ESTABLISHMENT OF A DECISION-SUPPORT SYSTEM FOR SMART RETROFITTING FOR OFFICE BUILDINGS

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

__________________________ (Signed)

Manimel Peirislage Sanduni Nuwanthika PEIRIS (Name of student)

This thesis is lovingly dedicated to all my dear ones who wholeheartedly wished this for me but left this world too soon. May your souls rest in peace in the arms of God! This achievement is for you.

Abstract

In an era of rapid urbanization, growing populations and rising energy demands, the need for sustainable and smart solutions has never been greater. Buildings account for a major share of worldwide energy consumption making the built environment a significant contributor to greenhouse gas emissions. In this regard, Smart Building (SB) technology is a promising solution as it allows for more efficient use of resources such as electricity, water and gas, facilitating a comfortable living environment for building occupants and contributing to a more sustainable future. Hence, it significantly helps to meet climate pledges while also addressing other social and economic challenges such as evolving patterns of work and the constant demand for cost reduction. For existing buildings, retrofitting them with SB technology through a process called 'Smart Retrofitting (SR)' appears to be the obvious choice for achieving these goals. SR is the comprehensive process of upgrading pre-existing building systems using appropriate, if not optimal, retrofit techniques to integrate SB technology. It transforms existing buildings into modern, automated structures through strategic applications of Information and Communication Technology (ICT) enhanced Renewable Energy Systems (RES) and Building Energy Management Systems (BEMS). SR achieves this through the integration of advanced technologies such as Internet of Things (IoT)-enabled devices and data driven decision-making algorithms, some of which are increasingly based on Artificial Intelligence (AI). These systems allow for real-time monitoring and control of building operations, creating environments that are not only efficient but also highly responsive to user needs.

Despite the transformative potential of SR projects, their implementation in office buildings involves significant challenges, including device interoperability, data integration, and balancing initial investment costs with long-term benefits. These challenges vary significantly between developing and developed regions, where differences in building stock, economic constraints, regulatory frameworks, and technological capacity necessitate distinct approaches to retrofitting decisions. For facility managers and decision-makers, these retrofits require addressing multi-faceted objectives: enhancing operational efficiency, ensuring occupant satisfaction, reducing environmental footprints, and achieving financial viability. To navigate these complexities, a robust Decision-Support Systems (DSS) is essential to provide a structured framework for selecting appropriate retrofit strategies. Developing such a holistic DSS for SR, with the present domain knowledge, is difficult, given the significant gaps in the

existing literature and practice. Therefore, the aim of this study is to establish a holistic Smart Retrofitting Decision-Support System (SRDSS) for office buildings. The envisaged SRDSS evaluates and ranks retrofit alternatives for an SR project based on their performance across assessment criteria. The scope of this research is confined to leasehold office buildings, where ownership is retained by a landlord, and the majority of the space is occupied by tenants. To evaluate the model's applicability across different economic contexts, Hong Kong and Sri Lanka are selected as representative cases of developed and developing regions, respectively.

The study employed a mixed-method research approach that utilized Multi-Criteria Decision-Making (MCDM) techniques. As an initial step in developing the SRDSS, a comprehensive literature review was conducted to identify the critical criteria to be considered when making SR decisions. A systematically identified set of publications was critically analysed using content analysis. The list of criteria identified from literature was finalized (by excluding any irrelevant criteria and adding any other important criteria) in two stages: a focus group meeting followed by a questionnaire survey. The final set of criteria includes: (1) investment cost, (2) operational cost, (3) financial return, (4) automated risk prediction and response capabilities, (5) reliability of retrofit option, (6) compatibility with existing systems, (7) requirement of competent Facility Management (FM) staff, (8) ease of implementing retrofitting project, (9) indoor environmental quality, (10) user-friendliness, (11) energy saving capabilities, (12) data protection capabilities, and (13) improved access control and surveillance.

The importance weights of criteria were then determined using a combination of two methods. The first method, the Analytic Network Process (ANP), generated weights based on expert opinions, while the second method, the Entropy method, generated weights based on empirical data of real-world SR projects. Combining these methods ensures a balanced, accurate and robust set of criteria weights, as ANP captures the interdependence amongst criteria and the Entropy method exploits data variability. Through a series of expert interviews, the final list of 13 criteria was presented to industry experts to establish ANP-based importance weights. Twelve experts were interviewed from Hong Kong and twelve from Sri Lanka, totalling 24 interviews, from which a fixed set of weights was produced for each criterion.

Next, the methods for scoring retrofit alternatives under each criterion were developed. These methods were presented to two experts, one from Hong Kong and one from Sri Lanka, to obtain feedback on their practicality. The scoring methods involved direct value inputs and subjective scoring on a Likert scale (1–5), depending on the nature of respective criterion. Direct value inputs were used for quantitative criteria such as investment cost, operational cost, financial return and energy saving capabilities. They were input directly using the quantitative values submitted by the suppliers or calculated by the facility manager's team. Likert-scale scoring was used for qualitative criteria, which include automated risk prediction and response capabilities, reliability of retrofit option, compatibility with existing systems, requirement of competent FM staff, ease of implementing retrofitting project, indoor environmental quality, user friendliness, data protection capabilities, and access control and surveillance capabilities. These qualitative criteria required assigning a subjective score based on the facility manager's perception of each retrofit alternative.

Case studies were conducted to develop the SRDSS further. Four office buildings were selected, comprising two from Hong Kong and two from Sri Lanka. The case studies included discussions with the facility managers overseeing the SR projects undertaken at the selected buildings. General project data and detailed data on various retrofit alternatives from different suppliers were collected. Referring to a bespoke questionnaire, each retrofit alternative was scored by the respective facility manager. The retrofit alternative scores were then used to calculate the objective, context-specific weights for each criterion using the Entropy method. Once the Entropy weights were calculated, the weights derived from the ANP method were merged with the Entropy weights to establish a combined weight for each criterion. Afterwards, the 'Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)' method was used to rank retrofit alternatives by determining each option's closeness to an ideal solution.

