest incomes (75% below urban average). Notably, 77.7% of respondents have lived in their homes for over 20 years, indicating strong place attachment. Reliability test demonstrated excellent internal consistency (Cronbach’s $\alpha = 0.915$) for the indicator importance ratings.

The validated set of 33 performance indicators that derived through rigorous development processes including systematic literature review and expert validation, and the importance ratings of these indicators supported by homeowner surveys and robust reliability test results, establishes a statistically sound foundation for subsequent analytical procedures. This comprehensive indicator system provides a reliable basis for both developing the subsequent index model and examining variations in renovation priorities across different demographic and socioeconomic groups.

Chapter 5: Development of an index model for assessing homeowners' preferences in ageing residential building renovation

5.1 Introduction

This chapter presents a structured analysis of KPIs reflecting homeowners' preferences in the ageing residential building renovation. Through a rigorous methodological approach, the study identifies, ranks, and clusters critical indicators. The chapter begins by evaluating 33 initial KPIs, assessing their importance based on mean scores and standard deviations. Normalization techniques are applied to standardize the data, ensuring comparability and facilitating the exclusion of less significant indicators. FA is then employed to categorize the 24 KPIs into six distinct clusters, each representing a key dimension of residential renovation. Subsequently, FSE is used to determine the relative weights of each indicator and cluster, culminating in an index model that quantifies homeowner preferences. Expert validation confirms the model's appropriateness, rationality, and practical applicability. Finally, the discussion highlights the prioritization of different indicators and clusters, reflecting homeowners' underling concerns.

5.2 Shortlisting of KPIs

In Table 5.1, the 33 indicators were ranked based on their mean values, with the indicator having the lowest standard deviation ranking higher if two or more indicators shared the same mean value. The results show that all the indicators scored above 3 on a five-point scale, indicating their relatively high importance level. The top five indicators were IN23, IN15, IN30, IN28 and IN25, with mean values of 4.69, 4.60, 4.55, 4.45 and 4.44, respectively. These top-performing indicators demonstrate mean scores approaching the maximum of 5, suggesting they represent indicators of exceptional importance to respondents. Conversely, the five least significant indicators were IN04 (mean = 3.53), IN19 (mean = 3.73), IN06 (mean = 3.73), IN13 (mean = 3.84), and IN05 (mean = 3.88).

The standard deviation (SD) values, ranging from 0.50 (IN07) to 0.83 (IN19), reflect varying degrees of respondent consensus. Lower SD values indicate stronger agreement among respondents about an indicator's importance, as seen in IN23 (SD=0.51) and IN07 (SD=0.50). Conversely, higher SD values, particularly those exceeding 0.70 (e.g., IN20, IN22, IN19, IN04), suggest substantial higher disagreement or contextual variability in perceived importance.

The normalization of indicator importance ratings enhances the analytical rigor and interpretative clarity. By anchoring the most important indicator (IN23) at 1.00 and the

least important (IN04) at 0.00, this technique transforms raw means into a relative performance scale. For instance, the normalized value of 0.92 for IN15 immediately communicates that it retains 92% of the observed importance range, a more intuitively meaningful representation than its raw mean of 4.60 on a 5-point scale. This proves particularly valuable when integrating these indicators into composite indices or multi-criteria decision models where relative weighting is essential. Consistent with prior research (Osei-Kyei and Chan, 2017), indicators with a normalized value ≥ 0.5 were considered significant and retained for further index model development. As a result, nine indicators with normalized values below this threshold were excluded, reducing the initial 33 indicators to a shortlist of 24 KPIs.

It is noted that certain indicators (IN12, IN26, IN33 and IN01) exhibit high raw importance scores (≥ 4), yet their normalized values fall below 0.5. This discrepancy arises from the normalization process, which converts absolute importance scores into relative importance values. Therefore, although these indicators are individually regarded as important, their relative significance diminishes when all indicators are considered altogether.

Table 5.1 Ranking and descriptive statistics of indicators.

Code	Rank	Mean	SD	Normalized value
IN23	1	4.69	0.51	1.00
IN15	2	4.60	0.54	0.92
IN30	3	4.55	0.52	0.88
IN28	4	4.45	0.60	0.79
IN25	5	4.44	0.67	0.78
IN32	6	4.43	0.70	0.78
IN31	7	4.42	0.65	0.77
IN16	8	4.35	0.65	0.71
IN21	9	4.35	0.70	0.71
IN14	10	4.26	0.53	0.63
IN11	11	4.26	0.64	0.63
IN27	12	4.22	0.61	0.59
IN09	13	4.20	0.67	0.58
IN03	14	4.18	0.53	0.56
IN10	15	4.18	0.67	0.56
IN20	16	4.18	0.79	0.56
IN07	17	4.17	0.50	0.55
IN02	18	4.17	0.56	0.55
IN18	19	4.16	0.57	0.54
IN08	20	4.15	0.60	0.53
IN22	21	4.14	0.80	0.53
IN29	22	4.12	0.64	0.51
IN24	23	4.11	0.60	0.50
IN17	24	4.11	0.66	0.50
IN12	25	4.07	0.63	0.47
IN26	26	4.07	0.68	0.47
IN33	27	4.05	0.68	0.45
IN01	28	4.00	0.62	0.41
IN05	29	3.88	0.64	0.30
IN13	30	3.84	0.71	0.27
IN06	31	3.73	0.71	0.17
IN19	32	3.73	0.83	0.17
IN04	33	3.53	0.81	0.00

5.3 Factor analysis results

FA was conducted to cluster the indicators using the principal component method and varimax rotation. As shown in Table 5.2, the KMO test yielded a value of 0.794, which surpasses the recommended threshold of 0.5, thereby indicating an adequate level of

sample adequacy (Shrestha, 2021). Additionally, Bartlett’s test of sphericity produced a statistic of 1,086.404 with a significance level of 0.000, confirming the suitability of the dataset for FA (Shrestha, 2021).

Table 5.2 KMO and Bartlett’s test results.

KMO and Bartlett’s test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.794
Bartlett’s Test of Sphericity	Approx. Chi-Square	1086.404
	df	276
	Sig.	.000

Table 5.3 shows the outcomes of the FA conducted on the shortlisted 24 indicators, which were grouped into six clusters. This analysis reveals the latent structure of the data, highlighting how various indicators group together based on their shared variances. The six components collectively explain 65.2% of the total variance, with each component exhibiting an eigenvalue greater than 1.0. The factor loadings for all indicators are close to or above 0.50, demonstrating the suitability of the survey data for FA (Osei-Kyei and Chan, 2017).

The 24 KPIs were grouped into six clusters (or component/factors), each labelled according to the KPIs they contain. Cluster 1, containing four indicators related to safety (IN30 to IN32 and IN14) and three pertaining to mental and physical health (IN17, IN10 and IN25), was labelled “safety and health”. Cluster 2 includes four

indicators: “indoor air quality”, “indoor thermal environment”, “indoor natural daylighting” and “acoustic comfort”. As in previous studies (Arif et al., 2016; Juan et al., 2009; Lai and Yik, 2009; Wang et al., 2021), these indicators shed light on the underlying factor of indoor environmental quality and comfort; thus, Cluster 2 was labelled as “indoor comfort”. Cluster 3 was named “facility and infrastructure” as it includes: indicators “parking spots” and “EV charging piles”, which are facilities in buildings; and indicators “waterproof” and “sewer blockage”, which are related to infrastructures. Cluster 4 was labelled “environmental protection and living environment” as indicators “energy saving” and “water saving” are behaviors of environment protection (Si et al., 2022; Wang and Chen, 2010) and indicators “green space” and “renovation disturbances” are associated with occupants’ living environment (Van den Berg et al., 2015). Cluster 5 comprises IN15, which directly involves structural design and engineering performance, along with two planning indicators (IN21 and IN16). Finally, Cluster 6 was labelled “social and sustainability” as it includes IN23 and IN18, which align with the goals of promoting social equity, community well-being and long-term sustainability. The six clusters, which represent the factor components, are designated as follows:

- Cluster 1: Safety and health
- Cluster 2: Indoor comfort
- Cluster 3: Facility and infrastructure
- Cluster 4: Environmental protection and living environment

- Cluster 5: Structure and planning
- Cluster 6: Social and sustainability

Cluster 1 explains 17.579% of the total variance and comprises seven indicators, with IN31 (0.818) and IN32 (0.806) exhibiting the strongest loadings. The high loadings suggest that these indicators are central to the latent construct of safety, encompassing aspects such as escapeway and anti-theft and monitoring. Dominated by IN07 (0.799) and IN09 (0.770), Cluster 2 reflects concerns related to indoor air quality and acoustic comfort. This cluster explains 12.672% of the total variance. Containing four indicators, Cluster 3 explains 10.963% of the total variances. With IN29 and IN11 both loading at 0.792, this cluster reflects concerns about main facilities such as parking spots and EV charging piles. Cluster 4 is led by IN02 (0.787) and IN03 (0.756), signifying the close ties to energy saving and water saving. Cluster 5 explains 7.784% of the total variance, with the IN15 (seismic resistance ability) having the largest factor loading of 0.795. Cluster 6 is the cluster with the smallest variance explained of 5.559%.

It is noted that in the FA, there may be overlapping phenomena among different components or factors. FA is based on the assumption that all indicators have some degree of correlation. It is highly useful to pinpoint the factors underlying the variables by grouping related variables within the same factor (Shrestha, 2021). Therefore, there are some overlaps in the indicators within the clusters. Factor loading represents the strength of the correlation between an indicator and a factor. Each indicator is assigned

a factor loading for each underlying factor (Yong and Pearce, 2013). This suggests that each indicator exhibits varying levels of correlation with each factor. By setting a factor loading threshold (such as 0.5), indicators are grouped into factors (or components) where they exhibit high factor loadings. For instance, the indicator “indoor air quality” is correlated with both the “indoor comfort” and “safety and health” factors. However, its factor loading is significantly higher in “indoor comfort” than in “safety and health”, leading to its classification under the “indoor comfort” factor. Furthermore, some clusters relate to each other. According to Costello and Osborne (2019), although orthogonal rotations like Varimax yield uncorrelated factors, some correlation among factors is expected in the social sciences since behaviors is rarely divided into distinct and independent units.

Table 5.3 Factor analysis results.

Indicators	Components loading					
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Cluster 1 (Safety and health)						
IN31	0.818					
IN32	0.806					
IN17	0.667					
IN30	0.651					
IN10	0.632					
IN14	0.572					
IN25	0.519					
Cluster 2 (Indoor comfort)						
IN07		0.799				
IN09		0.770				
IN08		0.737				
IN24		0.651				
Cluster 3 (Facility and infrastructure)						
IN29			0.792			
IN11			0.792			
IN27			0.610			
IN28			0.554			
Cluster 4 (Environmental protection and living environment)						
IN02				0.787		
IN03				0.756		
IN22				0.723		
IN20				0.497		
Cluster 5 (Structure and planning)						
IN15					0.795	
IN21					0.580	
IN16					0.515	
Cluster 6 (Social and sustainability)						
IN23						0.742
IN18						0.571
Eigenvalue	7.862	2.043	1.642	1.601	1.390	1.113
Variance explained (%)	17.579	12.672	10.963	10.659	7.784	5.559
Cumulative variance explained (%)	17.579	30.251	41.214	51.873	59.656	65.216

5.4 Fuzzy synthetic evaluation results

5.4.1 Weights of indicators and clusters

The mean value of each indicator was utilized to determine its relative weight within the cluster and the weight of the cluster. The weight allocated to each indicator was calculated using Equation (3), where the mean value of the indicator was divided by the sum of the mean values of all indicators within the corresponding cluster. For instance, the weight of indicator IN31 “pathways designed for emergency evacuation” in cluster 1 “safety and health” was calculated using the following method:

$$\begin{aligned} W_{i31} &= \frac{4.42}{4.42 + 4.43 + 4.11 + 4.55 + 4.18 + 4.26 + 4.44} \\ &= \frac{4.42}{30.39} = 0.15 \end{aligned}$$

The weight allocated to each cluster was computed using Equation (4), which involved dividing the sum of the means of all indicators within a cluster by the sum of the total means of all clusters. For instance, the weight of cluster 1 “safety and health” was calculated using the following method:

$$\begin{aligned} W_{c1} &= \frac{30.39}{30.39 + 16.63 + 17.05 + 16.67 + 13.30 + 8.85} \\ &= \frac{30.39}{30.39} = 0.30 \end{aligned}$$

Following these processes, the weights of the 24 indicators and six clusters are obtained and presented in Table 5.4.

Table 5.4 Weights of indicators and clusters.

Code	Indicators	Mean	Weights	Total mean of clusters	Weights of clusters
Cluster 1: Safety and health				30.39	0.30
IN31	Pathways designed for emergency evacuation	4.42	0.15		
IN32	Anti-theft facilities and surveillance coverage	4.43	0.15		
IN17	New life experiences and lifestyles	4.11	0.14		
IN30	The durability and quality of gas pipelines	4.55	0.15		
IN10	Satisfaction degree with lighting in the public space of the dwelling	4.18	0.14		
IN14	The building's fire safety level	4.26	0.14		
IN25	The standard of the renovated building's tap water quality	4.44	0.15		
Cluster 2: Indoor comfort				16.63	0.16
IN07	Satisfaction with the indoor air quality	4.17	0.25		
IN09	Satisfaction with the building's acoustic insulation quality	4.20	0.25		
IN08	Satisfaction with the building's indoor thermal environment	4.15	0.25		
IN24	Indoor natural daylighting	4.11	0.25		
Cluster 3: Facility and infrastructure				17.05	0.17
IN29	The ratio of parking spaces to housing units	4.12	0.24		
IN11	Number of charging piles available per resident	4.26	0.25		
IN27	Residents' satisfaction degree with the renovated building's waterproof quality	4.22	0.25		
IN28	The potential risk of sewer blockage	4.45	0.26		
Cluster 4: Environmental protection and living environment				16.67	0.16
IN02	Energy saving in renovated buildings	4.17	0.25		
IN03	Water consumption saved in renovated buildings	4.18	0.25		
IN22	The ratio of green cover to the land area occupied by the building	4.14	0.25		
IN20	Disturbances to occupants in renovation process	4.18	0.25		
Cluster 5: Structure and planning				13.30	0.13
IN15	The building's capacity to withstand and resist forces generated by seismic activity	4.60	0.35		
IN21	Perception of privacy given a specific building spacing	4.35	0.33		
IN16	The layout and quality of electrical wire	4.35	0.33		
Cluster 6: Social and sustainability				8.85	0.09
IN23	The lifespan of the building	4.69	0.53		
IN18	Residents' perceptions of the social status and prestige conferred by their dwellings	4.16	0.47		

5.4.2 Membership functions

The determination of membership functions for a specific indicator relies on the significance ratings provided by homeowners in the questionnaire survey. For example, the survey findings unveiled that the participants assessed IN31 with 0% for extremely unimportant, 1% for unimportant, 5% for neutral, 45% for important, and 49% for extremely important. Hence, the membership functions for IN31 can be defined as $\{0.00, 0.01, 0.05, 0.45, 0.49\}$. In this manner, the membership functions for all the 24 indicators were generated and are presented in Table 5.5. The membership functions for the clusters, which were derived using Equation (5). For example, the membership function for cluster 1 is calculated as follows:

$$MFC_1 = [0.15 \quad 0.15 \quad 0.14 \quad 0.15 \quad 0.14 \quad 0.14 \quad 0.15] \times$$

$$\begin{bmatrix} 0.00 & 0.01 & 0.05 & 0.45 & 0.49 \\ 0.00 & 0.02 & 0.05 & 0.40 & 0.52 \\ 0.00 & 0.02 & 0.11 & 0.62 & 0.26 \\ 0.00 & 0.00 & 0.01 & 0.43 & 0.56 \\ 0.01 & 0.00 & 0.09 & 0.61 & 0.30 \\ 0.00 & 0.00 & 0.04 & 0.66 & 0.30 \\ 0.01 & 0.00 & 0.03 & 0.46 & 0.50 \end{bmatrix}$$

$$MFC_1 = [0.00 \quad 0.01 \quad 0.05 \quad 0.51 \quad 0.42]$$

Following this process, the membership functions for remaining clusters are obtained and shown in Table 5.5.

5.4.3 Establishment of critical index

The critical index was calculated using Equation (6), where the membership functions of each cluster were multiplied by their corresponding values of the five-point scale and then aggregated. For instance, the critical index for cluster 1 is calculated as follows:

$$CIC_1 = 0.00 \times 1 + 0.01 \times 2 + 0.05 \times 3 + 0.51 \times 4 + 0.42 \times 5 = 4.344$$

Following the calculation process, the critical index of other five clusters are obtained and the results are shown in Table 5.5. The ranking of clusters based on their critical indices is as follows: Social and sustainability (Cluster 6) > Structure and planning (Cluster 5) > Safety and health (Cluster 1) > Facility and infrastructure (Cluster 3) > Environmental protection and living environment (Cluster 4) > Indoor comfort (Cluster 2). The overall membership function and critical index are calculated as follows:

$$MF_{overall} = [0.30 \quad 0.16 \quad 0.17 \quad 0.16 \quad 0.13 \quad 0.09]$$

$$\times \begin{bmatrix} 0.00 & 0.01 & 0.05 & 0.51 & 0.42 \\ 0.00 & 0.00 & 0.10 & 0.63 & 0.26 \\ 0.00 & 0.01 & 0.08 & 0.55 & 0.36 \\ 0.01 & 0.00 & 0.12 & 0.56 & 0.31 \\ 0.00 & 0.00 & 0.05 & 0.44 & 0.50 \\ 0.00 & 0.00 & 0.06 & 0.45 & 0.50 \end{bmatrix}$$

$$MF_{overall} = [0.00 \quad 0.01 \quad 0.08 \quad 0.53 \quad 0.38]$$

$$CI_{overall} = 0.00 \times 1 + 0.01 \times 2 + 0.08 \times 3 + 0.53 \times 4 + 0.38 \times 5 = 4.292$$

Table 5.5 Membership functions of indicators and clusters.