Following the case studies, a structured validation exercise was conducted to ensure the reliability, accuracy and practical applicability of the SRDSS. The validation exercise elicited feedback from ten industry experts in Australia using a bespoke interview guideline. The expert feedback was addressed by conducting iterative refinements on the SRDSS that increased its practicality, decision confidence and ease of use for facility managers. The validation by Australian industry experts ensured that the SRDSS is credible and adaptable beyond Hong Kong and Sri Lanka.

The final outcome of this study is a ready-to-use SRDSS in the form of a Visual Basic for Applications (VBA) macro-enabled Microsoft (MS) Excel tool. Using 13 decision criteria, the SRDSS applies ANP and Entropy for criteria weighting, followed by TOPSIS for selecting the optimal retrofit solution. Applying the SRDSS in the case studies of the two regions, Hong Kong and Sri Lanka, demonstrates its versatility in accommodating regional differences in

decision-making for SR projects. By integrating VBA automation in MS Excel, the SRDSS streamlines data entry, calculations and visualization, making it accessible and user-friendly for facility managers without requiring advanced computational knowledge. In addition to advancing data-driven decision-making in SR, the outcome of this study serves as a scalable framework adaptable to various building typologies and global contexts, contributing to the significant betterment of the built environment.

Keywords: Smart Retrofitting; Decision-Support System; Office Buildings; Developed Regions; Developing Regions; Multi-Criteria Decision-Making (MCDM); Analytic Network Process (ANP); Entropy; Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

LIST OF RESEARCH PUBLICATIONS

Refereed Journal Papers (published)

1. **Peiris, S.**, Lai, J. H. K., & Kumaraswamy, M. M. (2024). Smart retrofitting for office buildings: Comparison of decision-making criteria between developing and developed regions. *Journal of Building Engineering*, *97*, 110957. DOI: 10.1016/j.jobe.2024.110957

2. **Peiris, S.**, Lai, J. H. K., Kumaraswamy, M. M., & Hou, H. C. (2023). Smart retrofitting for existing buildings: State of the art and future research directions. *Journal of Building Engineering*, *76*, 107354. DOI: 10.1016/j.jobe.2023.107354

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1. **Peiris, S.**, Lai, J. H. K., Kumaraswamy, M. M., & Wong, J. K. W. Establishment of a decision-support system for smart retrofitting for office buildings.

2. **Peiris, S.**, Lai, J. H. K., & Kumaraswamy, M. M. Identifying criteria for smart retrofitting decisions in buildings.

3. **Peiris, S.**, Lai, J. H. K., & Kumaraswamy, M. M. Contextual determinants of smart retrofitting decisions: a comparative stakeholder analysis in Hong Kong and Sri Lanka.

Refereed Conference Papers (published)

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2. **Peiris, S.**, Lai, J. H. K. & Kumaraswamy, M. M. (2023). *Smart retrofitting decision-making criteria for buildings: shortlisting via a questionnaire survey* [Paper presentation]. The 46th Australasian Universities Building Education Association (AUBEA) 2023 Conference, Auckland, New Zealand.

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4. **Peiris, S.**, Lai, J., & Kumaraswamy, M. M. (2022). Smart retrofitting of buildings: a bibliometric study. *IOP Conference Series: Earth and Environmental Science*, *1101*, 022013. IOP Publishing. https://doi.org/10.1088/1755-1315/1101/2/022013.

5. **Peiris, S.**, Lai, J., & Kumaraswamy, M. M. (2020). *Holistic decision making for smart retrofitting for commercial buildings: literature review and a research methodology* [Paper presentation]. ASFM Fall 2020 Virtual Colloquium.

RESEARCH SEMINARS CONDUCTED

1. Speaker at the seminar on 'Decision-Making Strategies for Smart Retrofitting of Office Buildings' organised by the School of Built Environment, University of Technology Sydney, held on 27th August 2024.

2. Speaker at the BEEE RPg Student Orientation and Research Salon – Series 27 on 'Developing a Decision-making Model for Smart Retrofitting for Office Buildings' organised by the Department of Building Environment and Energy Engineering, The Hong Kong Polytechnic University, held on 27th October 2023.

3. Speaker at the 3rd FaMRU Research Seminar on 'Decision-Making Strategies for Smart Retrofitting of Office Buildings' organised by the Department of Facilities Management, University of Moratuwa, Sri Lanka, held on 17th August 2023.

4. Speaker at the Building Services Engineering Sectional Committee (BSESC) webinar on 'Decision-Making Strategies for Smart Retrofitting of Office Buildings' organised by the BSESC – The Institution of Engineers Sri Lanka, held on 30th March 2023.

HONOURS AND AWARDS

1. The Best Paper Award in the category 'W070 – Facilities Management and Maintenance' for the paper titled 'Developing a Smart Retrofitting Decision-Making Model for Office Buildings: A Case Study' at the CIB World Building Congress 2025 held at Purdue University, United States of America, from 19 – 23 May 2025.

2. The 4th Emerald Award with a cash prize of GBP 100 for the paper titled 'Developing a Smart Retrofitting Decision-Making Model for Office Buildings: A Case Study' at the CIB World Building Congress 2025 held at Purdue University, United States of America, from 19 – 23 May 2025.

3. Winner of the BEEE Three Minute Thesis (3MT®) Competition 2025 organised by the Department of Building Environment of Energy Engineering, The Hong Kong Polytechnic University, held on 7th May 2025.

4. The paper titled 'Establishing criteria for smart retrofitting decision-making for buildings' was honoured as one of the 8 Outstanding Papers based on the scientific reviews of anonymised papers at the CIB W070 Conference on Facility Management and Maintenance 2023, held at Norwegian University of Science and Technology, Trondheim, Norway, from 8 - 12 May 2023 .

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ABBREVIATIONS

AC	-	Average Citations
AES	-	Advanced Encryption Standard
AHP	-	Analytical Hierarchy Process
AHU	-	Air Handling Unit
AI	-	Artificial Intelligence
ANP	-	Analytic Network Process
ANPR	-	Automatic Number Plate Recognition
API	-	Application Programming Interface
APY	-	Average Publication Year
ASHRAE	-	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BACS	-	Building Automation Control System
BACnet	-	Building Automation and Control network
BAS	-	Building Automation System
BEAM	-	Building Environmental Assessment Method
BEM	-	Building Energy Modelling
BEMS	-	Building Energy Management Systems
BIM	-	Building Information Modelling
BIPV	-	Building-Integrated Photovoltaics
BMO	-	Building Management Offices
BMS	-	Building Management System
BREEAM	-	Building Research Establishment Environmental Assessment Method
BSOMES	-	Building Services Operation and Maintenance Executives Society
CBR	-	Case-Based Reasoning
CCTV	-	Closed Circuit Television
CEO	-	Chief Executive Officer
CFO	-	Chief Financial Officer
CI	-	Consistency Index
CIBSE	-	The Chartered Institution of Building Services Engineers
COP	-	Coefficient of Performance
CR	-	Consistency Ratio
CRITIC	-	Criteria Importance Through Intercriteria Correlation
CV	-	Coefficient of Variation
DR	-	Demand Response
DSS	-	Decision-Support System
EA	-	Emergy Analysis
ELECTRE	-	ELimination Et Choix Traduisant la REalité – Tri
EMS	-	Energy Management System
EPBD	-	Energy Performance of Buildings Directive
EPC	-	Energy Performance Contracting
ESG	-	Environmental, Social and Governance
EU	-	European Union
EV	-	Electric Vehicle
FM	-	Facility Management
GDPR	-	General Data Protection Regulation
GIS	-	Geographical Information Systems
GIT	-	Georgia Institute of Technology
HK	-	Hong Kong
HKD	-	Hong Kong Dollars
HKIE	-	The Hong Kong Institution of Engineers
HKIFM	-	The Hong Kong Institute of Facility Management
HKU	-	The University of Hong Kong
HOE	-	Holographic Optical Elements
HSRP	-	Hot Standby Router Protocol
HVAC	-	Heating, Ventilation and Air Conditioning

IAQ	-	Indoor Air Quality
ICT	-	Information and Communication Technologies
IEEE	-	The Institute of Electrical and Electronics Engineers
IFL	-	Intelligent Façade Layers
IFMA	-	International Facility Management Association
IMM	-	Integrated Monitoring Methodology
IoT	-	Internet of Things
IP	-	Internet Protocol
ISM	-	Industrial, Scientific and Medical
ISPC	-	Intelligent Supervisory Predictive Control
IT	-	Information Technology
KPI	-	Key Performance Indicator
LC	-	Letters of Credit
LCC	-	Life Cycle Cost
LED	-	Light Emitting Diode
LEED	-	Leadership in Energy and Environmental Design
LKR	-	Sri Lankan Rupees
LTHES	-	Latent Thermal Heat Energy Storage System
MBIS	-	Mandatory Building Inspection Schemes
MCDM	-	Multi-Criteria Decision-Making
MIVES	-	Modelo Integrado de Valor para una Evaluación Sostenible
MPC	-	Model Predictive Control
MS	-	Microsoft
NIS	-	Negative Ideal Solution
NLP	-	Natural Language Processing
NPV	-	Net Present Value
NTU	-	Nanjing Tech University
OAT	-	One-at-a-time
PCA	-	Principal Component Analysis
PCB	-	Printed Circuit Board
PCM	-	Phase Change Materials
PD	-	Potential Datum
PDM	-	Politecnico Di Milano
PI	-	Politecnico Di Milano
PIR	-	Passive Infrared
PIS	-	Positive Ideal Solution
POC	-	Proof of Concept
PPP	-	Public Private Partnerships
PRAC	-	Pattern Recognition Adaptive Control
PRISMA	-	Preferred Reporting Items for Systematic reviews and Meta-Analyses
PROMETHEE	-	Preference Ranking Organization METHod for Enrichment of Evaluations
PU	-	Purdue University
PV	-	Photovoltaics
PVT	-	Photovoltaic-Thermal
RDCC	-	Regional Digital Control Centre
RE	-	Renewable Energy
RES	-	Renewable Energy Systems
RFID	-	Radio-Frequency Identification
RH	-	Relative Humidity
RI	-	Random Index
RICS	-	The Royal Institution of Chartered Surveyors
ROI	-	Return on Investment
SAW	-	Simple Additive Weighting
SB	-	Smart Building

SD	-	Standard Deviation
SL	-	Sri Lanka
SMART	-	Simple Multi-Attribute Rating Technique
SMHRU	-	Smart Modular Heat Recovery Unit
SR	-	Smart Retrofitting
SRDSS	-	Smart Retrofitting Decision-Support System
SRI	-	Smart Readiness Indicator
TEC	-	Technical Evaluation Committee
TLS	-	Total Link Strength
TOPSIS	-	Technique for Order of Preference by Similarity to Ideal Solution
TR	-	Ton of Refrigeration
TU	-	Terminal Unit
UBC	-	The University of The Basque Country
UEV	-	Unit Emergy Values
UK	-	United Kingdom
UN	-	United Nations
UPC	-	Universitat Politècnica de Catalunya
US	-	United States
VAV	-	Variable Air Volume
VBA	-	Visual Basic for Applications
VIKOR	-	VlseKriterijumska Optimizacija I Kompromisno Resenje
VRM	-	Virtual Retrofit Model
W3C	-	World Wide Web Consortium
WoS	-	Web of Science
WPM	-	Weighted Product Model
WPT	-	Wireless Pneumatic Thermostat
WSM	-	Weighted Sum Model
WSN	-	Wireless Sensor Network