Code	Weights	Membership function of indicators					Membership function of clusters					Critical index
		1	2	3	4	5	1	2	3	4	5	
Cluster 1	0.30						0.00	0.01	0.05	0.51	0.42	4.344
IN31	0.15	0.00	0.01	0.05	0.45	0.49						
IN32	0.15	0.00	0.02	0.05	0.40	0.52						
IN17	0.14	0.00	0.02	0.11	0.62	0.26						
IN30	0.15	0.00	0.00	0.01	0.43	0.56						
IN10	0.14	0.01	0.00	0.09	0.61	0.30						
IN14	0.14	0.00	0.00	0.04	0.66	0.30						
IN25	0.15	0.01	0.00	0.03	0.46	0.50						
Cluster 2	0.16						0.00	0.00	0.10	0.63	0.26	4.157
IN07	0.25	0.00	0.00	0.05	0.72	0.22						
IN09	0.25	0.00	0.00	0.14	0.52	0.34						
IN08	0.25	0.00	0.01	0.09	0.65	0.26						
IN24	0.25	0.00	0.00	0.13	0.64	0.23						
Cluster 3	0.17						0.00	0.01	0.08	0.55	0.36	4.264
IN29	0.24	0.00	0.01	0.12	0.62	0.26						
IN11	0.25	0.00	0.01	0.07	0.56	0.35						
IN27	0.25	0.00	0.00	0.10	0.59	0.32						
IN28	0.26	0.00	0.00	0.05	0.45	0.50						
Cluster 4	0.16						0.01	0.00	0.12	0.56	0.31	4.168
IN02	0.25	0.00	0.00	0.09	0.66	0.26						
IN03	0.25	0.00	0.00	0.06	0.69	0.24						
IN22	0.25	0.02	0.00	0.13	0.52	0.33						
IN20	0.25	0.00	0.01	0.20	0.38	0.40						
Cluster 5	0.13						0.00	0.00	0.05	0.44	0.50	4.436
IN15	0.35	0.00	0.00	0.02	0.36	0.62						
IN21	0.33	0.00	0.01	0.10	0.43	0.47						
IN16	0.33	0.01	0.00	0.03	0.54	0.41						
Cluster 6	0.09						0.00	0.00	0.06	0.45	0.50	4.441
IN23	0.53	0.00	0.00	0.02	0.27	0.71						
IN18	0.47	0.00	0.00	0.10	0.65	0.26						

A higher index reflects the greater criticality of the respective cluster. The significance of the critical indices of clusters was evaluated based on the five-point scale, as shown in Table 5.6. Notably, the critical index values of all the six clusters exceeded 4, indicating that they are highly critical

Table 5.6 Critical index and significance rating of the clusters.

No.	Cluster	Coefficient	Critical index	Significance rating
Cluster 1	Safety and health	0.168	4.344	Highly critical
Cluster 2	Indoor comfort	0.161	4.157	Highly critical
Cluster 3	Facility and infrastructure	0.165	4.264	Highly critical
Cluster 4	Environmental protection and living environment	0.161	4.168	Highly critical
Cluster 5	Structure and planning	0.172	4.436	Highly critical
Cluster 6	Social and sustainability	0.172	4.441	Highly critical
Overall			4.292	Highly critical

5.4.4 Establishment of the index model

The index model was developed using a linear additive approach. The normalized critical indices of the six clusters, which serve as the coefficients of these clusters, were calculated using Equation (7), and the results are summarized in Table 5.6. By combining these cluster coefficients with the weighted indicators identified within each cluster, the index model for evaluating the homeowners' preferences *IMHP* was established, as represented by the following Equation (12) and illustrated in Figure 5.1.

$$IMHP = (0.168 \times \text{Safety and health}) + (0.161 \times \text{Indoor comfort}) + (0.165 \times \text{Facility and infrastructure}) + (0.161 \times \text{Environmental protection and living environment}) + (0.172 \times \text{Structure and planning}) + (0.172 \times \text{Social and sustainability}) \quad (12)$$

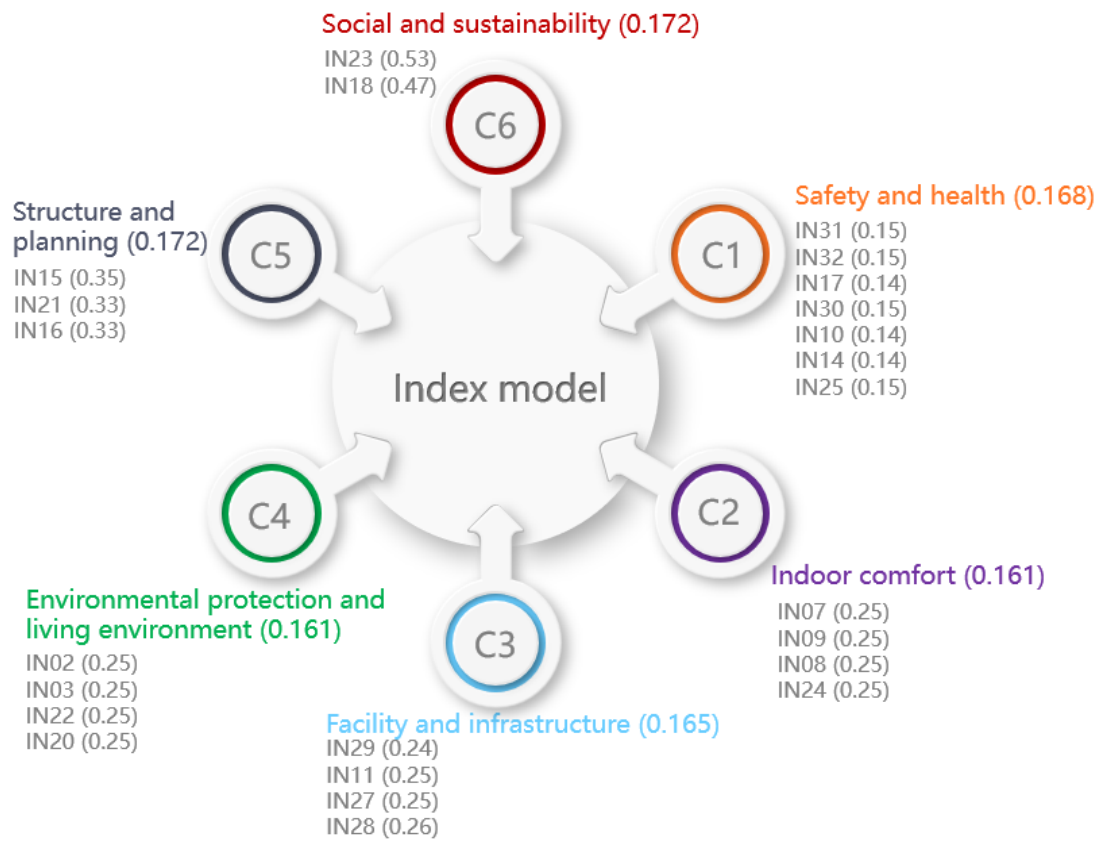


Figure 5.1 Homeowner index model.

5.4.5 Validation results

The mean values of the five evaluation parameters rated by the experts in the validation survey are displayed in Table 5.7. In this survey, the scale for rating the model's attributes such as appropriateness, rationality, practicality and replicability is from "0"

(the lowest level) to “10” (the highest level). The mean scores of the attributes were found to be between 7.42 and 8.67, with an overall average of 7.92. Hence, it can be inferred that the experts generally agreed that the proposed index model is suitable and practical for assessing homeowners’ preferences in building renovation projects.

Table 5.7 Validation of the attributes of the index model.

No.	Attribute	Mean score	SD
1	The model employs a five-point scale, which is appropriate for this context.	8.67	0.78
2	The clustering of the indicators is rational.	7.75	0.87
3	The indicators within each cluster are suitable.	7.42	1.00
4	The index model is a practical tool for stakeholders involved in residential building renovation projects to evaluate homeowners’ preferences.	8.08	0.90
5	The methodology utilized in this study can be easily replicated in other cases.	7.67	0.89

5.5 Interpretation of clusters

The 24 indicators included in the index model are KPIs that can be utilized to assess homeowner preferences regarding the renovation of ageing residential buildings. FA indicated that these 24 KPIs could be grouped into six underlying clusters. The social and sustainability cluster records the highest critical index value (4.441), followed by structure and planning (4.436), safety and health (4.344), facility and infrastructure (4.264), environmental protection and living environment (4.168), and indoor comfort (4.157). The discussion and interpretation of these six clusters are as follows.

5.5.1 Safety and health

Cluster 1 comprises seven KPIs, and its high criticality index (4.344) highlights the vital role of the safety and health factor. The importance of this cluster echoes several previous studies (Evans et al., 2003; Krieger and Higgins, 2002; Shaw, 2004), which shows that housing conditions are related to diverse health conditions. Public health has been deeply engaged in housing issues. Tackling housing issues provides public health professionals with a critical opportunity to intervene in a key social determinant of health. Cluster 1 also confirms the study of Yau et al. (2008), which asserts that safety is a fundamental prerequisite for health and highlights the strong correlation between the quality of the built environment and human safety. However, the perceived significance of safety issues among homeowners contrasts with the findings of Al-Homoud and Khan (2004) that a majority of residents were largely unaware of numerous safety issues in their homes.

Within this cluster, the durability and quality of gas pipelines (IN30) carries the highest mean value of 4.55, indicating its critical importance. The ageing of gas pipelines has emerged as a significant issue, particularly in older residential areas, as evidenced by various gas pipeline explosions in recent years (Xu et al., 2024). The deterioration of pipelines is primarily attributed to ageing infrastructure and corrosion defects (Velázquez et al., 2022). Poor-quality pipelines and connections have been directly linked to higher rates of pipeline safety incidents (Scott and Scott, 2019). Homeowners

in the sample have shown an awareness of the importance of selecting optimal renovation methods to upgrade to safer gas pipeline systems. However, prior studies often overlooked the significance of gas pipelines, focusing instead on other safety criteria such as fire alarms and evacuation protocols (Juan et al., 2009). This unveils an underestimation of the critical role gas pipelines can play in ensuring residential safety through renovation and implies the need to integrate health and safety indicators, such as IN30, into a proper renovation decision-making process.

5.5.2 Indoor comfort

With a critical index of 4.157, this cluster contains four indicators representing various dimensions of indoor comfort. The significance of this cluster aligns with a notable body of prior research (Amorocho and Hartmann, 2022; Beldean-Galea et al., 2020; Broderick et al., 2017; Chen et al., 2020; Flamant et al., 2022; Földváy et al., 2015; Juan et al., 2009; Liu et al., 2022; Ortiz et al., 2016; Ortiz et al., 2020; Risholt et al., 2013; Serrano-Jiménez et al., 2020), which has consistently identified indoor comfort as a critical factor in residential building renovation. This finding corroborates the study by Ortiz et al. (2020), which highlighted that thermal discomfort in ageing residential dwellings has long been a pressing issue. Indoor air quality is strongly linked to residents' satisfaction with their living environment and health outcomes. According to Wang et al. (2021), given the considerable amount of time individuals spend indoors, the quality of the indoor environment profoundly affects occupants' cognitive functions,

thereby affecting their learning and work performance. Accordingly, as Arif et al. (2016) emphasized, it is important for designers and engineers to take into account a comprehensive range of indoor comfort factors, including thermal, visual and acoustic comfort, to ensure the well-being of occupants. However, in previous studies that compared the refurbishment versus redeployment strategies (Gaspar and Santos, 2015; Power, 2008; Schwartz et al., 2018, 2022), the indoor comfort factor was overlooked, resulting in the lack of a comprehensive and credible decision-making process.

5.5.3 Facility and infrastructure

This cluster has a critical index of 4.264 and includes four indicators reflecting the significance of facility and infrastructure. This finding corroborates an earlier study by Ukoha and Beamish (1997), which asserted that the availability of facilities and services within housing units plays a crucial role in determining resident satisfaction. Notably, indicator IN11 highlights the growing significance of electric vehicle (EV) charging facilities—a point supported by Apostolopoulos et al. (2022), who recognized the importance of integrating EV charging infrastructure into residential building retrofitting projects. According to Blonsky et al. (2021), the global market share of EVs in new car sales is projected to rise significantly, from 2.7% in 2020 to 28% by 2030. Meanwhile, the majority of EV charging facilities are installed at home due to convenience and cost-effectiveness. Hence, the increasing adoption of EVs has led to a corresponding surge in demand for residential charging infrastructure (Sørensen et al.,

2021). Gong et al. (2020) also noted that residential areas, as the primary locations for parking and charging, play a pivotal role in meeting EV charging demands. However, they emphasized that many older residential areas lacked adequate planning for EV charging needs. Renovating ageing residential buildings presents a valuable opportunity to redesign public spaces to accommodate additional EV charging facilities. To address this, designers and planners are advised to ensure the provision of sufficient EV charging infrastructure based on factors such as number of households and projected EV ownership rates in the renovated buildings.

5.5.4 Environmental protection and living environment

With a critical index of 4.168, this cluster covers four key indicators related to environmental protection and living environment. Consistent with prior research that compared redevelopment versus refurbishment (Gaspar and Santos, 2015), the “energy saving” indicator (IN02) within this cluster was identified as a significant factor in decision-making. This indicator reflects a mutual goal between homeowners and governments. For governments, energy saving is critical for addressing the global energy crisis and achieving carbon neutrality goals (Chen et al., 2024). For homeowners, their energy saving preference is often motivated by dual considerations. On the one hand, they are driven by the potential expense reduction associated with energy savings. However, this kind of perception can vary among homeowners due to differences in cost sensitivity. Martinsson et al. (2011) found that occupants’ energy-saving behaviors

are influenced by socioeconomic factors such as age and income. Those with less economic resources are more motivated to reduce their energy expenditure. On the other hand, homeowners' concern of energy saving may also root in their environmental awareness. Yet, this awareness can differ significantly among individuals based on their demographic or socioeconomic backgrounds. Vassileva and Campillo (2014) observed that in high-income countries like Sweden, energy conservation behaviors are primarily driven by environmental awareness. Whereas environmental attitudes have a relatively minor influence on energy-saving behaviors of low-income households, this may also explain why the "carbon reduction" indicator (IN01) is considered less important by homeowners in this study, which contrasts with previous studies that emphasize the significance of carbon emissions in refurbishment or redevelopment decisions (Schwartz et al., 2018, 2022). Unlike energy saving, carbon mitigation may not provide direct cost-saving benefits to individual homeowners. Since a large proportion of the homeowners sampled are low-income individuals who may have relatively low levels of environmental awareness, carbon reduction is perceived as significantly less important than energy saving (see Table 5.1). Therefore, it is suggested that in future decision-making processes for ageing residential building renovations, the relative importance of energy saving over carbon emissions could be increased to better align with homeowners' preferences and priorities.

5.5.5 Structure and planning

Ranked second with a high critical index of 4.436, this cluster contains three indicators reflecting the significance of structure and planning. Indicator IN15 within this cluster, which evaluates the seismic resistance of buildings, has achieved the second-highest mean score of 4.60. This finding aligns with the research of Pohoryles et al. (2020), which suggested that building stock is ageing and requires significant renovation efforts to improve its energy performance and ensure structural safety. Pohoryles et al. (2022) further highlighted the importance of both seismic and energy performances, suggesting the integration of them in the retrofitting of existing buildings. By accounting for energy costs and expenses related to structural damage, a combined retrofitting approach significantly reduces payback periods, particularly in regions with moderate to high seismic activities (Pohoryles et al., 2020). China, with its predominantly mountainous terrain, is prone to frequent natural and geological disasters, particularly earthquakes. These seismic events, among the most severe and deadly incidents, can significantly influence regional economic development and impede the enhancement of residents' livelihoods and well-being (Zeng et al., 2021). Recent earthquakes have resulted in substantial economic losses, severe injuries and fatalities, largely due to the vulnerability of older buildings constructed without adherence to modern safety standards (Gkournelos et al., 2021; Pohoryles et al., 2022). Therefore, addressing seismic risks needs to be a priority in the development of long-term building renovation strategies. As noted by Gkournelos et al. (2021), extending the lifespan of existing

buildings should include seismic upgrades, especially in earthquake-prone regions. However, previous studies comparing refurbishment and redevelopment options have largely overlooked the critical aspect of seismic performance (Gaspar and Santos, 2015; Power, 2008; Schwartz et al., 2018, 2022). It is recommended that future decision-makers prioritize renovation strategies that optimize seismic resistance ability, especially for ageing residential buildings located in seismic zones.