CHAPTER ONE

1 INTRODUCTION

1.1 Research Background

Buildings have been an integral part of human-life over the years, yet they substantially contribute to the pressing global issues such as high energy demand, carbon emissions, resource depletion and pollution (Lu and Lai, 2019). While 39% of global energy-related carbon emissions are attributed to buildings (ASITE, 2020), 28% of these emissions stems from buildings in operation, predominantly for heating, cooling and lighting (World Green Building Council, 2025). In the absence of timely intervention, the ongoing high carbon emissions from existing buildings will significantly worsen climate-related risks and place the planet under serious environmental threat (Parson and Ernst, 2013). As remarked by Lord Deben, Chairman of the United Kingdom (UK)'s independent Committee on Climate Change, 2050 is the latest possible date for reaching the net zero target (Griggs et al., 2023). United Nations (UN) Sustainable Development Goals (SDGs), especially those related to sustainable cities, climate action and responsible consumption, promote the advancement of global efforts for sustainability and resilience in the built environment. Governments have implemented various regulatory and incentive-based policies at national level to promote green buildings and energy efficiency, demonstrating the significant impact these policies can have on sustainability (Lu and Lai, 2019). While newly constructed buildings increasingly incorporate these considerations, reports indicate that carbon emissions remain particularly high in the older building stock (Wilkinson and Reed, 2006). With up to 75% of today's buildings likely to remain in operation by 2050, emission reduction goals must be met by upgrading existing buildings on a large scale (ASITE, 2020). The urgency of building retrofitting has shifted from an option to a necessity, driven by increasing sustainability demands and carbon reduction targets stemming from both national/regional and global e.g., United Nations sustainability development and carbon reduction goals. The urgency of building retrofitting has shifted from being an option to a necessity, driven by increasing sustainability demands and carbon reduction targets set at national, regional and global levels (e.g., UN SDGs (United Nations, 2015)).

In this regard, Smart Building (SB) technology is a promising solution as it significantly helps to meet climate pledges while also addressing other social and economic challenges such as evolving patterns of work and the constant demand for cost reduction (Pinto et al., 2023). SB technology allows for more efficient use of resources such as electricity, water and gas, facilitating a comfortable living environment for building occupants and contributing to a more sustainable future (Sheela et al., 2024). Therefore, retrofitting existing buildings with SB technology through a process called 'Smart Retrofitting (SR)' appears to be the obvious choice, given its modularity, scalability and short payback period (Jayarathne and De Silva, 2022). SR is defined by Peiris et al. (2024) as "the comprehensive process of upgrading pre-existing building systems using appropriate, if not optimal, retrofit techniques to integrate SB technology. It transforms existing buildings into modern, automated structures with a focus on energy efficiency, human comfort, convenience and sustainability. This is accomplished through the strategic application of Information and Communication Technology (ICT)-enhanced Renewable Energy Systems (RES) and Building Energy Management Systems (BEMS)"[1]. One outstanding example of SR is the Empire State Building in New York (Al-Kodmany, 2015). Built in 1931, old buildings as such pose a significant barrier to the pursuit of carbon neutrality. However, after a substantial retrofit in 2010, this 102-storey building's carbon emissions were drastically reduced by more than 50% by 2021. This retrofit includes automation of the chiller plant with upgrades to controls, variable speed drives, and primary loop bypasses among other interventions (Hong Kong Green Building Council Limited, 2021).

Digitalization and automation in SR can help to reduce energy use and carbon emissions arising from errors by human operators and inappropriate use and/or unforeseen behaviour of building occupants (Buckman et al., 2014). In SR projects, intelligence is also utilized to optimize resource utilization in real-time and react to changing environmental circumstances through the integration of smart sensors, data analytics and the Internet of Things (IoT) (Gluszak et al., 2019). This link between technologies not only promotes a more sustainable, green and responsive physical environment, but it also provides the groundwork for tomorrow's smart cities, where technology works in tandem with community needs.

Despite its promising advantages, the adoption rate of SR technologies varies significantly across the world, influenced by diverse factors including economic capability, technical

[1]The definition of SR used throughout this thesis was developed during the course of this study to address the absence of a standard definition at the time the study began. It was later published in: Peiris, S., Lai, J. H., & Kumaraswamy, M. M. (2024). Smart retrofitting for office buildings: Comparison of decision-making criteria between developing and developed regions. *Journal of Building Engineering*, *97*, 110957. DOI: 10.1016/j.jobe.2024.110957

expertise, market maturity and decision-making frameworks. In developed regions, SR often benefits from sophisticated infrastructure, stringent regulations and increased technological adoption. With the governance and financial capabilities of the developed regions, they stand quite strong, particularly in terms of sustainability goals. To encourage carbon neutrality, governments in developed regions offer financial assistance for energy-efficient, environmentally friendly and smart renovation projects (CLP Power Hong Kong Limited, 2023, EU Directorate-General for Communication, 2023). Many of these regions, including the UK, European Union (EU) and New Zealand, have established strict national targets to reach carbon neutrality in the near future (EU Directorate-General for Climate Action, 2020). To achieve these goals, the corporate sectors have also followed the government guidelines, e.g., Global Greener Stores Commitment by Starbucks (Starbucks Corporation, 2018). Leading developers are striving towards retrofitting to support the government and keep their good standing in the industry (Sun Hung Kai Properties Limited, 2023, Swire Properties Limited, 2021). These regions and industries also have the potential to source such sophisticated retrofit systems and human resources with the necessary technical knowledge (Peiris et al., 2024).

Yet, SR is often hindered in these regions due to the high initial costs, strict cybersecurity and data privacy regulations, compatibility issues with legacy systems and complexity in decision-making for technology selection. While funding is more available in developed regions, cost-benefit justifications are still critical. Retrofit decisions are often judged on strict return-on-investment timelines (Weerasinghe et al., 2024). There is less tolerance for unclear long-term payback, even if capital is available. System compatibility and integration is a recurring issue due to legacy systems in older buildings. There is a higher demand for seamless integration with existing BEMS and enterprise systems, raising the technical bar for SR (Al Dakheel et al., 2024). Due to stricter data protection laws, e.g., General Data Protection Regulation (GDPR) (EU Directorate-General for Communication, 2018), cybersecurity and privacy become high-stakes concerns. Investors and building owners worry about vulnerabilities in IoT systems and breaches that could result in fines, lawsuits or reputational harm (Yang, 2023). Buildings in developed regions often face stringent and complex regulatory environments (zoning, fire safety, green certifications, accessibility, etc.). Smart systems must align with existing legal and code requirements, which vary between municipalities or states (Iwuanyanwu et al., 2024). Navigating this landscape increases project complexity and cost, leading to delays or hesitations in implementation. These factors make decision-making for SR highly complex, particularly given the involvement of multiple institutional stakeholders who each have a significant influence on the process. Consequently, many buildings still operate below optimal performance levels (Al Dakheel et al., 2020), underlining the need for improved decision-making systems.