5.5.6 Social and sustainability

This cluster has the highest critical index (4.441) and comprises two indicators that reflect the significance of considering social and sustainability factors in renovation decision-making. The findings support the perspectives of Schwartz et al. (2022) and Power (2008): social factors play a crucial role in decisions between refurbishment and redevelopment. The indicator IN23, which measures the lifespan of buildings, holds the highest priority among all the indicators, demonstrating homeowners' strong preference for extending the durability and longevity of their renovated residences. Through a comparative case study that analyzed refurbishment versus new construction, Palacios-Munoz et al. (2019) estimated building lifespans based on structural durability, revealing that new buildings can have lifespans more than six times longer than the refurbished ones. This study also pointed out that longer lifespans correlate with reduced environmental impacts. When taking lifespan into consideration, demolition and new construction were found to outperform refurbishment in terms of lower carbon

emissions in the long term. This finding contrasts sharply with earlier studies (Gaspar and Santos, 2015; Power, 2008; Schwartz et al., 2022), which concluded that refurbishment had a lower carbon footprint compared to redevelopment. Additionally, Ross et al. (2000) emphasized that low residential turnover can increase social integration and a stable living environment contributes positively to community well-being. Homeowners' aspirations for longer building lifespans can contribute to a more stable living environment, enhancing community well-being by ensuring safe, secure and comfortable residential conditions. Another indicator IN18 sheds light on the importance of prestige and status, aligning with the study of Liu et al. (2022). According to Evans et al. (2003), poor-quality housing may trigger feelings of shame and low status, whereas high-quality housing improves self-esteem and social prestige. Residents who previously lived in deteriorating or low-quality housing conditions can achieve enhanced social prestige and status through the renovation of their dwellings. This improvement may help narrow the social gap between them and those living in modern, new residential buildings, thereby promoting greater social equity.

5.6 Implications for residential renovation strategies

The index model and rankings of the 24 KPIs have significant practical implications for decision-making in residential renovation. Apart from benefiting homeowners and improving their satisfaction with the renovation, the application of the model can also benefit a wide range of stakeholders. These include policymakers, developers, urban

planners, industry professionals and construction contractors, who can leverage the model to inform and optimize their practices.

First, the shortlisted 24 KPIs and six clusters, along with their critical indices, serve as a valuable tool for pinpointing key areas of concern (e.g., safety, health, social) in ageing dwellings. Policymakers can utilize this tool to formulate targeted policies to address these issues. Additionally, they can incorporate the KPIs into building codes and regulations to ensure that renovation projects align with homeowners' expectations and meet established standards. The model also enables the development of tailored communication strategies that emphasize the renovation benefits most valued by homeowners, thereby promoting support and cooperation. For architects and engineers, the model serves as a guide to prioritize essential factors such as safety, durability and energy efficiency during the design process. Urban planners can refer to the KPIs to optimize residential area planning, ultimately enhancing residents' quality of life. Furthermore, the rankings of the KPIs facilitate the effective allocation of resources and budgets, ensuring that the most critical needs of homeowners are prioritized and addressed.

Second, the model serves as a practical and reliable framework for assessing the performances of residential building renovation projects. Policymakers can utilize the constituent indicators of this index model to monitor and track the progress and outcomes of residential renovation initiatives over time. Similarly, developers can

employ these indicators as benchmark elements to assess the performance of their renovated buildings and identify significant opportunities for future enhancements, focusing on renovation features that align with homeowner preferences. This approach can help developers win more support from homeowners in future renovation projects.

Third, the comprehensive KPIs, along with their critical indices, can be incorporated into the decision-making model for evaluating residential renovation. This integration enables an inclusive evaluation of renovation options, allowing for the consideration of trade-offs and the identification of synergies. As a result, it assists policymakers and stakeholders in making more optimal, holistic and well-informed decisions. For instance, integrated retrofitting strategies that address both seismic and energy efficiency improvements can be more cost-effective (Pohoryles et al., 2022). Therefore, incorporating these critical indicators into the decision-making model would promote more rational and comprehensive evaluations, ultimately leading to optimal renovation choices.

5.7 Summary

In this chapter, 24 KPIs reflecting homeowners' preferences in the ageing residential building renovation decision-making were identified and then categorized into six clusters to determine their significance levels. The mean importance ranking results unveiled that the highest-priority indicator for homeowners is “building lifespan”,

followed by “seismic resistance capability” and “the durability and quality of gas pipelines”. Using the FSE, a homeowner index model was developed, with the weight of each indicator and cluster determined. The result revealed that the social and sustainability cluster as the most important (critical index = 4.441), with the structure and planning cluster ranking second, and the safety and health cluster ranking third. This chapter provides valuable evidence for stakeholders, policymakers, and practitioners in the decision-making of residential building renovation with concerns on homeowners’ perceptions. The index model developed in this chapter can serve as a foundation for future residential renovation decision-making studies.

Chapter 6: Homeowners' priorities in residential building renovation: The role of demographic and socioeconomic factors

6.1 Introduction

This chapter addresses the research gaps concerning the lack of consideration of the disparities in homeowners' renovation decision priorities among various demographic and socioeconomic groups. Importance ratings of the 33 indicators among different demographic and socioeconomic subgroups were analyzed using statistical methods, including mean ranking analysis, the intraclass correlation coefficient, and the Kruskal-Wallis test followed by post-hoc Dunn's pairwise comparison test. These analyses facilitated the identification of variations in the importance ratings across different demographic and socioeconomic subgroups. Finally, interviews with homeowners were conducted to explore the underlying reasons for these discrepancies. Through these efforts, this chapter aims to contribute to informed policymaking and the design and implementation of renovation projects that align with the needs of homeowners across diverse demographic and socioeconomic contexts.

6.2 Demographic and socioeconomic subgroups

6.2.1 Demographic and socioeconomic subgroups of respondents

The study examined six key demographic and socioeconomic characteristics of respondents (gender, age, education, annual income, family size, and length of residence) to analyze variations in importance perception, with each subgroup systematically coded as presented in Table 6.1. Gender distribution shows a predominance of female respondents (57.4%) compared to males (42.6%). Age distribution indicates that middle-aged homeowners (45-59 years) constitute the largest cohort (41.5%), followed by younger adults (18-44 years, 34.0%) and seniors (≥ 60 years, 24.5%). Educational attainment demonstrates that an overwhelming majority (80.8%) have middle school education. Income analysis reveals that 44.7% of respondents fall within the upper middle-income bracket (30,000-50,000 CNY annually). Family size data shows most households (53.2%) comprise 3-4 members, while a significant minority (39.3%) represent smaller households of 1-2 persons. The majority of the sampled homeowners (77.7 %) had lived in their current dwellings for over two decades.

Table 6.1 Demographic and socioeconomic subgroups of survey participants.

Factor	Code	Subgroup	N	Percentage (%)
Gender	Male	Male	40	42.6%
	Female	Female	54	57.4%
Age (years)	AGE1	18–44	32	34.0%
	AGE2	45–59	39	41.5%
	AGE3	≥ 60	23	24.5%
Education	EDU1	Primary school or below	9	9.6%
	EDU2	Middle school	76	80.8%
	EDU3	College or above	9	9.6%
Annual income per capita (CNY)	INC1	< 20,000	12	12.8%
	INC2	20,000–30,000	16	17.0%
	INC3	30,000–50,000	42	44.7%
	INC4	≥ 50,000	24	25.5%
Family size	FS1	1–2	37	39.3%
	FS2	3–4	50	53.2%
	FS3	5–6	7	7.5%
Length of residence (years)	LR1	< 10	7	7.4%
	LR2	10–20	14	14.9%
	LR3	≥ 20	73	77.7%

6.2.2 Comparison of demographic and socioeconomic characteristics between survey respondents and country population

Fig. 6.1 presents a comparative analysis of demographic and socioeconomic characteristics between the survey respondents and the latest available statistics (2023) for China's total population. Notably, the proportion of female homeowners in the sample (57.40%) is substantially higher than the share of females in the total population (48.90%). This finding aligns with previous research by Smith (2008), which suggests

that women are more likely than men to participate in surveys, potentially leading to their overrepresentation in respondent samples. Middle-aged individuals (AGE2: 45-59 years) comprise 41.5% of the respondents—nearly double the national proportion of 23.6%. This overrepresentation can be attributed to the legacy of China’s historical housing allocation system. Prior to the housing market reform in 1998, urban housing was predominantly distributed through the danwei (work-unit) system (Gong and MacLachlan, 2021), whereby state-owned enterprises allocated housing to their employees (Wu and Yu, 2024). As a result, many current homeowners of ageing buildings are individuals who benefited from this system and now fall within the middle-aged demographic. Respondents with secondary education (EDU2) dominate the sample at 80.8%, substantially exceeding the national rate of 52.01%. This disparity reflects the educational background of the urban workforce prior to the expansion of higher education enrollment in 1999 (Xiong et al., 2022), when secondary education was the norm among employees in local enterprises. The sample further demonstrates an overrepresentation of upper-middle income earners (INC3: 44.7% vs. 22.0% nationally). This may be explained by the fact that owners of ageing residential buildings are predominantly current or former employees of local enterprises, a group that typically enjoys relatively stable and higher incomes. Family size patterns reveal a higher proportion of medium-sized families (FS2) representing 53.20% of survey respondents compared to 39.47% in the national population.

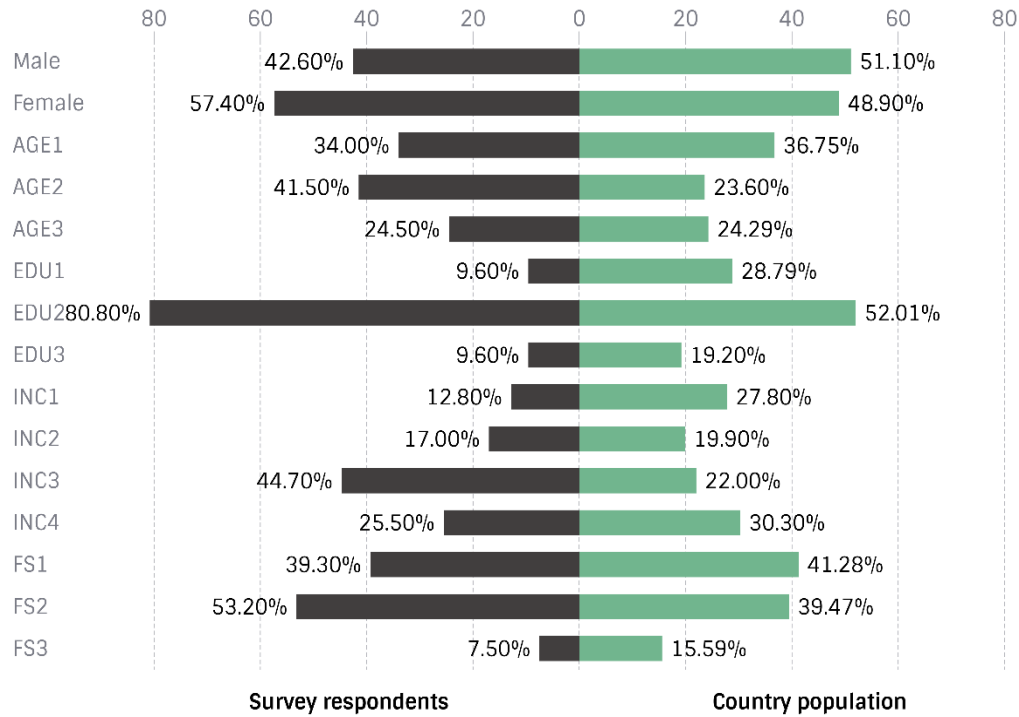


Figure 6.1 Comparison of demographic and socioeconomic characteristics between survey respondents and country population.

6.3 Mean ranking analysis

The 33 indicators were ranked in descending order based on their mean importance scores rated by all respondents and the 18 subgroups, where rank 1 represents the highest level of importance and rank 33 the lowest, as shown in Table 6.2 and illustrated in Figure 6.2. The size and color of the dots correspond to their assigned rankings: larger dots with deeper red represent higher rankings and greater importance, whereas smaller and bluer dots denote lower rankings and reduced significance. Overall, “building lifespan” was rated as the most significant indicator (mean = 4.69), followed by “seismic resistance ability” (mean = 4.60) and “gas pipeline safety” (mean = 4.55). Most demographic and socioeconomic subgroups ranked “building lifespan” as the

most important indicator except for EDU1, EDU3, INC3, FS3 and LR1.

For male respondents, the importance ranking of “waterproof” is 9th, compared to 19th for females. The ranking of “public lighting” is 11th for males versus 22nd for females. Similarly, “parking spot” ranks 15th among male participants but drops to 25th among females, and “elevator” are prioritized 16th by males compared to 28th by females. Conversely, female respondents assign substantially higher rankings to environmental sustainability features, with “water saving”, “energy saving”, and “green space” all receiving higher priorities from women than from their male counterparts.

Among respondents aged over 60 (AGE3), both “public lighting” and “green space” received substantial higher rankings compared to younger age groups. Conversely, the youngest homeowner cohort (AGE1) demonstrated remarkable stronger preference for modern infrastructure and lifestyle features, as evidenced by their higher rankings of “EV charging pile” and “New lifestyle” indicators relative to the other two older age groups. These differential prioritizations suggest generational variations in housing needs and values, with older residents emphasizing traditional community amenities while younger homeowners show greater concern for contemporary technological and new lifestyle-oriented facilities.

Homeowners with college or higher education levels (EDU3) assign substantially greater importance to building function features including “EV charging pile”,

“waterproof”, “parking spot” and “social space” compared to less-educated groups. Conversely, this demographic shows relatively lower concern for security-focused amenities, ranking both “anti-theft and monitoring” and “escapeway” as less critical than respondents with lower education levels.

Large families (FS3) demonstrate particularly sensitivity to renovation disturbances, ranking this concern 3rd—substantially higher than its overall 16th-place ranking—suggesting this group’s greater vulnerability to construction-related disruptions. Interestingly, FS3 respondents assign markedly lower priority to “privacy” considerations compared to smaller household groups. Conversely, the smallest family cohort (FS1) shows distinctive concern for “acoustic comfort”, ranking it 6th compared to significantly lower rankings of 26th (FS2) and 27th (FS3) among larger families.

Residents with shorter living periods (LR1, <10 years) demonstrate substantially higher importance ranking of “renovation disturbance” (3rd) and “fire safety” (4th) than longer-term residents. This group also shows greater emphasis on “water saving” and “parking spot” compared to those with longer living periods. On the contrary, long-term residents (LR3) prioritize fundamental infrastructure quality, assigning “water quality” a markedly higher ranking (3rd) compared to LR1 (20th) and LR2 (15th).

Table 6.2 Mean rankings of the 33 indicators in different demographic and socioeconomic subgroups.

Performance indicator	Overall rank	Male	Female	AGE 1	AGE 2	AGE 3	EDU 1	EDU 2	EDU 3	INC 1	INC 2	INC 3	INC 4	FS 1	FS 2	FS 3	LR 1	LR 2	LR 3
Building lifespan	1	1	1	1	1	1	2	1	6	1	1	2	1	1	1	10	14	1	1
Seismic resistance ability	2	2	2	2	2	4	3	2	2	4	4	1	4	2	3	2	2	2	2
Gas pipeline safety	3	3	3	3	3	2	1	3	5	2	7	3	2	4	2	1	1	3	5
Sewer blockage risk	4	4	4	5	4	11	7	7	1	7	10	7	3	8	4	11	26	6	4
Water quality	5	5	5	8	6	3	6	5	7	16	5	4	9	3	7	14	20	15	3
Anti-theft and monitoring	6	6	7	4	8	6	5	6	19	25	3	5	8	7	5	16	11	5	7
Escapeway	7	7	6	6	7	5	8	4	18	15	11	6	6	10	6	8	10	9	6
Electric wire layout	8	10	8	9	10	7	4	9	8	14	6	9	10	9	9	4	5	12	8
Privacy	9	8	9	10	5	19	9	8	13	24	12	8	5	5	8	27	9	4	9
Fire safety	10	14	11	18	12	10	11	11	12	3	23	10	18	11	15	7	4	18	12
EV charging pile	11	12	14	7	13	24	15	12	4	13	26	11	7	13	11	12	8	11	11
Waterproof	12	9	19	14	14	16	19	17	3	17	20	14	12	16	14	5	25	10	10
Acoustic comfort	13	18	15	12	16	17	28	10	23	29	9	12	20	6	27	26	27	8	14
Water saving	14	26	10	17	11	26	10	19	20	10	14	18	16	18	17	9	6	16	18
Public lighting	15	11	22	19	21	8	16	18	17	20	25	15	11	15	24	6	12	30	13

Renovation disturbance	16	19	17	11	19	23	14	20	15	8	16	23	13	29	10	3	3	14	21
Indoor air quality	17	20	16	16	17	15	23	14	10	21	22	13	17	17	18	21	15	17	17
Energy saving	18	25	13	27	9	20	13	15	25	9	8	20	22	12	22	18	19	20	15
Prestige and status	19	13	23	15	20	14	20	16	24	19	13	19	24	19	12	31	22	24	16
Indoor thermal comfort	20	21	18	23	18	13	26	13	26	22	19	16	23	14	21	25	28	7	19
Green space	21	27	12	20	24	9	24	21	22	6	2	26	26	24	13	19	13	13	23
Parking spot	22	15	25	25	15	29	29	23	9	18	28	21	14	21	23	15	7	23	22
Indoor natural daylighting	23	24	21	24	22	12	30	22	21	26	24	17	25	20	26	22	24	27	20
New lifestyle	24	17	26	13	27	25	12	25	14	27	17	22	21	23	16	30	17	21	24
Aesthetics	25	23	24	22	25	21	17	24	27	12	21	24	27	28	20	23	16	19	27
Elevator	26	16	28	21	26	22	18	26	16	23	15	25	15	26	19	29	21	26	25
Social space	27	22	27	26	28	18	25	27	11	5	27	29	19	27	25	28	23	28	26
Carbon reduction	28	29	20	29	23	30	21	28	31	11	18	28	28	22	28	17	18	22	28
House value increment	29	30	29	28	29	31	27	29	29	31	29	27	29	30	30	20	30	25	29
Residential density	30	28	30	31	30	28	22	30	28	30	30	30	30	25	29	33	32	29	30
Rental	31	32	31	30	31	33	31	32	30	33	32	31	32	31	32	13	31	31	32
Construction duration	32	31	32	32	32	27	32	31	32	28	31	32	31	32	31	32	33	32	31
Maintenance cost	33	33	33	33	33	32	33	33	33	32	33	33	33	33	33	24	29	33	33