There are additional layers of complexity present in developing regions. The gap between developed and developing regions in terms of achieving sustainable development goals expanded by 56%, amounting to 3.9 trillion United States (US) dollars in 2020 (OECD, 2022). Since the developing economies are under pressure to respond to the many global crises due to a lack of fiscal and monetary buffers, sustainable development is currently one of their lowest priorities (Shalal, 2025). There is very limited access to financing, green incentives or government subsidies for SR projects (Madushika and Lu, 2023). There is also shortage of skilled professionals to install, maintain and operate smart systems (Yang and Peng, 2001). Social resistance is another significant constraint in developing regions (Ejidike and Mewomo, 2023). Lack of awareness of SB benefits among decision-makers, occupants and even contractors often hinder the initiation of such projects (Ghansah et al., 2022). Regulatory frameworks are often outdated with respect to data privacy, cybersecurity or energy performance (The World Bank Group, 2021). Approval processes for retrofit interventions are slow, inconsistent or unclear (Liu et al., 2022). Moreover, SR decisions are frequently made without the support of structured frameworks and are often influenced by vendor-driven perspectives (Peiris et al., 2024). This results in the selection of suboptimal retrofit strategies, undermining long-term sustainability goals and economic efficiencies. The repercussions of these poor retrofit decisions are particularly acute in office buildings (Zhai et al., 2011), which represent essential infrastructure driving economic growth, urban productivity and employment generation in developing economies.

As office buildings constitute a significant portion of the commercial building stock, enhancing their energy efficiency and operational performance is critical to achieving broader sustainability targets (Al Dakheel et al., 2020). In an office environment, SR has the potential to facilitate improved resource utilization, environmental performance and workplace functionality through the integration of intelligent systems such as smart Heating, Ventilation and Air Conditioning (HVAC) controls, lighting automation and occupancy-based space management (King and Perry, 2017, Fairchild, 2019). These technologies enable real-time monitoring, predictive maintenance and proactive facility management, thereby reducing energy waste and enhancing occupant comfort (Talon and Goldstein, 2015). SR supports optimal space allocation and creates adaptive, user-centric work environments, contributing to improved employee well-being and productivity (Araszkiewicz, 2017). Security enhancements through intelligent surveillance and access control further reinforce the value of SR in offices (Salosin et al., 2020). These initiatives contribute to environmental stewardship and green certifications, boosting the market value and reputation of office buildings (Wiley et al., 2010). In developed regions, where office buildings are often central to economic and business activity, even minor inefficiencies can translate into significant financial and environmental impacts (CBRE, 2025). In developing regions, rapid urbanization and economic growth have accelerated the construction of new office buildings while existing buildings often remain technologically outdated, further exacerbating environmental pressures (Zhang, 2016, Andrić et al., 2019).

1.2 Problem Statement

Given the distinct yet interconnected challenges associated with SR implementation, it is imperative that SR decisions are approached through structured and well-considered processes. However, the current practices adopted by facility managers often mirror those used in traditional energy retrofitting, relying primarily on single-method approaches such as cost-benefit analysis or return-on-investment evaluations (Anarene, 2024). As a result, decision-making tends to be narrowly focused on financial considerations, particularly initial costs and projected returns. In contrast, decisions involving the adoption of SB technologies are inherently more complex, requiring the balancing of multiple, and often conflicting, objectives such as improving operational efficiency, ensuring occupant satisfaction, minimizing environmental impact and maintaining financial viability (Ghansah et al., 2021).

Despite their transformative potential, implementing SR in office buildings involves significant challenges, including device interoperability, data integration and balancing initial investment costs with long-term benefits (Farsater and Olander, 2019). These challenges manifest in several critical ways in the industry. Facility managers often lack the technical expertise or resources to evaluate emerging technologies (Yang and Peng, 2001), leading to overdependence on vendors or contractors whose recommendations may be biased by commercial interests. Owners and investors, on the other hand, remain hesitant to allocate capital without clear, quantifiable returns (Ghansah et al., 2022), resulting in delayed adoption. In practice, many projects are further constrained by fragmented procurement processes, siloed departmental responsibilities and difficulties in justifying investment decisions to senior management. In developing economies, affordability and shortage of skilled professionals limit uptake, whereas in developed economies, stringent regulations and higher occupant expectations place additional pressure on facility teams (Sarkar and Singh, 2010). Industry practitioners repeatedly highlight that the absence of standardized benchmarks prevents meaningful comparison across projects (Jayarathne and De Silva, 2022), making it difficult to establish best practices or evaluate long-term business cases (Kim and Medal, 2024). Hence it is clear that robust Decision-Support Systems (DSSs) are essential to navigate these complexities, providing structured frameworks for selecting appropriate retrofit strategies for SR.

Whereas attempts have been taken in the previous studies to devise DSSs for retrofit projects, there are deficiencies with those tools when they are applied to SR projects (Peiris et al., 2020). Most studies primarily investigated energy efficiency and technical criteria or were evaluated from a 'green' perspective (Jradi, 2020, Ibn-Mohammed et al., 2014, Abidin et al., 2019, Lu et al., 2021). However, SR must consider additional criteria such as user friendliness, convenience, data privacy and security, to name a few (Al Dakheel et al., 2020). Further, the 'operation and maintenance' factor has not been considered in most studies such as Yang and Peng (2001), Kaashi and Vilventhan (2023) and Jayarathne and De Silva (2022). However, the ultimate expectation of the users is to see the SB remain smart throughout its lifetime that is, justice to their investment (Ji and Chan, 2020). Operation and maintenance play a key role in this aspect as its attributes need to be adjusted to suit the complexity of the systems (Lai, 2010). There have been reported cases of buildings operating under unsuitable and uncomfortable operating set points and schedules, resulting from improper monitoring and controlling features that are caused by inappropriate maintenance (Shen et al., 2017). This has caused energy wastage and/or chronic discomfort conditions. There is currently no DSS that adopts a holistic approach to SR. Furthermore, most research methodologies lack the capacity to simultaneously account for multiple, often conflicting, decision criteria. The development of an advanced DSS necessitates the application of a Multi-Criteria Decision-Making (MCDM) approach (Egiluz et al., 2021). MCDM can be utilized to improve the decision-making process by considering the net costs, benefits and associated complexities. Previous studies employing MCDM in retrofitting contexts have often lacked a comprehensive consideration of relevant criteria, and the proposed approaches were not always practical for real-world application (Si et al., 2016, Baseer et al., 2023). While real-time data collection through approaches such as temporary sensor installations and modelling through simulation offer major benefits to the SR decision-making process (Kaashi and Vilventhan, 2023), not all buildings have the capabilities or capital to implement them at the decision-making stage. The recommended approach must be user-friendly and time-efficient.