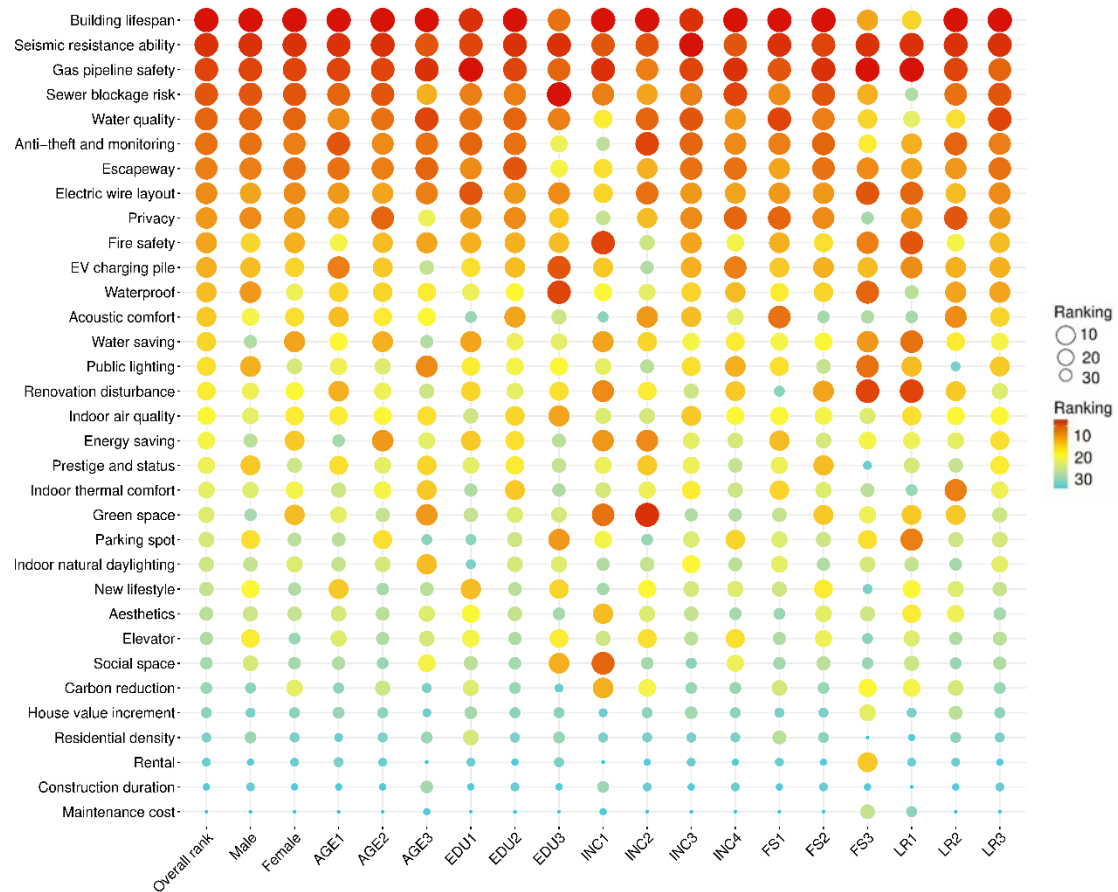


Figure 6.2 Rankings by different subgroups of respondents.

6.4 Intraclass correlation coefficient results

To assess whether the mean importance ratings of indicators are consistent across different subgroups within a demographic or socioeconomic factor, ICC was utilized using a two-way random effects model that accounts for both participant and measurement variability. ICC values range from 0 to 1, with values close to 1 indicating strong agreement among subgroups in rating the indicators, and values close to 0 suggesting weak agreement. The ICC results are summarized in Table 6.3. The results demonstrate ICC values ranging from 0.802 (family size) to 0.902 (gender), all

statistically significant at $p < .001$ with 32 degrees of freedom, indicating a statistically significant level of consistency among subgroups within each demographic and socioeconomic characteristics. Particularly noteworthy is the gender classification ((ICC = 0.902), which has exceeded 0.8, demonstrating excellent agreement between male and female homeowners. The ICC values for age (0.869), education (0.853), income (0.896), family size (0.802) and length of residence (0.859) fell between 0.75 and 0.9, indicating good agreement among these subgroups. Figure 6.3 provides a visualization that demonstrates the overall consistency of the mean ratings for the 33 indicators across different subgroups within each demographic and socioeconomic factor.

Table 6.3 Interclass correlation coefficient results.

	Gender	Age	Education	Income	Family size	Length of residence
N	2	3	3	4	3	3
ICC ^a	0.902	0.869	0.853	0.896	0.802	0.861
df	32	32	32	32	32	32
Sig.	<.001	<.001	<.001	<.001	<.001	<.001

Two-way random effects model where both people effects and measures effects are random. (a: Type A ICCs using an absolute agreement definition)

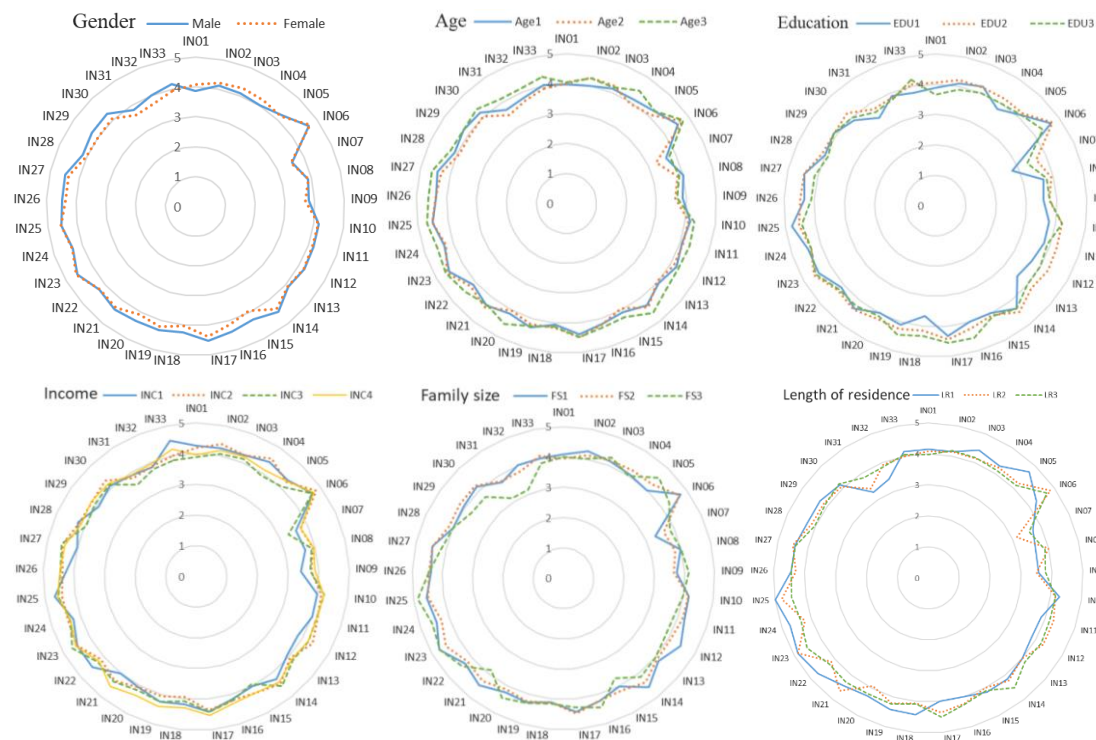


Figure 6.3 Mean importance ratings of the indicators by different subgroups.

6.5 Kruskal-Wallis test and Dunn's test results

Kruskal-Wallis tests were conducted to examine differences in homeowners' importance ratings of the 33 performance indicators in six demographic and socioeconomic groups. Table 6.4 presents the Kruskal-Wallis test p-values of the 33 indicators in each group. For each group, indicators with significant Kruskal-Wallis test results ($p\text{-value} < 0.05$) were retained for post-hoc Dunn's test with Bonferroni correction. Table 6.5 summarizes the significant Kruskal-Wallis and Dunn's test results. For indicators with significant Dunn's test results (with Bonferroni adjusted $p\text{-value} < 0.05$), homeowners' preferences are compared based on mean ranks (presented in parentheses). A detailed analysis of the Kruskal-Wallis and Dunn's test results is

provided in the following subsections.

Table 6.4 Kruskal-Wallis test p-values of 33 indicators.

Code	Indicator	Kruskal-Wallis test p-value					
		Gender	Age	Education	Income	Family size	Length of residence
IN01	Carbon reduction	0.1345	0.8047	0.0876	0.1616	0.6701	0.7438
IN02	Energy saving	0.5034	0.0992	0.3521	0.3021	0.3195	0.9868
IN03	Water saving	0.1177	0.6735	0.6376	0.7950	0.7928	0.4208
IN04	Maintenance cost	0.8465	0.0136*	0.0037**	0.0268*	0.0763	0.1034
IN05	House value increment	0.9556	0.3832	0.2802	0.3580	0.5367	0.2414
IN06	Rental	0.4639	0.5277	0.7278	0.4112	0.2814	0.4569
IN07	Indoor air quality	0.9415	0.2885	0.0574	0.5664	0.6757	0.7328
IN08	Indoor thermal comfort	0.8452	0.1538	0.1316	0.7965	0.3546	0.5941
IN09	Acoustic comfort	0.9426	0.5875	0.0314*	0.2054	0.0058**	0.4362
IN10	Public lighting	0.0892	0.0120*	0.5084	0.4679	0.5501	0.5710
IN11	EV charging pile	0.2821	0.6219	0.5917	0.5673	0.9212	0.7552
IN12	Aesthetics	0.3153	0.1526	0.5901	0.3593	0.5854	0.5505
IN13	Residential density	0.0818	0.0930	0.8997	0.5793	0.0072**	0.2664
IN14	Fire safety	0.7189	0.0359*	0.6205	0.3149	0.4853	0.0385*
IN15	Seismic resistance ability	0.5758	0.4462	0.7679	0.5691	0.0559	0.0367*
IN16	Electric wire layout	0.6377	0.1324	0.8385	0.9029	0.3720	0.1586

IN17	New lifestyle	0.0799	0.2669	0.9960	0.8357	0.2013	0.3167
IN18	Prestige and status	0.0410*	0.0994	0.2039	0.6617	0.1300	0.7862
IN19	Construction duration	0.3065	0.0220*	0.4982	0.1266	0.1078	0.1415
IN20	Renovation disturbance	0.7491	0.6443	0.9131	0.6055	0.1418	0.1634
IN21	Privacy	0.7070	0.7054	0.8041	0.3694	0.0737	0.2183
IN22	Green space	0.4601	0.0562	0.1308	0.0241*	0.2695	0.8549
IN23	Building lifespan	0.4871	0.1880	0.1372	0.6953	0.1548	0.0931
IN24	Indoor natural daylighting	0.8575	0.0246*	0.0121*	0.6733	0.7177	0.6619
IN25	Water quality	0.5912	0.0816	0.7293	0.7628	0.2335	0.4395
IN26	Elevator	0.0314*	0.2060	0.9212	0.2027	0.2451	0.8365
IN27	Waterproof	0.0464*	0.7181	0.1142	0.9522	0.5297	0.6732
IN28	Sewer blockage risk	0.3190	0.5734	0.8027	0.8671	0.6422	0.1677
IN29	Parking spot	0.1054	0.6898	0.1118	0.2530	0.9899	0.3855
IN30	Gas pipeline safety	0.9364	0.3298	0.3882	0.6369	0.2360	0.0060
IN31	Escapeway	0.5086	0.2969	0.4041	0.9438	0.6675	0.8706
IN32	Anti-theft and monitoring	0.4095	0.3075	0.5174	0.5757	0.7944	0.4814
IN33	Social space	0.1441	0.0959	0.3718	0.0182*	0.6506	0.8886

Note: * $p < 0.05$, ** $p < 0.01$

Table 6.5 Significant Kruskal-Wallis and Dunn's test results.

Group	Indicators with significant Kruskal-Wallis test results	Kruskal-Wallis test p-value	Preference comparison (based on significant Bonferroni adjusted p-values and mean ranks)
Gender	Elevator	0.0314*	Male (53.85) > Female (42.80) *
Male	Waterproof	0.0464*	Male (53.20) > Female (43.28) *
Female	Prestige and status	0.0411*	Male (53.13) > Female (43.33) *
Age (years)	Maintenance cost	0.0136*	AGE3 (56.67) > AGE2 (38.92) *
AGE1: 18–44	Indoor natural daylighting	0.0247*	AGE3 (58.76) > AGE2 (42.60) *
AGE2: 45–59	Public lighting	0.0120*	AGE3 (60.17) > AGE2 (42.69) *
AGE3: ≥ 60	Fire safety	0.0359*	AGE3 (57.54) > AGE1 (41.88) *
	Construction duration	0.0220*	AGE3 (59.48) > AGE2 (41.00) *
Education	Maintenance cost	0.0037**	EDU2 (51.41) > EDU1 (24.28) *
EDU1: Primary school or below	Acoustic comfort	0.0314*	EDU2 (50.47) > EDU1 (28.72) *
EDU2: Middle school	Indoor natural daylighting	0.0121*	EDU2 (50.45) > EDU1 (26.5) *
EDU3: College or above			
Income (CNY)	Green space	0.0241*	INC2 (61.50) > INC3 (41.15) *
INC1: < 20,000	Maintenance cost	0.0268*	
INC2: 20,000–30,000	Social space	0.0182*	INC1 (63.96) > INC3 (40.48) *
INC3: 30,000–50,000			
INC4: ≥ 50,000			
Family size	Acoustic comfort	0.0058**	FS1 (57.38) > FS2 (41.95) *
FS1: 1–2	Residential density	0.0072**	FS1 (54.00) > FS3 (23.79) *
FS2: 3–4			
FS3: 5–6			
Length of residence (years)	Fire safety	0.0385*	LR1 (67.64) > LR2 (41.93) *
LR1: < 10	Seismic resistance ability	0.0367*	
LR2: 10–20	Gas pipeline safety	0.0060**	LR1 (68.00) > LR3 (43.51) *
LR3: ≥ 20			

Note: * $p < 0.05$, ** $p < 0.01$; the values in parentheses represent the mean rank of the group; nonsignificant results are not presented in the table.

6.5.1 Gender

Differences in the importance rankings of performance indicators between male and female homeowners were analyzed using the Kruskal-Wallis test. As shown in Table 6.4, the Kruskal-Wallis test of gender-based differences reveals statistically significant variations ($p < 0.05$) in importance ratings for only three indicators: “elevator” ($p = 0.0314$), “waterproof” ($p = 0.0464$), and “prestige and status” ($p = 0.0411$) while the remaining indicators demonstrate no significant gender-based disparities ($p > 0.05$), suggesting that male and female respondents generally share similar perceptions of importance for most ageing residential building renovation performance indicators. This pattern indicates that gender influences perception primarily in these specific domains, whereas broader consensus exists across other measured indicators. Figure 6.4 illustrates the three indicators for which the test yielded statistically significant differences between male and female respondents. As shown in both Table 6.5 and Figure 6.4, men assigned significantly higher importance to “elevator”, “waterproof” and “prestige and status” than women, as evidenced by their higher mean ranks.

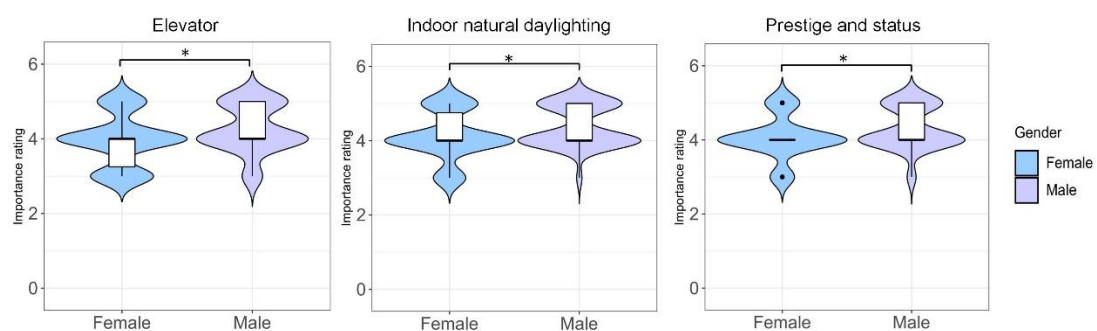


Figure 6.4 Indicators with significant Kruskal-Wallis test results (by gender).

Note: * $p < 0.05$; y-axis represents the 5-point Likert scale importance ratings.

6.5.2 Age

The results of the Kruskal-Wallis test, as presented in Table 6.4, revealed statistically significant differences ($p < 0.05$) in importance ratings among three age subgroups for five performance indicators: “maintenance cost” ($p = 0.0136$), “indoor natural daylighting” ($p = 0.0247$), “public lighting” ($p = 0.0120$), “fire safety” ($p = 0.0359$) and “construction duration” ($p = 0.0220$). In contrast, the remaining indicators do not exhibit significant differences ($p > 0.05$) among these subgroups.