Therefore, given the current imperatives and gaps in SR decision-making, the importance of a comprehensive and adaptable DSS for SR becomes clear. It is essential to navigate the emphasized complexities, providing a structured framework for selecting appropriate technologies in SR. Even though previous studies have attempted to develop DSSs for SR, there lies various inherent issues such as the lack of holistic multi-criteria integration, over-reliance of complex methodologies, limited applicability across regions and limited scalability and adaptability. With regard to a DSS that takes a holistic approach to address the critical issues of SR, currently there is a significant gap in the existing literature and practice.

1.2.1 Research Aim

Having identified multiple challenges and complexities in SR decision making, this research aims to develop a Smart Retrofitting Decision-Support System (SRDSS) for holistic, optimal selection of SR alternatives for office buildings.

1.2.2 Research Objectives

The following objectives were formulated to address the stated research aim.

1. Identify, refine and structure a comprehensive set of criteria for evaluating SR alternatives in office buildings
2. Establish the relative importance of the identified criteria by capturing their interdependence
3. Develop an SRDSS through the integration of MCDM methods
4. Apply the SRDSS to real-world case studies from both developed and developing regions and compare the findings between the regions
5. Validate the usability, reliability and practicality of the SRDSS and refine the system based on validation outcomes

1.3 Scope of the Study

The scope of this research is confined to leasehold office buildings, where ownership is retained by a landlord, and most of the space is occupied by tenants. To demonstrate the applicability of the envisaged SRDSS across different economies, Hong Kong and Sri Lanka were selected as cases to represent developed and developing regions, respectively. The SRDSS considers

SR for building services installations rather than structural retrofitting such as seismic reinforcement.

1.4 Research Design

A structured approach was adopted in this study to address the identified research gap. The SRDSS was developed through a five-phase process, as illustrated in Figure 1-1, guided by a mixed-methods research approach.

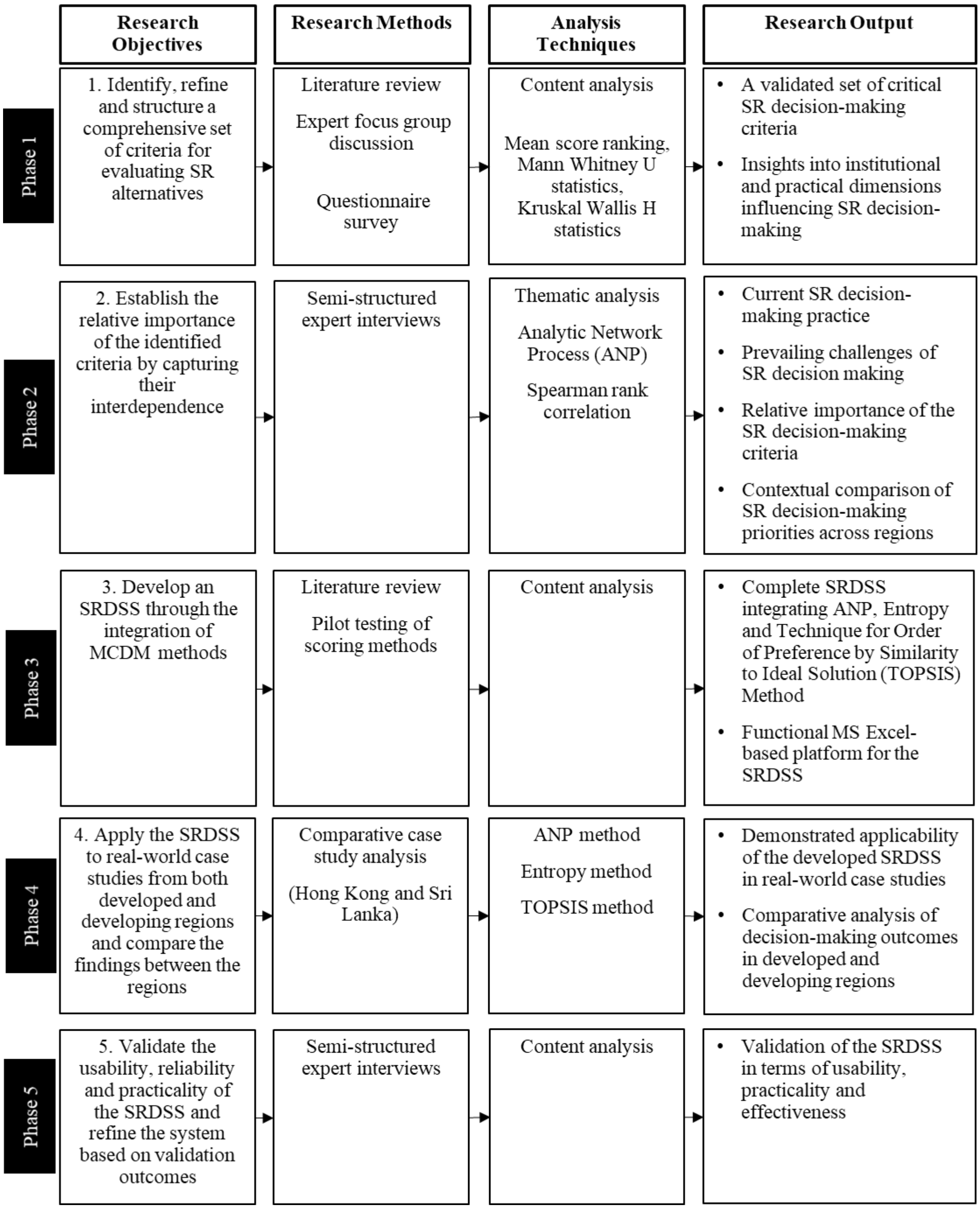

Figure 1-1: Research framework of the study

1.4.1 Phase One

As an initial step, a comprehensive list of criteria influencing SR decisions was identified through a systematic literature review. The identified criteria were then consolidated through content analysis and presented to a focus group comprising Facility Management (FM) industry experts from Hong Kong. The experts provided feedback on the relevance and practicality of the criteria, suggesting the removal of less applicable items and the addition of relevant ones. They also shared insights into the importance of selecting criteria that reflect real-world SR decision-making. Based on the focus group's input, the criteria list was refined and subjected to further validation through an industry-wide questionnaire survey conducted in Hong Kong. In this survey, respondents rated each criterion based on its perceived importance, and the highest-rated criteria were shortlisted to form the final set of criteria for use in the next phase of the study.