The five significant indicators were then processed for Post-hoc Dunn’s test with Bonferroni adjustment to examine pairwise differences between age subgroups. The Dunn’s test p-values and the comparison of the mean ranks in Table 6.6 reveal that the elderly respondents (AGE3) demonstrate significant stronger concern than middle-aged participants (AGE2) on building performances including “maintenance cost”, “indoor natural daylighting”, “public lighting” and “construction duration”. Furthermore, the elderly (AGE3) assigned significantly greater importance to “fire safety” compared to young adults (AGE1). The statistically significant variations in importance ratings of indicators across age subgroups are visually represented in Figure 6.5.

Table 6.6 Post-hoc Dunn's test with Bonferroni adjustment results (by age).

Indicators	Mean rank			Adjusted p-value		
	AGE1	AGE2	AGE3	AGE1 vs. AGE2	AGE1 vs. AGE3	AGE2 vs. AGE3
Maintenance cost	51.36	38.92	56.67	0.11	1.00	0.02*
Indoor natural daylighting	45.38	42.60	58.76	1.00	0.11	0.02*
Public lighting	44.25	42.69	60.17	1.00	0.04	0.01*
Fire safety	41.88	46.19	57.54	1.00	0.03*	0.17
Construction duration	46.81	41.00	59.48	1.00	0.21	0.02*

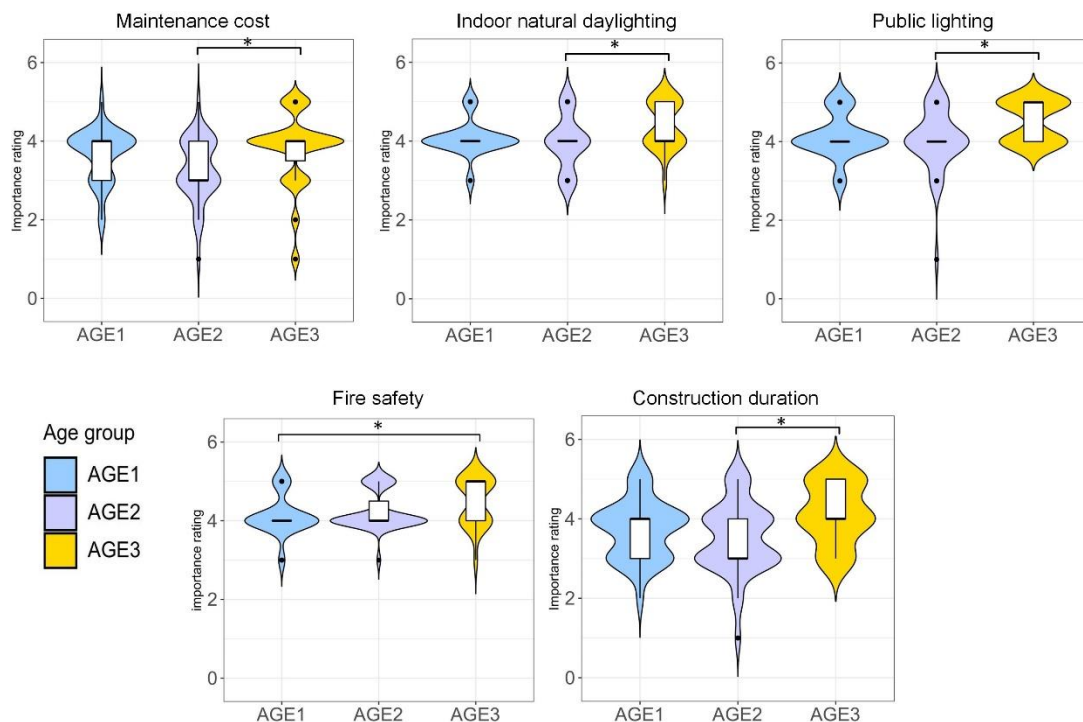


Figure 6.5 Indicators with significant Kruskal-Wallis test results (by age).

Note: * $p < 0.05$; y-axis represents the 5-point Likert scale importance ratings.

6.5.3 Education

The Kruskal-Wallis test was employed to examine variations in homeowners' importance ratings of performance indicators across three educational attainment levels:

primary school or below (EDU1), middle school (EDU2), and college or above (EDU3). As revealed in Table 6.4, three indicators obtained significant Kruskal-Wallis test results ($p < 0.05$): “maintenance cost” (0.0037), “acoustical comfort” (0.0314), and “indoor natural daylighting” (0.0121). The importance ratings of other indicators demonstrate no significant differences among the education subgroups.

A post-hoc Dunn’s test with Bonferroni-adjusted p-values along with the mean ranks of the three indicators between each pair of education subgroups are presented in Table 6.7. EDU1 and EDU2 demonstrates p-values less than 0.05 for “maintenance cost” (0.01), “acoustical comfort” (0.04), and “indoor natural daylighting” (0.01). The higher mean ranks of EDU2 compared to EDU1 indicates that homeowners with a middle school level of educational attainment (EDU2) prioritized “maintenance costs”, “acoustical comfort” and “indoor natural daylighting” more compared to those with primary school education or below (EDU1). The observed variations in importance ratings of indicators across education subgroups are visually represented in Figure 6.6.

Table 6.7 Post-hoc Dunn’s test with Bonferroni adjustment results (by education).

Indicators	Mean rank			Adjusted p-value		
	EDU1	EDU2	EDU3	EDU1 vs. EDU2	EDU1 vs. EDU3	EDU2 vs. EDU3
Maintenance cost	24.28	51.41	37.67	0.01*	0.76	0.35
Acoustic comfort	28.72	50.47	41.17	0.04*	0.85	0.85
Indoor natural daylighting	26.5	50.45	43.61	0.01*	0.35	1.00

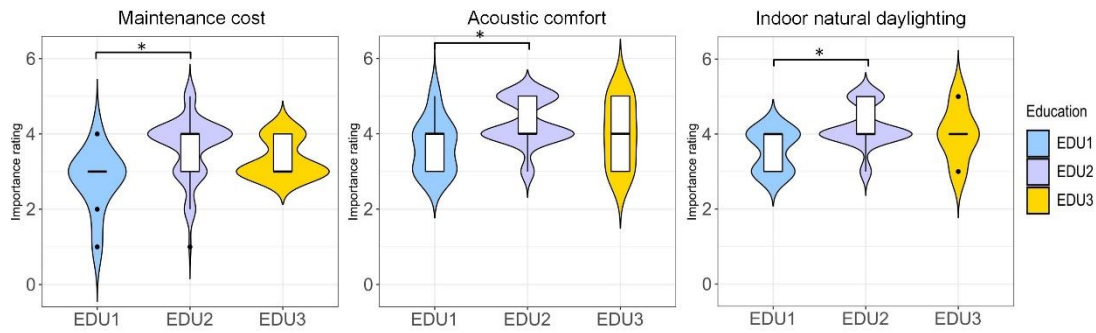


Figure 6.6 Indicators with significant Kruskal-Wallis test results (by education).

Note: * $p < 0.05$; y-axis represents the 5-point Likert scale importance ratings.

6.5.4 Income

Using the Kruskal-Wallis test, variations in the importance ratings of performance indicators among four income subgroups were examined, with statistically significant results ($p < 0.05$) observed for three indicators: “green space” (0.0241), “maintenance cost” (0.0268) and “social space” (0.0182), as presented in Table 6.4. The statistical analysis reveals no significant differences ($p > 0.05$) in the perceived importance of the remaining indicators across education subgroups, indicating a consistent valuation of these building performance factors regardless of respondents’ educational attainment levels.

The three indicators identified as statistically significant underwent post-hoc analysis using Dunn’s test with Bonferroni correction to examine pairwise comparisons between each pair of income subgroups. Dunn’s test results and mean ranks for each indicator in each income group are shown in Table 6.8. As revealed in the Table, post-hoc Dunn’s test with Bonferroni adjustment results demonstrate significant pairwise differences for “green space” between INC1 and INC3 (adjusted p-value = 0.03), as well as for “social

space” between INC1 and INC3 (adjusted p-value = 0.02). No significant differences were found in importance ratings for “maintenance cost” between any pair of income subgroups. Mean rank comparisons presented in Table 6.8 reveal that the lower-middle income group (IN2: 20,000–30,000 CNY) placed significantly greater importance on “green space” compared to the upper-middle income group (IN3: 30,000–50,000 CNY). Low-income group (INC1: < 20,000 CNY) demonstrated a significantly higher level of concern for “social space” than the upper-middle income group (IN3: 30,000–50,000 CNY). The statistical test results are visually summarized in Figure 6.7, which presents the variations in the importance ratings of indicators across income subgroups.

Table 6.8 Post-hoc Dunn’s test with Bonferroni adjustment results (by income).

Indicators	Mean rank				Adjusted p-value					
	INC1	INC2	INC3	INC4	INC1	INC1	INC1	INC2	INC2	INC3
					vs.	vs.	vs.	vs.	vs.	vs.
					INC2	INC3	INC4	INC3	INC4	INC4
Green space	55.67	61.5	41.15	45.19	1.00	0.44	1.00	0.03*	0.24	1.00
Maintenance cost	51.96	56.56	38.99	54.13	1.00	0.66	1.00	0.09	1.00	0.10
Social space	63.96	45.47	40.48	52.92	0.30	0.02*	1.00	1.00	1.00	0.29

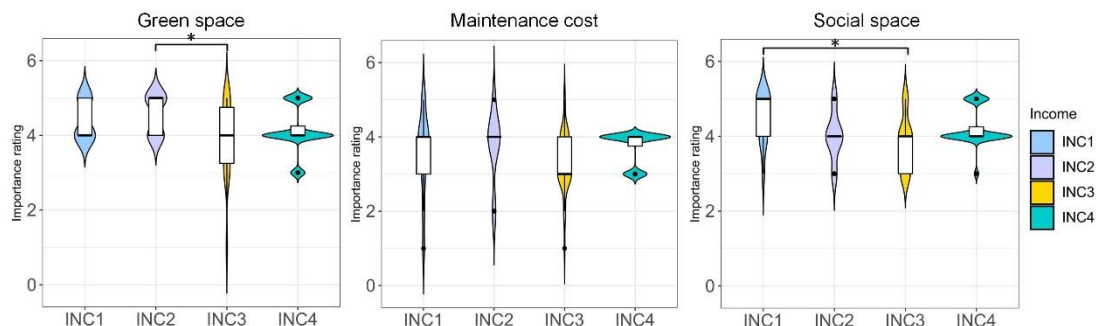


Figure 6.7 Indicators with significant Kruskal-Wallis test results (by income).

Note: * $p < 0.05$; y-axis represents the 5-point Likert scale importance ratings.

6.5.5 Family size

Analysis using the Kruskal-Wallis test revealed significant variations in homeowners' perceived importance of both "acoustic comfort" ($p = 0.0058$) and "residential density" ($p = 0.0072$) among the three family size subgroups, as presented in Table 6.4. This statistical analysis indicates no significant variations ($p > 0.05$) in the perceived importance of the remaining 31 indicators among different family size subgroups.

Post-hoc pairwise comparisons were conducted for the two significant indicators using Dunn's test with Bonferroni correction between each pair of the family size subgroups. As demonstrated in Table 6.9, significant post-hoc Dunn's test with Bonferroni adjusted p-values were observed between FS1 and FS2 for "acoustic comfort" ($p = 0.01$), and between FS1 and FS3 for "residential density" ($p = 0.01$). As evidenced by higher mean ranks, homeowners from small family units (FS1: ≤ 2 members) tended to prioritize "acoustic comfort" more than those from medium-size families (FS2: 3-4 members). Small families also placed greater importance on "residential density" compared to those from large households (FS3: 5-6 members). These findings are presented in Figure 6.8, which provides a comprehensive visualization of the Kruskal-Wallis test and post-hoc Dunn's test outcomes across family size subgroups.

Table 6.9 Post-hoc Dunn's test with Bonferroni adjustment results (by family size).

Indicators	Mean rank			Adjusted p-value		
	FS1	FS2	FS3	FS1 vs. FS2	FS1 vs. FS3	FS2 vs. FS3
Acoustic comfort	57.38	41.95	34.93	0.01*	0.08	1.00
Residential density	54	46.01	23.79	0.37	0.01*	0.06

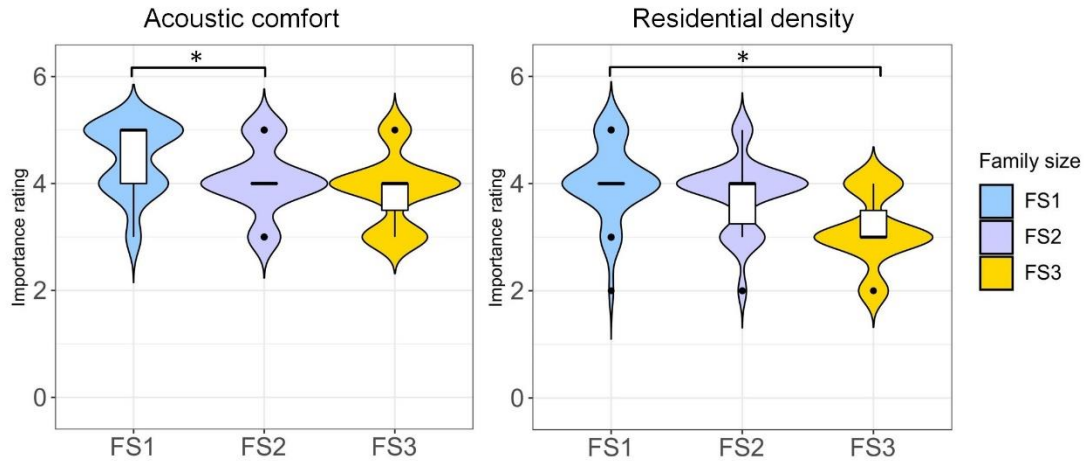


Figure 6.8 Indicators with significant Kruskal-Wallis test results (by family size).

Note: * $p < 0.05$; y-axis represents the 5-point Likert scale importance ratings.

6.5.6 Length of residence

Differences in the importance ratings of performance indicators among three residence length subgroups were analyzed using the Kruskal-Wallis test, with statistically significant results ($p < 0.05$) identified for “fire safety” ($p = 0.0385$), “seismic resistance ability” ($p = 0.0367$) and “gas pipeline” ($p = 0.0060$), as presented in Table 6.4. The findings reveal no significant differences ($p > 0.05$) in the importance ratings of the remaining 30 indicators across the three length of residence subgroups.

To identify specific differences in importance ratings between any two length of residence subgroups for the three indicators, post-hoc pairwise comparisons were performed using Dunn’s test with Bonferroni correction. As illustrated in Table 6.10 and Figure 6.9, post-hoc Dunn’s test with Bonferroni correction results reveal significant pairwise differences (adjusted p -value < 0.05) for “fire safety” between LR1 and LR2 and for “gas pipeline” between LR1 and LR3. No significant differences were

found between any two length of residence subgroups with respect to the importance perception of “seismic resistance ability”. Mean rank comparisons presented in Table 6.10 unveil that homeowners with relatively short residential length (LR1: <10 years) valued “fire safety” more highly than homeowners lived between 10 to 20 years (LR2) and prioritized “gas pipeline safety” more than long-term residents (LR3: > 20 years).

Table 6.10 Post-hoc Dunn’s test with Bonferroni adjustment results (by length of residence).

Indicators	Mean rank			Adjusted p-value		
	LR1	LR2	LR3	LR1 vs. LR2	LR1 vs. LR3	LR2 vs. LR3
Fire safety	67.64	41.93	46.64	0.04*	0.06	1.00
Seismic resistance ability	58.93	58.93	44.21	1.00	0.32	0.09
Gas pipeline safety	68	58.04	43.51	1.00	0.03*	0.10

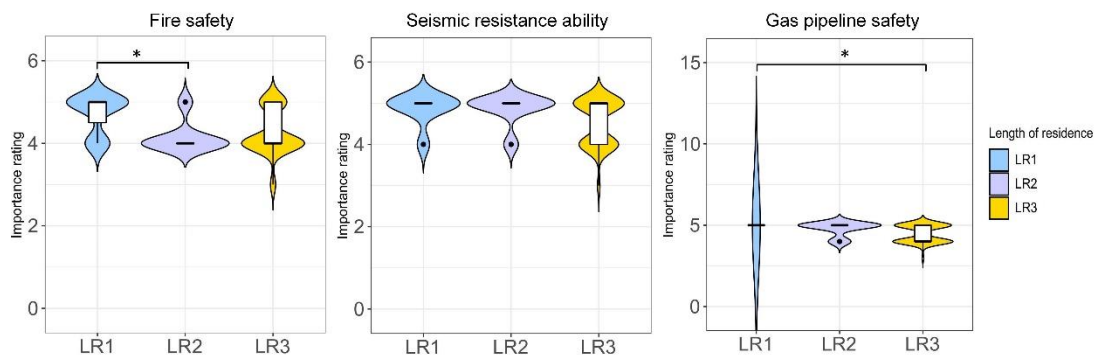


Figure 6.9 Indicators with significant Kruskal-Wallis test results (by length of residence).

Note: * $p < 0.05$; y-axis represents the 5-point Likert scale importance ratings.

6.6 The underlying reasons for homeowners' priorities

6.6.1 Gender

The statistical analysis indicates that male participants placed greater emphasis on “prestige and status” in the context of residential renovation compared to their female counterparts. Insights from the interviews further illuminate this finding: male homeowners often regard housing renovation as an opportunity to significantly enhance the aesthetic appeal and modernity of their living environment, which is closely associated with an increased sense of personal pride and a heightened perception of social standing. For men, housing is frequently viewed as a tangible manifestation of financial capability, which is intrinsically tied to notions of prestige and status. One illustrative example emerged from an interviewee who mentioned his experience visiting friends' modern residences. He expressed admiration for the grand entrance lobbies in model residential buildings, interpreting these architectural elements as clear indicators of higher socioeconomic status. He also indicated the embarrassment associated with the cramped entrance of his own dwelling, particularly when hosting friends and relatives. In contrast, female interviewees acknowledged that while residential renovations could exert some influence on their perceived social status, they generally considered this effect to be relatively minor compared to men.