1.4.2 Phase Two

The final set of SR decision-making criteria were then evaluated to determine their relative importance. Expert interviews were conducted in Hong Kong and Sri Lanka to capture perspectives from both developed and developing economic contexts. In the first part of each interview, the experts were invited to share their experiences with current SR decision-making practices and the associated challenges. In the second part, the experts performed pairwise comparisons of the criteria, which were then analysed using the Analytic Network Process (ANP) to derive the relative importance weights.

1.4.3 Phase Three

A literature review was undertaken in phase three to develop appropriate methods for scoring SR alternatives under each identified criterion. The adapted and self-developed scoring methods were subsequently validated through consultations with two industry experts each from Hong Kong and Sri Lanka.

Drawing on the criteria, expert-derived relative importance weights, and the validated scoring methods, the SRDSS was developed as a Microsoft (MS) Excel - based platform. The methodological framework underpinning the SRDSS integrates three MCDM techniques: ANP, Entropy, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

1.4.4 Phase Four

Two office buildings were selected from each of Hong Kong and Sri Lanka, resulting in a total of four buildings, to demonstrate the applicability of the developed SRDSS. The SRDSS was applied to evaluate retrofit alternatives associated with a specific SR project in each building. The evaluation process incorporated both expert-derived criteria weights obtained through ANP and objective data-driven weights determined via the Entropy method. These inputs were then synthesized using the TOPSIS technique to generate a logical ranking of retrofit alternatives. The results from the four case studies were subsequently compared to derive context-specific insights and broader implications.

1.4.5 Phase Five

In the fifth and final phase, a series of expert interviews were conducted to assess the usability, reliability and practicality of the developed SRDSS thereby supporting its validation. Industry experts from Australia were consulted to evaluate the applicability of the SRDSS beyond the initial contexts of Hong Kong and Sri Lanka. The ensuing feedback not only affirmed the system's validity but also provided valuable suggestions for enhancement. Based on this input, the SRDSS was further refined into an automated MS Excel tool incorporating Visual Basic for Applications (VBA) macros, thereby improving its functionality, user-friendliness and practical applicability.

1.5 Research Significance

SR can be considered as an ideal solution to overcome the burden of high energy consumption and emission of greenhouse gases. However, it should not be the sole reason for retrofitting office buildings. SR can contribute to attaining sustainability goals while enhancing comfort and liveability. Occupants or tenants are willing to invest in facilities that provide a promising return not only in monetary terms but also in well-being. However, there are many factors discouraging building owners and facility managers to consider SR. Many fear risking their capital on such an expensive project if the payback does not seem encouraging. Moreover, the lack of performance measurement indicators for post-retrofit operations and the knowledge gap of the FM team in taking over new technology are a few of many other factors which make decision-makers worry. A model that addresses these concerns by adopting a holistic approach in decision making is the best way of overcoming these challenges.

From an academic perspective, the proposed SRDSS is the first of its kind to adopt a holistic approach in evaluating SR alternatives. It integrates a comprehensive set of decision-making criteria, including financial, technical, user comfort, convenience, environmental, legal, safety, and security considerations, within a unified framework. While previous DSSs in literature have applied various MCDM techniques for criteria weighting, they rarely combine more than one method. In contrast, the SRDSS incorporates both the ANP, which captures interdependencies among criteria, and the Entropy method, which reflects the specific nature of each retrofit project. This integration enhances the robustness of the resulting criteria weights and contributes to the methodological rigour of the system.

From a practical standpoint, the research delivers a ready-to-use, MS Excel-based DSS that can be directly applied to real-world SR projects. The tool offers facility managers a structured and transparent evaluation framework underpinned by a rigorous ANP-Entropy-TOPSIS methodology. Its ability to provide justifiable, data-driven rankings supports more informed and defensible decision-making, particularly when seeking top management approval. The SRDSS provides enhanced decision transparency, which is particularly valuable in projects involving multiple stakeholders. Its standardized approach has the potential to support performance benchmarking and policy development, offering practical value not only to facility managers but also to consultants and policy advisors. The system's adaptability to region-specific preferences further strengthens its applicability across diverse market and geographic contexts.

In a broader context, the SRDSS contributes meaningfully to the global sustainability agenda by facilitating more strategic and efficient building upgrades. Through its support for improved retrofit decision-making, the SRDSS can help reduce energy consumption and greenhouse gas emissions in the built environment, thereby advancing progress toward international climate and sustainability goals.

1.6 Structure of the Thesis

The thesis comprises eight chapters. Chapter one introduces the research by establishing the background and context of the study, thereby highlighting the need for investigating SR decision-making. It presents the research aim, objectives, scope, significance and research design offering a comprehensive overview of the study's structure and relevance. The chapter concludes with an outline of the thesis.

Chapter two presents the findings of a systematic literature review on the SR research domain. This review consists of a bibliometric analysis and a qualitative content analysis of a systematically selected body of literature. The bibliometric analysis identifies key contributors to SR research, including prominent authors, journals, organizations, regions and keywords. This is followed by an in-depth content analysis that explores past and recent research areas as well as potentially useful future research directions. The aim of this chapter is to identify pressing research gaps in SR. Based on the findings, the need for a holistic decision-making model for SR was identified and selected as the focus of this study. The chapter concludes with an in-depth discussion of this gap and the unaddressed needs of SR decision-making.

Chapter three details the overall methodological framework adopted in the study, which is built upon the integration of ANP, Entropy and TOPSIS. It provides a comprehensive explanation of the different phases of the study, along with the selected research approaches, data collection methods, and data analysis techniques.