The significance attributed to “prestige and status” in residential renovation is consistent with the findings of Hu and Wang (2020) and Fang and Tian (2018), who argue that housing signifies family's social status. The interviews conducted in this study further elucidate the underlying mechanisms driving gender differences in the

prioritization of “prestige and status” within the context of residential building renovation. In the Chinese sociocultural context, homeownership is widely regarded as a prerequisite for marriage. Males are found to compete intensely for marital prospects, primarily through the provision of housing (Fang and Tian, 2018). Men who are unable to offer a desirable marital home are often perceived as lacking financial capability, which significantly diminishes their competitiveness as potential partners. Furthermore, the traditional gender division norm—“men are breadwinners and women are homemakers” (Chen and Hu, 2021)—continue to shape the division of labor within households. Under this conventional framework, men are regarded as the primary economic pillars of the family, with their social standing closely tied to their financial capacity. Residential property, as a visible form of capital, enables housing upgrades to serve as performative demonstrations of masculine financial capability. Consequently, renovating and upgrading one’s residence becomes a more significant source of pride and social status for men than for women. In summary, the emphasis men place on “prestige and status” in residential renovation is inextricably linked to socioeconomic factors, particularly the enduring expectation that men bear the primary responsibility for providing housing within the context of marriage and family life.

6.6.2 Age

The quantitative analysis reveals that elderly homeowners place significantly greater emphasis on “indoor natural daylighting” compared to their younger counterparts. Qualitative data from interviews further elucidate this finding: older individuals reported experiencing feelings of depression and gloom in environments with insufficient natural daylight. They emphasized the irreplaceable value of natural light,

highlighting its positive psychological effects, such as mood enhancement and the alleviation of depressive and anxious symptoms. This perspective is supported by Taniguchi et al. (2022), who demonstrated that sunlight exposure has a beneficial impact on mental health, including reductions in depression, anxiety, and stress. Notably, the elderly are more susceptible to the psychological symptoms compared to younger individuals (Wuthrich et al., 2015), thereby amplifying the importance of natural daylighting in their living environments. In contrast, younger respondents exhibited a higher degree of acceptance toward artificial lighting solutions, generally considering them functionally adequate to meet their illumination needs. Additionally, Tähkämö et al. (2019) suggested that artificial light may have adverse effects on human health, as exposure at inappropriate times can disrupt circadian rhythms and potentially lead to health issues. This evidence further reinforces the rationality of elderly's preference for natural daylight, as it not only supports psychological well-being but also promotes healthier physiological functioning. These findings align with the study of Yang et al. (2021), which found that older adults have a strong desire for sunlight and their demand for natural daylight might be driven not only by visual requirements but also by psychological non-visual needs. This helps explain the underlying reasons for the observed age differences in the perceived importance of “indoor natural daylighting” in residential renovation.

In line with the findings of the statistical analysis, elderly participants also expressed significant concern regarding “fire safety”, a sentiment largely attributable to their reduced physical responsiveness and limited mobility. In contrast, younger residents generally exhibited confidence in their ability to respond effectively to fire emergencies, perceiving themselves as less vulnerable in such situations. This heightened concern

among the elderly aligns with the findings of Coty et al. (2015), who identified that urban older adults face distinct challenges in maintaining home fire safety, including restricted mobility and financial limitations, both of which can impede the implementation of adequate fire prevention measures. Furthermore, the general health and cognitive status of elderly individuals were found to significantly influence their capacity to uphold fire safety within the home environment. According to Karemaker et al. (2021), risk perception, self-efficacy, habits, and perceived barriers such as physical disabilities, are significant determinants influencing fire safety behaviors among the elderly. Interestingly, their research revealed that older adults often perceive the risk of home fires as relatively low and maintain a high degree of confidence in their ability to respond effectively during such incidents. This finding contrasts with the present study, in which elderly participants demonstrated heightened awareness of their own vulnerabilities and expressed greater concern regarding fire safety. Empirical evidence further underscores the disproportionate vulnerability of older adults to fire-related fatalities. Cassidy et al. (2021) reported that individuals aged 60 and above are overrepresented in global statistics on fatal residential fires, highlighting the critical need for targeted fire safety interventions within this demographic. In summary, the statistically significant emphasis placed on fire safety by elderly homeowners is corroborated by qualitative interview data, which reveal that limited physical responsiveness and mobility are key underlying factors contributing to this concern.

6.6.3 Education

The findings uncover that residents with higher attainment demonstrate greater concern for “acoustic comfort” in residential renovation compared to those with lower education

levels. Interviewees with higher education levels emphasized the importance of acoustic comfort for ensuring effective rest and work at home, as well as for avoiding adverse health impacts. This perspective corroborates an earlier study by Meng et al. (2021), who identified the acoustic environment as a significant determinant of workers' performance. Their concerns are also supported by Jensen et al. (2019) found that poor acoustic conditions can induce negative emotional reactions—such as irritability, distress, or other stress-related symptoms—which may negatively affect various health risk factors, including blood pressure, circulating blood lipids and glucose levels, and heart rate. These can increase the risk of common non-communicable diseases, such as cardiovascular, respiratory, and metabolic disorders. This heightened awareness among more educated residents can be attributed to their greater understanding of the adverse effects of noise pollution on health and well-being. Individuals with higher educational attainment are more likely to recognize how environmental factors, such as noise, can impact cognitive functioning, concentration, and overall mental health. Consequently, they are more proactive in seeking living conditions that minimize noise and support their daily activities. Moreover, the prioritization of acoustic comfort among more educated residents may also reflect broader lifestyle and occupational differences. Those with higher educational attainments are more likely to engage in activities that require quiet environments, such as reading and remote work, thereby increasing their sensitivity to noise-related disruptions. In contrast, individuals with lower educational backgrounds may exhibit greater tolerance for environmental noise, either due to habituation, differing lifestyle demands, or a greater focus on other aspects of life quality improvement. In summary, the analysis indicates that heightened awareness of the adverse health effects of noise, coupled with lifestyles that necessitate quieter environments, are key underlying factors contributing to the greater concern for

acoustic comfort observed among homeowners with higher educational attainment.

6.6.4 Income

The findings indicate that lower-middle income groups, specifically those with incomes between 20,000 and 30,000 CNY, place significantly greater value on green spaces compared to their upper-middle income counterparts (30,000–50,000 CNY). Interviewees from lower-income backgrounds perceive green spaces as essential public amenities that provide accessible opportunities for fresh air, recreation, and social interaction at no cost, which are crucial to their daily well-being. For these residents, green spaces are not merely aesthetic enhancements; rather, they serve as vital components of everyday life, offering respite from densely populated living conditions and compensating for limited outdoor areas. This heightened prioritization of green spaces among lower-income groups can be understood within the broader context of socioeconomic disparities in health and access to environmental resources. Santana et al. (2021) have demonstrated that lower income levels are associated with increased psychological distress, highlighting the importance of accessible environments that can help mitigate such stressors. However, as Astell-Burt et al. (2014) found, neighborhoods with a higher proportion of low-income households often have significantly less green space available. This inequitable distribution of green spaces exacerbates health vulnerabilities, as those residents who are more likely to suffer from preventable chronic health issues such as obesity, cardiovascular disease, and type 2 diabetes mellitus, yet reside in environments that offer minimal opportunities for positive lifestyle changes. Furthermore, the multifaceted benefits of green spaces are well-documented. Jabbar et al. (2022) concluded that access to green spaces can

enhance mental health, reduce anxiety, alleviate depression, purify the air, diminish noise pollution, and provide areas for physical activity and social interaction. For lower-middle income groups, these benefits are particularly salient, as green spaces serve as critical resources for maintaining both physical and psychological health in the absence of private amenities. In summary, the pronounced emphasis on green spaces among lower-middle income residents reflects both their heightened need for accessible, health-promoting environments and the structural inequalities that limit their availability.

In terms of “social space” in residential renovation, low-income populations demonstrate significantly greater concern than their upper-middle-income counterparts. Interviews reveal that individuals from low-income backgrounds regard social spaces within their residential environments as essential, since these areas provide convenient and low-cost venues for entertainment, leisure, and social interaction. For these residents, accessible social spaces are not merely desirable amenities but a fundamental part of daily life, compensating for the lack of private recreational areas. Godwyll et al. (2024) noted that populations living below the poverty line often reside in communities with inadequate private outdoor spaces and limited available recreational spaces. Additionally, economic constraints hinder their ability to access recreational destinations that require paid entry. Moreover, research further indicates that low-income individuals’ out-of-home activities are more geographically concentrated near their residences compared to higher-income groups. As a result, low-income populations predominantly engage in leisure activities within typical low-income neighborhoods, further highlighting their dependence on proximate, accessible social spaces (Zhou et al., 2015). In summary, the pronounced concern for social spaces

among low-income groups reflects both their pressing need for affordable recreation and structural barriers restricting access to such resources.

6.6.5 Family size

The quantitative findings indicate that homeowners with smaller family sizes express significantly greater concern about residential density compared to those with large families. This disparity in priorities can be attributed to distinct lifestyle needs, preferences and adaptability to living conditions. Small families (typically comprising no more than two members) reported a stronger emphasis on residential density due to its direct impact on their quality of life, comfort, and access to resources. This observation aligns with Gifford (2007), who argued that residential density affects privacy and livability, particularly for smaller households. Such families often prioritized larger homes and yards, which were more readily available in lower-density areas (Clark and Onaka, 1983), which is driven by the desire for privacy, personal space and a quieter living environment. Additionally, smaller families value access to green spaces and nature, which are more abundant in lower-density neighborhoods. These features contributed to an enhanced quality of life by providing opportunities for recreation, relaxation and mental well-being (Glaeser and Gottlieb, 2006). In contrast, homeowner respondents with large family sizes indicated that they have become accustomed to higher residential density in their current living situations. Having become accustomed to managing space constraints and cohabiting in close quarters, these families tend to be less sensitive to the potential drawbacks of higher-density environments. This distinction underscores the heterogeneous considerations that different family sizes bring to the residential decision-making and renovation process.

Smaller families prioritize spatial quality and environmental amenities, while larger families demonstrate a pragmatic adaptability to density-related challenges.

6.6.6 Length of residence

The findings indicate that homeowners who have resided in their current dwellings for less than ten years place significantly greater emphasis on “fire safety” and “gas pipeline safety” compared to those with longer residential period. Long-term residents reported no significant experiences with severe fires or gas pipeline explosions. Consequently, these individuals perceived a lower likelihood of such hazards and exhibited diminished concern for corresponding safety measures. This pattern is consistent with the theory of Slovic (1987), which posits that individuals adjust their risk perceptions over time, particularly when repeatedly exposed to a hazard without encountering negative consequences. This process of risk adjustment can lead to a diminished sense of urgency or concern regarding these risks. The concept of risk habituation and psychological adaptation to environmental risk further supports this phenomenon. Norris et al. (2008) explored how communities and individuals adapted to risks over time, highlighting that prolonged exposure to risks could lead to a process known as risk normalization. Under prolonged exposure without incident, risks that were once perceived as acute threats gradually become integrated into the routine aspect of daily life. As a result, the perceived necessity to implement or maintain preventive measures diminishes, and the risk becomes part of the background rather than a prominent threat. In summary, the observed divergence in safety priorities between short-term and long-term residents can be interpreted through the lens of psychological adaptation and risk normalization. While short-term residents maintain heightened

concerns due to unfamiliarity and perceived vulnerability, long-term residents, shaped by their uneventful experiences, exhibit reduced concern and a lower perceived urgency for safety improvements in residential renovation.

6.7 Implications for residential building renovation practices

Examining variations in homeowners' perceptions of the importance of residential building renovation performance across different demographic and socioeconomic groups can yield valuable insights. Such understanding can inform urban renovation decision-making, planning, and housing policy, enabling them to more effectively address the diverse needs of households with varying family structures.

Firstly, understanding these differences facilitates the development of more effective and tailored communication strategies to gain greater support and approval from homeowners. By aligning incentives with the significant values of different demographic and socioeconomic characteristics, the adoption of sustainable renovation practices can be accelerated, as homeowners are more inclined to engage in renovation initiatives that resonate with their personal beliefs, lifestyle preferences, and long-term interests. For example, in redevelopment projects focused on neighborhoods with a predominantly elderly population, developers could highlight the health and comfort benefits of increased indoor natural daylighting—achievable through features such as larger windows—to enhance appeal and participation. In communities predominantly inhabited by residents with shorter-term occupancy (e.g., less than ten years), emphasizing improvements in safety may prove more persuasive in fostering renovation approval.

Secondly, actively involving homeowners in renovation decision-making is essential to align interventions with the heterogeneous priorities of different demographic and socioeconomic groups. Understanding the varying priorities of different groups allows designers and planners to tailor technical and spatial solutions to meet the specific needs and preferences of homeowners. When renovation measures are matched to these differentiated priorities, projects are more likely to achieve higher occupant satisfaction and improved social and environmental sustainability. For example, in communities with a high proportion of highly educated residents, acoustic insulation enhancement measures such as the installation of laminated glass windows are likely to yield substantial gains in occupant satisfaction. In urban renewal contexts where residential areas are predominantly inhabited by small family units, urban planners and architects should prioritize design interventions aimed at deliberately reducing residential density through strategic spatial reconfiguration.

Thirdly, these insights provide a critical evidence base for policymakers in crafting targeted incentives and regulatory frameworks that promote specific renovation practices while accounting for the heterogeneous motivations and constraints associated with different demographic and socioeconomic groups. Rather than adopting a one-size-fits-all approach, policymakers and urban planners should develop differentiated renovation strategies that address the distinct functional, cultural, and economic priorities of each group, with particular emphasis on safeguarding inclusivity for lower-income households and other vulnerable populations. For instance, in communities with a predominantly older population, interventions aimed at improving public lighting and strengthening fire safety can enhance both comfort and security.

Similarly, in renovation projects located in lower-income districts, the provision of accessible and well-designed green and social spaces can substantially improve residents' overall well-being. Through the systematic integration of demographic and socioeconomic considerations into policy formulation, more effective interventions can be developed that simultaneously address equity and sustainability concerns. This evidence-informed approach enables policymakers to address the differentiated needs of diverse population groups, mitigate structural inequalities, and promote inclusive urban development—thereby enhancing the quality of housing and fostering long-term resident well-being.

6.8 Summary

This chapter addresses the gap in understanding the differences in perceptions of the importance of residential building renovation performances among homeowners with varying demographic and socioeconomic characteristics. The findings reveal that, although the mean importance ratings of 33 performance indicators are generally consistent across different subgroups within an individual demographic or socioeconomic factor, significant differences arise concerning specific performance indicators within subgroups of gender, age, education, income, family size, and length of residence. The analysis indicates that male respondents tend to assign greater importance to elevator, waterproofing and prestige and status compared to female respondents; elderly homeowners place higher value on maintenance cost, indoor natural daylighting, public lighting and construction duration than their middle-aged counterparts; homeowners with secondary education levels rate acoustical comfort and indoor natural daylighting as more important than those with lower educational

attainment; lower-income groups prioritize both green space and social space than relatively higher-income homeowners; small families are more concerned with acoustic comfort and residential density; and short-term residents demonstrate greater concern for fire safety and gas pipeline safety compared to longer-term occupants.

Chapter 7: Policy evolution and strategic recommendations for China's urban residential renovation

7.1 Introduction

The policy context constitutes a critical dimension in the development of a homeowner decision-making model for ageing residential building renovation, as it directly shapes the constraints, incentives, and frameworks within which individual and collective renovation choices are made. This chapter critically examines the evolution of China's urban renovation policies, with a particular focus on the transition from large-scale demolition and redevelopment to a more sustainable, refurbishment-oriented approach. By scrutinizing the key national policy milestones, the chapter highlights the challenges and opportunities arising from this policy shift, especially under current fiscal constraints. Drawing on empirical findings regarding homeowners' diverse priorities for building renovation, the chapter further provides evidence-based recommendations for optimizing residential renewal strategies. Through this comprehensive analysis, the chapter aims to inform policymakers and practitioners on how to balance quality, sustainability, and social equity in urban regeneration, ultimately supporting the development of more resilient and livable urban communities.

7.2 Policy transition of urban renovation

7.2.1 Large-scale demolition and redevelopment between 2013 and 2017

China has implemented numerous urban renovation policies over the past few decades, reflecting the significance of urban renewal initiatives. A key milestone in this process was the 2013 *Guiding Opinions on Accelerating Shantytown Redevelopment* (State Council of the People's Republic of China, 2013) which marked the acceleration of large-scale redevelopment efforts. To address the challenges posed by urbanization and with the fundamental objective of enhancing housing conditions for its population, this policy was initiated to accelerate the redevelopment of all categories of shantytowns. To achieve this, China set an ambitious target of renovating ten million shantytown units between 2013 and 2017 to enhance residents' living standards and contribute to the continuous improvement of urban infrastructure and public service facilities.

The 2015 *Guiding Opinions on Further Improving Urban Shantytown and Rural Dilapidated Housing Redevelopment and Supporting Infrastructure Construction* (State Council of the People's Republic of China, 2015) marked a significant policy enhancement by intensifying efforts in urban shantytown redevelopment. This directive introduced a comprehensive Three-Year Plan (2015-2017) targeting the renovation of 18 million housing units across various shantytown categories, including urban dangerous buildings and informal urban settlements. The policy initiative actively promoted monetized compensation in shantytown redevelopment projects, aiming at reducing the resettlement timeline and saving temporary relocation expenses.

In 2016, a subsequent policy, *Notice on Further Improving the Work Related to Shantytown Redevelopment* (Ministry of Housing and Urban-Rural Development, 2016), emphasized the acceleration of shantytown redevelopment and an increase in the proportion of monetized compensation for resident relocation. *The 13th Five-Year Plan for Urban and Rural Earthquake Resistance and Disaster Prevention* (Ministry of Housing and Urban-Rural Development, 2016) proposed the enhancement of seismic resilience in existing housing through shantytown redevelopment. *Implementation Measures for Incentive Policies on Shantytown Redevelopment (Trial)* (State Council of the People's Republic of China, 2016) introduced the measures for incentivizing provinces demonstrating proactive engagement and notable achievements in annual shantytown redevelopment initiatives.

The 2017 *Notice on Further Strengthening the Management of Shantytown Redevelopment Projects and Funds* (Ministry of Housing and Urban-Rural Development of China, 2017) mandated that local housing and urban-rural development departments enhance their commitment to meticulous budgeting by thoroughly assessing the appropriateness of both the average renovation area per household and the average cost per unit in shantytown redevelopment projects, thereby ensuring strict cost control in accordance with relevant laws and regulations. Furthermore, in cities and counties experiencing limited commercial housing inventory and considerable upward pressure on housing prices, local authorities are required to promptly revise shantytown redevelopment resettlement policies by prioritizing the construction of new resettlement housing, with monetary compensation no longer serving as the primary method of resettlement in these areas. The policy signified a transformative shift in urban renovation governance, characterized by three

fundamental transitions: first, from quantity-driven targets to quality-focused implementation; second, from expansionary financing to controlled fiscal management; and third, from uniform approaches to solutions tailored to local conditions. This strategic realignment was implemented as a direct response to mitigate the sustained surge in housing prices observed from 2015 to 2017 (Bank for International Settlements, 2025).

The series of policies implemented prior to 2017 resulted in extensive demolition and development activities throughout China. Between 2008 and 2017, shantytown redevelopment projects led to the renovation of 38.96 million housing units, enabling approximately 100 million individuals to transition from substandard dwellings to modern apartments. Notably, from 2013 to 2017 alone, 26.45 million units were renovated as part of the nationwide shantytown redevelopment initiative (Xinhua News Agency, 2018). Shantytown redevelopment has functioned not only as a significant livelihood improvement project but also as a catalyst for economic development, stimulating investment, consumption, and overall economic growth. From 2008 to 2018, China invested around 9.7 trillion CNY in shantytown redevelopment, with total investment in redevelopment and related industries surpassing 20 trillion yuan in 2017 alone (Xinhua News Agency, 2019). While stimulating substantial urban development, these policy incentives simultaneously created several critical challenges. The approach triggered a rapid accumulation of local government debt (Wu, 2023) and drove up urban housing prices to a level that imposed severe financial burdens on residents (Lin et al., 2021).

7.2.2 Post-2018 urban ageing building refurbishment initiatives

Since 2018, the Chinese government has progressively refined its urban renewal policies, shifting emphasis toward preserving and adaptively reusing existing buildings while discouraging excessive real estate redevelopment. A pivotal milestone occurred in September 2018 with the issuance of the *Notice on Further Improving the Preservation, Utilization, and Renovation of Existing Urban Buildings* (Ministry of Housing and Urban-Rural Development of China, 2018), which emphasized adherence to principles of maximum utilization and functional adaptation. It specifically required (1) strengthening the preservation, adaptive reuse, and renovation of existing buildings, (2) avoiding disproportionate emphasis on land development value by prohibiting indiscriminate demolition practices, and (3) implementing green development principles and encourage the energy-efficient retrofitting of existing buildings in compliance with green building standards, aiming at simultaneously enhance buildings' functional performance, occupant comfort and energy efficiency. As the first national policy explicitly prioritizing building conservation over redevelopment, the document significantly advanced adaptive reuse practices while raising public awareness of urban heritage preservation and sustainable development principles.

Subsequent policies have reinforced the shift in urban renovation from large-scale redevelopment to the refurbishment of existing communities. According to the *Notice on Advancing the Renovation of Old Residential Communities in 2019* (Ministry of Housing and Urban-Rural Development of China, 2019), the primary focus is on conducting a nationwide survey to assess the basic conditions of old urban residential neighborhoods and guiding local governments in developing renovation plans and

standards tailored to regional circumstances. The refurbishment of these communities has been elevated to a national priority, functioning not only as a livelihood project but also as an effective means to stabilize investment. Furthermore, by improving the external environment, upgrading infrastructure, and enhancing service facilities, these initiatives encourage residents to renovate their own homes, thereby boosting domestic demand while simultaneously safeguarding public wellbeing and contributing to investment stability (Ministry of Housing and Urban-Rural Development of China, 2019).

In 2020, the *Guiding Opinions on Comprehensively Advancing the Renovation of Old Urban Residential Areas* (State Council of the People's Republic of China, 2020) emphasized that urban refurbishment initiatives must adopt an evidence-based approach by rationally delineating the scope of target neighborhoods within local administrative jurisdictions, with particular focus on the renovation of pre-2000 ageing residential communities. Implementation should adhere to human-centered development principles, employing location-specific strategies that ensure precise policy interventions while strictly maintaining the voluntary participation of affected residents.

In 2021, policy focus sharpened on curbing unsustainable redevelopment practices. *Notice on Preventing Large-Scale Demolition and Construction During Urban Renewal Actions* (Ministry of Housing and Urban-Rural Development of China, 2021) adopted a prudent approach that strictly limits large-scale demolition of existing structures. As a fundamental principle, the floor area to be demolished within any urban renewal unit must not exceed 20% of the total existing floor area. The policy advocated

small-scale renovations, with emphasis on maximizing existing resources by encouraging the preservation, restoration and structural reinforcement of current buildings while upgrading their facilities, enhances structural safety, functional adaptability and energy efficiency performance. *Notice on Strengthening the Construction of Supporting Facilities in Urban Old Residential Area Renovations* (National Development and Reform Commission, 2021) further detailed the refurbishment by emphasizing the critical need to integrate supporting facilities development with safety hazard remediation in urban renewal projects. The policy proposed to prioritize communities exhibiting substantial safety risks, severely inadequate infrastructure, and strong resident renovation demand for inclusion in annual refurbishment plans. Furthermore, it advocated establishing multi-channel funding mechanisms to actively support the refurbishment initiatives.

7.2.3 The policy shift from redevelopment to refurbishment

The historical national urban renovation policies were compiled and presented in Figure 7.1. As shown in the figure, China's historical national urban renovation policies demonstrate a significant shift from large-scale demolition and redevelopment (2013-2017) to a more sustainable, preservation-oriented approach (post-2018). The earlier phase focused on rapid shantytown redevelopment, renovating over 26 million housing units while stimulating economic growth but also contributing to local debt and housing inflation. Since 2018, policies have emphasized building preservation, energy-efficient retrofits, and small-scale organic renewal, with strict limits on demolition ($\leq 20\%$ of existing area). This policy transition reflects a strategic rebalancing from quantity-

driven expansion to quality-focused, community-sensitive urban regeneration that prioritizes heritage conservation, environmental sustainability, and resident wellbeing.

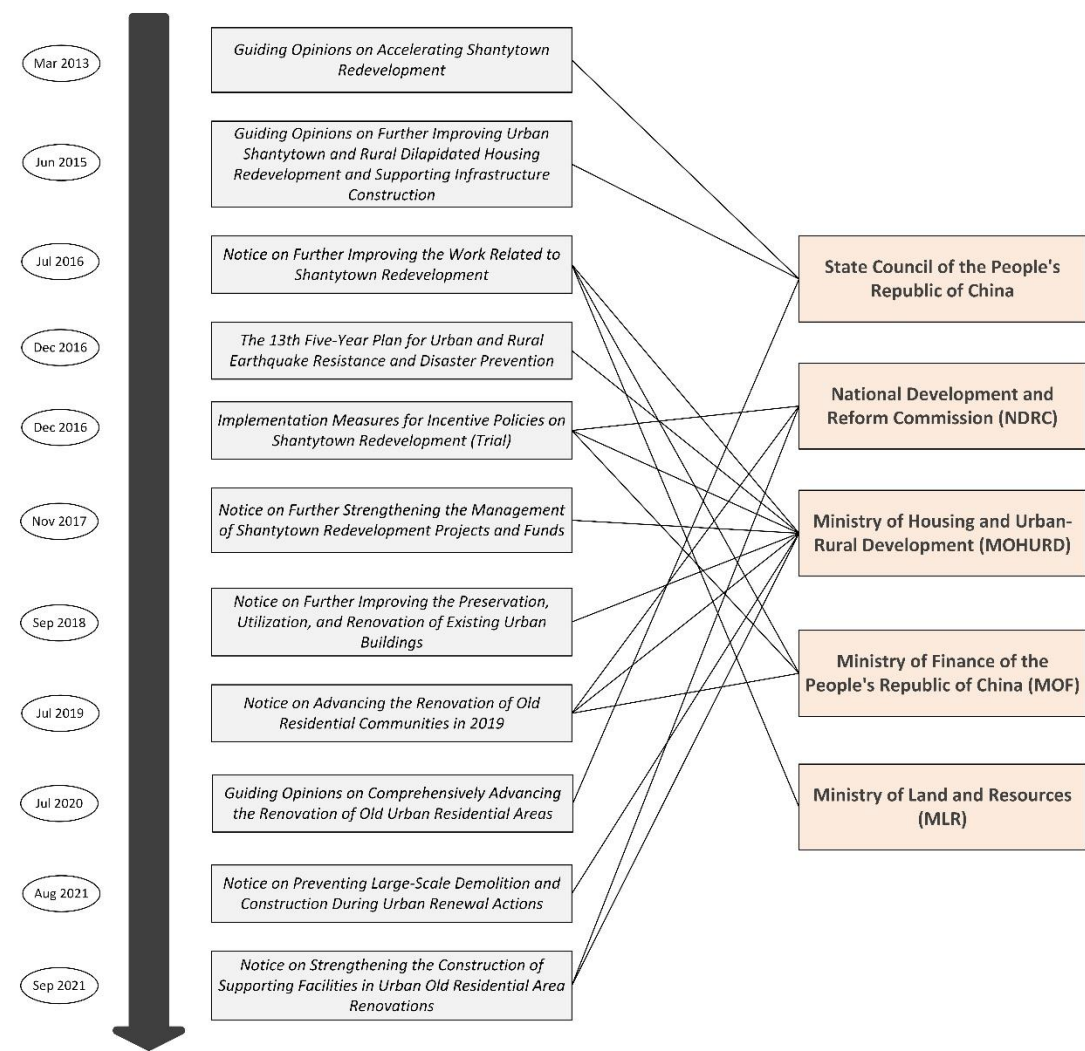


Figure 7.1 Historical renovation policy.

7.2.4 Challenges in the policy transition

China’s urban renewal policy shift since 2018, which emphasizes the preservation and adaptive reuse of existing buildings while curbing excessive real estate-driven redevelopment, has introduced notable challenges despite its intended benefits. A key

issue arises when local governments mechanically implement national policies, leading to the refurbishment of residential areas that may actually require comprehensive redevelopment, thereby wasting resources and delaying necessary urban upgrades. This misalignment generates multidimensional challenges: structurally unsafe buildings remain unaddressed, perpetuating safety risks; economically, redundant investments in superficial renovations lead to fiscal inefficiencies and poor resource allocation; and socially, inadequate improvements force residents to endure prolonged substandard living conditions, exacerbating urban inequality and fostering community dissatisfaction. These outcomes unveil the necessity for more nuanced urban regeneration policy execution, requiring local authorities to develop context-specific planning methodologies that support urban regeneration (Ministry of Natural Resources, 2023).

7.3 Recommendations for residential renovation policies and strategies based on study findings

The ranked indicators (Section 6.3) provide critical insights into residents' priorities and technical requirements for urban renewal. By aligning policy frameworks with these findings, governments can enhance the effectiveness, sustainability, and social acceptance of renewal projects. Below are evidence-based recommendations based on the findings of this study.

The findings highlight “building lifespan” as the most critical factor (Section 6.3) in homeowners' decision-making processes, indicating the necessity of systematically integrating this consideration into cost-benefit analyses for renovation projects. Given

that refurbishment may only marginally extend the lifespan of some ageing buildings, whereas demolition and reconstruction can provide over 50 years of service life, refurbishing dwellings with inherently short lifespans often leads to subsequent demolition and redevelopment within a relatively brief period, thereby resulting in unnecessary expenditure and resource wastage. From the sustainability perspective, the inclusion of “building lifespan” into decision-making is essential. When building lifespan was considered in the decision-making process, redevelopment outperformed refurbishment in terms of achieving lower carbon emissions (Palacios-Munoz et al., 2019). This finding contrasts sharply with earlier studies (Gaspar and Santos, 2015; Schwartz et al., 2022), which did not include lifespan into the decision-making. Furthermore, the government should mandate that all new renovations and reconstruction projects comply with scientifically established durability benchmarks to optimize long-term urban sustainability.

In Section 6.3, the study findings reveal that “seismic resistance ability” was rated by homeowners as the second most important indicator in the renovation of ageing residential buildings. In the context of advancing urban renewal initiatives, it is imperative that seismic resistance capacity be established as a core decision-making indicator, particularly for residential buildings situated in seismically active regions. Policymakers should mandate comprehensive seismic assessments as an integral part of the evaluation process for all renewal projects. For buildings located in areas with heightened seismic risk, the adoption of higher seismic retrofit standards is essential to ensure the safety and resilience of the built environment. In such cases, the costs associated with implementing advanced seismic retrofitting measures should be systematically compared with the costs of complete reconstruction. This comparative

analysis will enable stakeholders to make informed decisions that balance safety, economic efficiency, and long-term sustainability. Furthermore, policy frameworks should provide clear guidelines and financial incentives to support homeowners and developers in meeting these enhanced standards, thereby promoting the creation of safer and more resilient urban communities.

Gas pipeline safety emerged as the third most critical concern for homeowners in older residential renovation (Section 6.3), reflecting heightened public awareness of ageing infrastructure risks, which necessitates a risk-based decision-making framework for policymakers balancing cost-effective renovation strategies with safety imperatives. This approach should commence with third-party expert assessments to identify high-risk zones, particularly areas with pipelines exceeding 20 years of service, corrosion-prone systems, or neighborhoods with documented leak histories, followed by targeted technological interventions including mandatory safety devices such as automatic shut-off valves, corrosion-resistant materials, and IoT-enabled monitoring systems to optimize long-term safety outcomes. However, economic considerations require rigorous cost-benefit analysis, wherein comprehensive redevelopment becomes the preferred option when lifecycle refurbishment costs (with safety enhancements) approach or exceed redevelopment expenses—a threshold particularly relevant for areas requiring complete pipeline replacement or exhibiting structural vulnerabilities. Hybrid models may provide viable intermediate solutions, combining targeted safety upgrades in structurally sound buildings with selective redevelopment in high-risk clusters, thereby addressing both immediate safety concerns and long-term urban resilience objectives while maintaining fiscal responsibility.

Given the government's current emphasis on refurbishment over new construction, as well as the reality of limited fiscal resources, policy recommendations for the renewal of ageing residential buildings should prioritize targeted, cost-effective interventions that address the diverse needs of different homeowner groups. The findings of this study highlight that demographic and socioeconomic differences significantly influence residents' priorities regarding renovation performance indicators. Therefore, a one-size-fits-all approach may not be optimal. Instead, the government could implement a flexible, needs-based subsidy or incentive scheme that allocates resources according to the specific concerns of various subgroups—for example, supporting elevator upgrades and waterproof in communities with a higher proportion of male residents, improving indoor natural daylighting and public lighting qualities for the elderly, enhancing green and social spaces in lower-income neighborhoods, strengthening acoustic insulation for communities with higher education levels or small family sizes, and improving fire and gas safety in areas with more short-term occupants. This targeted approach would not only improve the effectiveness of government spending but also promote greater satisfaction and participation among homeowners in the renewal process.

7.4 Summary

This chapter traces China's urban renovation policy transition from the focus on large-scale demolition and redevelopment approach (2013–2017) to the refurbishment-focused model (post-2018). While the early phase successfully renovated over 26 million housing units and stimulated economic growth, it also contributed to local debt accumulation. The post-2018 shift toward refurbishment, energy-efficient retrofits, and organic renewal reflects a commitment to sustainable urban development but has

introduced new challenges, including misaligned priorities between national directives and local ageing dwellings.

Building on empirical findings, the chapter proposes evidence-based policy recommendations to optimize renewal strategies within fiscal constraints. Key priorities emerge, such as: (1) integrating building lifespan as a critical decision-making factor in cost-benefit analyses to guide refurbishment versus redevelopment choices; (2) elevating seismic resilience standards for ageing residential buildings in high-risk zones; and (3) implementing demographic and socioeconomic-sensitive interventions (e.g., green and social spaces enhancements in lower-income neighborhoods, acoustic improvements for small families). The recommendations emphasize hybrid models that combine targeted safety retrofits with selective redevelopment, balancing immediate needs with long-term resilience. By aligning policy frameworks with resident priorities, this chapter provides a roadmap for sustainable urban renovation that respects fiscal limits while addressing safety, equity, and environmental goals—critical for China’s next-phase urbanization.

Chapter 8: Conclusions

8.1 Introduction

This chapter presents the conclusion of the research study by summarizing the key results, findings, and the extent to which the study's objectives have been achieved. In addition, this chapter discusses the research significance and both academic and practical contributions of the research. Finally, it points out the study's limitations and proposes directions for future research.

8.2 Research objectives fulfilments and key findings

The fulfillment of the research objectives is illustrated in Figure 8.1. The study commenced by establishing seven defined research aims. To address these, a systematic literature review was first conducted, which pinpointed a critical gap: the limited consideration of homeowner preferences in the decision-making of residential building renovation. Building upon this gap, the research identified 33 homeowner relevant performance indicators and collected homeowner importance ratings to shortlist 24 KPIs. Furthermore, the study uncovered six underlying components. Subsequently, an index model was developed to quantify the significance of each indicator and component. The analysis further revealed significant variations in preferences across different demographic and socioeconomic subgroups. Ultimately, the research formulated evidence-based policy and strategic recommendations.

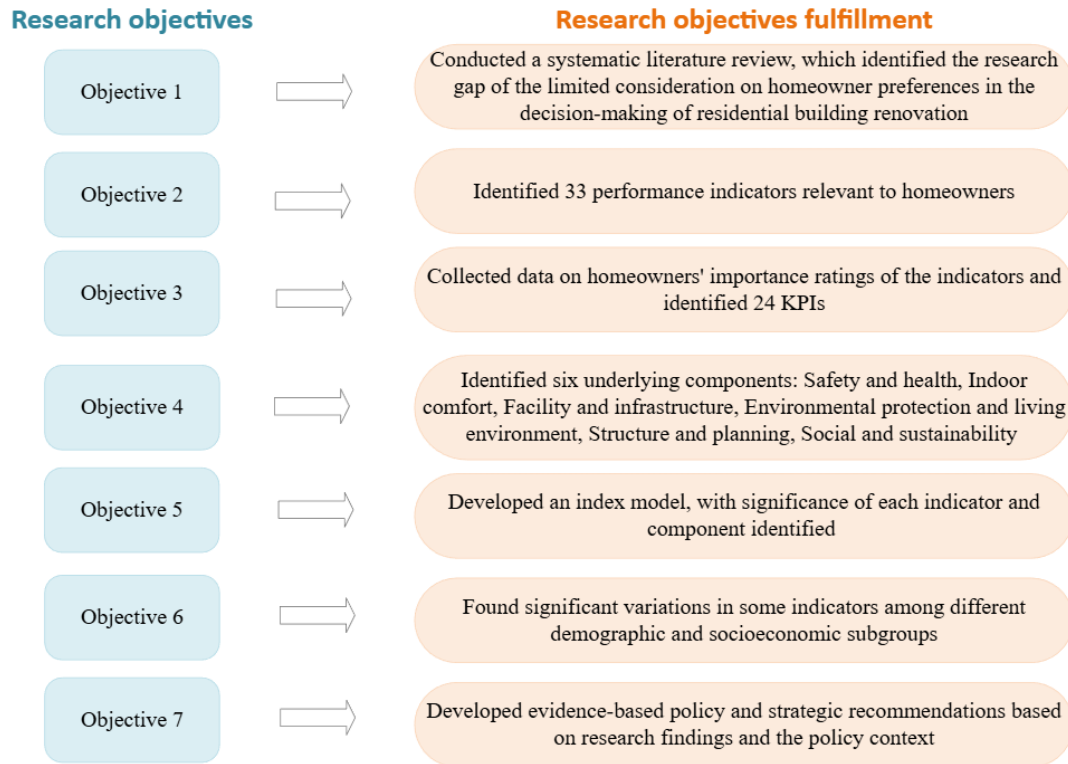


Figure 8.1 Research objectives fulfilment.

8.2.1 Current trends and research gaps in residential building performance evaluation

The first objective of this study was to identify research gaps in the performance evaluation of residential buildings, as addressed in Chapter 2. A hybrid review methodology was employed, involving a three-stage analysis of relevant literature. Initially, Scopus-retrieved publications were screened for relevance, followed by a scientometric analysis of bibliographic data using VOSviewer. Finally, an in-depth qualitative review was conducted on key studies. This research uncovered the study trend, research hotspots, prominent contributors, research gaps and directions in the field of performance evaluation of residential buildings. Through comprehensive analysis, four primary research hotspots were identified, as shown in Table 2.2: (1)

energy retrofit and energy efficiency assessment, (2) life cycle assessment and sustainability, (3) thermal comfort and other housing quality assessments, and (4) decision-making criteria and methods. Furthermore, the investigation uncovered several significant research gaps and proposed future directions (Figure 2.8): (i) assessments of retrofits incorporating renewable energy and energy storage systems; (ii) evaluation of policy options and financial incentives to overcome financial constraints; (iii) establishment of reliable embodied energy and carbon datasets; (iv) indoor environment assessment concerning requirements of COVID-19 prevention and involvement of water quality, acoustic insulation, and daylighting indicators; and (v) holistic decision-making model concerning residents' intentions and safety, health, well-being, and social indicators.

8.2.2 Performance indicators relevant to homeowners in residential building renovation

The study's second objective sought to identify the comprehensive range of performance indicators relevant to homeowners in residential renovation. This was achieved through a dual approach combining systematic literature review and semi-structured expert interviews. The review yielded 32 indicators from literature, while the expert interviews eliminated 11 non-essential indicators and added 12 new indicators. These processes resulted in a final set of 33 performance indicators, as presented in Table 4.1 and visually summarized in Figure 4.1.

8.2.3 Homeowner-perceived key performance indicators

The third objective of this study was to assess the importance levels assigned by homeowners to the 33 performance indicators and identify the most critical KPIs for inclusion in the decision-making framework. This objective was achieved through a questionnaire survey conducted on homeowners residing in ageing residential buildings, who provided importance ratings for all 33 indicators. Using normalization techniques, the study identified 24 KPIs from the original set, as detailed in Table 5.1. These selected indicators demonstrated mean importance values ranging from 4.69 (highest priority) to 4.11 (lowest priority among the selected KPIs), establishing a clear hierarchy of homeowner preferences for residential renovation considerations. The top three important KPIs were “building lifespan”, “seismic resistance ability” and “gas pipeline safety”, with respect mean values of 4.69, 4.60 and 4.55.

8.2.4 The underling factors of key performance indicators

The fourth objective of this study was to explore the underlying factors of KPIs. This objective is addressed through the application of FA, a dimensionality reduction technique that consolidates measurable and observable variables into a smaller set of latent variables characterized by shared variance. As detailed in Section 5.3, the analysis identifies six clusters underlying the 24 KPIs: Safety and Health, Indoor Comfort, Facility and Infrastructure, Environmental Protection and Living Environment, Structure and Planning, and Social and Sustainability. Collectively, these six components account for 65.2% of the total variance.

8.2.5 Development of a homeowner decision-making index model for residential renovation

The fifth objective of this study was to develop an index model to support homeowner decision-making in residential building renovations. This was achieved through FSE, which determined the weights of individual indicators and their respective clusters, established critical index values of each cluster and the overall model. The analysis revealed that Social and Sustainability cluster had the highest critical index value (4.441), followed by Structure and Planning (4.436), Safety and Health (4.344), Facility and Infrastructure (4.264), Environmental Protection and Living Environment (4.168), and Indoor Comfort (4.157). The finalized index model is presented in Figure 5.1, providing a structured framework for evaluating renovation priorities.

8.2.6 Demographic and socioeconomic differences in homeowners' importance perceptions

For the sixth objective, the variations in homeowners' importance ratings of residential renovation performance indicators across different demographic and socioeconomic groups were examined. This objective was addressed through a comprehensive statistical analysis, including mean ranking analysis, ICC assessment, and the Kruskal-Wallis test followed by post-hoc Dunn's tests. The analysis reveals that while mean importance ratings of the 33 performance indicators remain generally consistent across various demographic and socioeconomic subgroups, statistically significant differences emerge for specific indicators among subgroups within gender, age, education level, income, family size, and length of residence factors. Notably, male respondents

attribute greater importance to “elevator”, “indoor natural daylighting”, and “prestige and status” compared to female respondents. Elderly homeowners prioritize “maintenance cost”, “indoor natural daylighting”, “public lighting” and “construction duration” more than middle-aged residents. Homeowners with middle school level of education value “acoustic comfort” and “indoor natural daylighting” more highly than those with lower educational attainment. Lower-income groups place greater emphasis on “green space” and “social space” than higher-income households. Small families show heightened concern for “acoustic comfort” and “residential density”, while short-term residents demonstrate greater prioritization of “fire safety” and “gas pipeline safety” compared to long-term occupants. These findings highlight how distinct demographic and socioeconomic characteristics influence homeowners’ valuation of specific renovation performance indicators.

8.2.7 Policy and strategy recommendations for residential renovation

The seventh objective of this study focused on developing evidence-based policy recommendations and implementation strategies to promote homeowner-inclusive approaches in residential renovation practices. This objective was achieved through a comprehensive analysis of China’s urban renovation policy evolution, specifically examining the paradigm shift from large-scale demolition and redevelopment (2013-2017) to the current refurbishment-oriented model (post-2018). By integrating these policy insights with the study’s empirical findings, the research proposed policy and strategy recommendations to enhance urban renewal renovation with considerations on both policy context and prioritization of resident participation and sustainability.

8.3 Contributions

This study offers both theoretical and practical contributions, which are multidimensional, offering insights into the field of urban renovation. Theoretically, it advances discipline by establishing a comprehensive evaluation framework that captures the multifaceted nature of homeowners' preferences. By identifying 33 critical indicators, the research enriches the existing literature on residential renovation decision-making. Furthermore, the study addresses a critical theoretical gap by uncovering preference heterogeneity across demographic and socioeconomic groups, offering new insights into how these variations reshape renovation priorities.

Practically, the developed index model and shortlisted KPIs serve as a strategic toolkit for a wide range of stakeholders to optimize the planning, design, and implementation of ageing dwelling renovations. By aligning renovation efforts with identified homeowner priorities, project teams can foster consensus and elevate resident satisfaction, ensuring more sustainable and socially accepted outcomes. Besides, the study provides practical implications for tailored decision-making to accommodate the diverse motivations and priorities of various demographic and socioeconomic features. Ultimately, the study contributes to the development of more sustainable and effective urban housing renovation solutions, which not only elevate housing quality but also enhance the overall well-being and satisfaction of diverse resident groups.

The study findings have several practical applications. For policymakers, by utilizing the ranked importance of performance indicators, they can formulate targeted renovation policies and refine building codes that align with actual resident needs.

Furthermore, the model facilitates the design of evidence-based communication and motivation strategies, thereby increasing the social acceptance of urban renewal initiatives. For developers, the index model serves as a robust risk-mitigation tool. By identifying high-priority KPIs—such as those in the top tier of Table 5.1—developers can strategically allocate resources toward enhancements that secure the strongest homeowner support, effectively reducing project execution risks and social conflicts. For architects, engineers, and planners, they can employ the index model to optimize building designs during the planning phase. By focusing on indicators with high importance scores (e.g., IN23 and IN15), design teams can ensure that technical solutions are both resource-efficient and fundamentally resident-centric.

8.4 Limitations and future research directions

Admittedly, this study has several limitations. In terms of the limitations in the systematic literature review, the literature data collected was confined to the Scopus database. Besides, keywords used in searching the literature could hardly be exhaustive. Future research of this kind may cover other literature databases and keywords to complement the foregoing review findings. Moreover, as the publications reviewed under this study were limited to journal articles, other publication types such as government reports, conference papers, and working papers could be included in the future to enrich the review results (Benzies et al., 2006). Lastly, the review focused on ageing residential buildings. Future research can take a similar approach to study the performance assessment of other building types, the results of which will benefit a wider community including practitioners and researchers in the built environment sector.

Regarding the development of the index model, the study focused exclusively on homeowners living in ageing multi-story residential buildings in China, leaving other housing types such as apartments, houses, bungalows and urban villages unexplored. Besides, different regions exhibit varying climatic, cultural and social contexts, which may significantly influence homeowners' attitudes and preferences toward renovating their dwellings. For instance, residents living in seismic zones are likely to place greater importance on seismic resistance capabilities compared to those living in non-seismic areas. While such regional disparities remain unexplored, future research is recommended to utilize the list of indicators presented in this study as a reference framework. By conducting interviews with local experts, surveying local residents and applying the FA and FSE processes, the index model can be customized to suit the unique characteristics of different regions. This approach would enhance the model's applicability and accuracy across diverse geographical contexts.

While this study provides valuable insights into significant variations in homeowners' perceptions of renovation performance indicators across different demographic and socioeconomic groups, several limitations should be addressed in future research. The use of purposive sampling, though yielding preliminary significant findings, constrains broad generalizability. Although rigorous measures were implemented to ensure data quality and questionnaire reliability, the sample size remained limited. Future research could employ probability sampling methods to obtain larger, more representative samples, thereby enhancing the external validity of findings. Government bodies, with their superior resources for large-scale data collection, could facilitate this through random sampling designs and multivariate modeling to investigate homeowner

renovation priorities. The indicators and demographic/socioeconomic variables identified in this study may serve as critical variables for future research to incorporate into analytical models examining how these factors influence homeowners' renovation decisions. Additionally, while this study focused on demographic and socioeconomic factors, it did not extensively explore external factors such as climate, location, or policy context that could influence homeowners' perceptions. Future research could incorporate these external variables to provide a more comprehensive understanding, thereby aiding in the development of more effective renovation strategies for attaining a sustainable built environment.

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Appendix

A1. Questionnaire survey

Questionnaire

The purpose of this survey is to investigate the degree of residents' concern in the decision-making of renovation of old residential areas. The survey was conducted by a research team from the Hong Kong Polytechnic University and approved by the PolyU Review Board (PolyU IRB) (Reference No.: HSEARS20230317006). This research is purely for academic purposes, and we promise not to disclose your identity. We hope you answer every question honestly and seriously, thank you for your cooperation.

Part 1 Basic information

Please tick your answer:

Basic personal information

1. Gender: Male ☐ Female ☐
2. Ages: 18-44 ☐ 45-59 ☐ 60 and over ☐
3. Education: Primary school and below ☐
Middle school (junior high school/high school) ☐
University ☐
4. Personal annual income: Income < 20,000 ☐ 20,000 ≤ Income < 30,000 ☐
30,000 ≤ Income < 50,000 ☐ 50,000 ≤ Income < 90,000 ☐
Income ≥ 90,000 ☐

Residence information

5. Type of residence: Self-owned ☐ Rent ☐
6. Housing size: _____square meters
7. Permanent resident population in the household: _____people
8. Length of residence: _____years
9. Building age: _____years

Part 2 Importance Rating

In the consultation on the renovation of old residential buildings, what do you think is the importance of the following aspects? Please rate the importance of each aspect:

	Extremely unimportant	Unimportant	Neutral	Important	Extremely important
	1	2	3	4	5
Carbon reduction	☐	☐	☐	☐	☐
Energy saving	☐	☐	☐	☐	☐
Water saving	☐	☐	☐	☐	☐
Green space	☐	☐	☐	☐	☐
Renovation disturbance	☐	☐	☐	☐	☐
Building lifespan	☐	☐	☐	☐	☐
Maintenance cost	☐	☐	☐	☐	☐
House value increment	☐	☐	☐	☐	☐
Rental	☐	☐	☐	☐	☐
Indoor air quality	☐	☐	☐	☐	☐
Indoor thermal comfort	☐	☐	☐	☐	☐
Acoustic comfort	☐	☐	☐	☐	☐
Indoor natural daylighting	☐	☐	☐	☐	☐
Water quality	☐	☐	☐	☐	☐
Elevator	☐	☐	☐	☐	☐
Waterproof	☐	☐	☐	☐	☐
Sewer blockage risk	☐	☐	☐	☐	☐
Parking spot	☐	☐	☐	☐	☐
EV charging pile	☐	☐	☐	☐	☐
Public lighting	☐	☐	☐	☐	☐
Privacy	☐	☐	☐	☐	☐

	Extremely unimportant	Unimportant	Neutral	Important	Extremely important
	1	2	3	4	5
Fire safety	☐	☐	☐	☐	☐
Seismic resistance ability	☐	☐	☐	☐	☐
Electric wire layout	☐	☐	☐	☐	☐
Gas pipeline safety	☐	☐	☐	☐	☐
Escapeway	☐	☐	☐	☐	☐
Anti-theft and monitoring	☐	☐	☐	☐	☐
Aesthetics	☐	☐	☐	☐	☐
New lifestyle	☐	☐	☐	☐	☐
Prestige and status	☐	☐	☐	☐	☐
Construction duration	☐	☐	☐	☐	☐
Residential density	☐	☐	☐	☐	☐
Social space	☐	☐	☐	☐	☐

A2. Semi-structured expert interview guide

Semi-structure interview

Introduction of the purposes and objectives of the interview

This semi-structured interview is conducted to validate, filter, and supplement the list of indicators collected from prior literature, which may be of concern to homeowners regarding the renovation of ageing residential buildings. All information collected during this interview will be treated with the strictest confidentiality and used solely for academic research purposes. To protect your privacy, all personal identifiers will be removed, and your responses will be anonymized in any subsequent reports or publications.

Part 1 Expert background

1. Could you please briefly describe your professional experience in residential renovation and construction, or your involvement in homeowner-related projects?
2. Could you specify your total years of professional experience in this field?

Part 2 Indicator validation, filter and supplementation

1. Based on your expertise, do you consider the following indicator critical for homeowners' decisions regarding their dwelling renovation?
2. In your professional opinion, should this indicator be retained or removed from our list of important performance indicators for homeowners?
3. Beyond the current indicator list, are there any additional indicators that you believe are critical to homeowners regarding residential renovation and should be added? Could you please provide the rationale for their importance?