Chapter four addresses the first research objective: the identification of decision-making criteria influencing SR. It describes the methodology employed, including a literature review, expert focus group discussion and an industry-wide questionnaire survey. The findings from each stage are presented, culminating in the finalized list of SR decision-making criteria.

Chapter five presents the process and findings related to the second objective: establishing the relative importance of the identified criteria. It discusses two rounds of expert interviews conducted in Hong Kong and Sri Lanka, through which pairwise comparisons were obtained to calculate criteria weights using ANP. The first section of the chapter explores insights from the interviews, including current SR decision-making practices and region-specific challenges, while the second section presents the derived ANP weights.

Chapter six addresses the third and fourth objectives. It explains the development of scoring methods for evaluating SR alternatives under each criterion and describes how these methods were integrated with the ANP, Entropy and TOPSIS techniques to develop the SRDSS. The chapter also presents the application of the SRDSS in four real-world case studies, two each from Hong Kong and Sri Lanka, followed by a comparative analysis of the results.

Chapter seven outlines the validation process undertaken to achieve the fifth research objective. It describes expert interviews conducted in Australia, focusing on feedback regarding the usability, reliability and practicality of the SRDSS. The findings from these interviews are presented and subsequent refinements made to enhance the system's transparency and user-friendliness are discussed.

Chapter eight concludes the thesis by reviewing the research process and summarizing the key findings. It highlights the theoretical and practical contributions of the study, along with its broader implications. The chapter also discusses the study's limitations and outlines directions for future research.

1.7 Chapter Summary

This chapter establishes the foundation of the research by identifying and outlining the need for a holistic DSS for SR, grounded in the prevailing gaps identified in both literature and practice. It presents the research aim and objectives formulated to address the identified research problem. Building on this foundation, the chapter defines the scope of the study and introduces the research design, summarizing the key phases and methodological approaches adopted. The significance of the research is then articulated to briefly convey upfront, its contributions to both academic knowledge and professional practice. The chapter concludes by outlining the structure of the thesis, serving as a roadmap of the chapters that follow.

CHAPTER TWO

2 LITERATURE REVIEW[2]

2.1 Introduction to the Chapter

Given the limited knowledge about the SR concept, this chapter presents the findings of a systematic literature review conducted using a mixed-methods approach. Initially, a bibliometric analysis of SR-related literature was carried out to identify the prominent contributors to SR research. A further, qualitative review of the shortlisted literature unveiled the SR research gaps and six future research areas. A framework consolidating the review findings and a mapping of the nexus of future research directions was developed and presented in order to contribute knowledge to the SR domain and guide further research.

Following the selection of one of the identified future research directions as the focus of this study, a targeted review of literature was conducted within that focus area and is also presented here, to further establish the nature and extent of the knowledge gap.

2.2 The need of investigating the past development and the status quo of SR

Urbanization, which causes a multitude of environmental issues including excessive energy consumption and carbon emissions (Liu et al., 2022, Lu and Lai, 2019), leads to the elevating demand for smart cities (Obringer and Nateghi, 2021). As the core hardware of smart cities, SBs play a vital role in determining the cities' performance (Bach et al., 2010). SBs are the more advanced successors of Intelligent Buildings (IBs) with better longevity, energy efficiency, comfort and satisfaction (Buckman et al., 2014); they go beyond the form and function of traditional buildings by incorporating intelligent control systems and automation of interconnected components (Dincer, 2018).

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[2]The core research and findings in this chapter have been peer-reviewed before publication in:

Peiris, S., Lai, J. H. K., Kumaraswamy, M. M., & Hou, H. C. (2023). Smart retrofitting for existing buildings: State of the art and future research directions. *Journal of Building Engineering*, *76*, 107354. DOI: 10.1016/j.jobe.2023.107354

Peiris, S., Lai, J., & Kumaraswamy, M. M. (2022). Smart retrofitting of buildings: a bibliometric study. *IOP Conference Series: Earth and Environmental Science*, *1101*, 022013. IOP Publishing. https://doi.org/10.1088/1755-1315/1101/2/022013

The IoT facilitates connectivity between systems and devices of an SB, allowing for the efficient use of web-connected hardware, remote controls and sensor networks. An SB can learn to forecast the future states of the building by analysing the surroundings and tenant behaviour and can make operational decisions on its own rather than requiring regular human intervention to conduct automatic duties (Cook and Das, 2004).

Not merely newly developed SBs but also existing buildings can attain smartness if they are retrofitted appropriately (Hong et al., 2021). This way of retrofitting – a process called SR – is defined by Al Dakheel et al. (2020) as: "The process to transform the existing building into an SB, that is a Nearly Zero-Energy Building (nZEB) with the capability to respond to the changing conditions of climate and grid, communicate with the user and predict failures in its operations, through the use of ICT, RES, and BEMS". Unlike green retrofits or general energy retrofits, SR can be achieved by retrofitting existing, non-SBs with smart features such as smart sensors, smart controls, smart management and smart appliances (Aliyu et al., 2017). It is clear that carbon reduction and energy savings are the primary drivers of SR, and there is a myriad of other benefits gained by making buildings smarter (Wong et al., 2008b). They include reduced operating and maintenance costs as well as a more flexible, convenient and comfortable environment. These lead to more productive and happier occupants thereby increasing the marketability of the building (Huseien and Shah, 2022). SR is considered by many an excellent technique to modernize and improve the performance of buildings (Al Dakheel et al., 2020, Farahani et al., 2019, Luddeni et al., 2018). However, a standard definition for the concept of SR is not yet available[3].

In spite of their benefits, SBs or SR applications exhibit certain loopholes. Issues such as cybersecurity risks related to IoT devices (Wendzel, 2016), the necessity to optimize existing systems to interface with new technologies (Al Dakheel et al., 2020), the lack of IoT-related experience within the facility management team (Pašek and Sojková, 2018) and non-technical

[3]At the time this study commenced, there was no universally accepted definition of SR in literature. As part of this research, a working definition was developed through literature synthesis and expert input and was later formalized and published in a peer-reviewed journal article: Peiris, S., Lai, J. H. K., & Kumaraswamy, M. M. (2024). Smart retrofitting for office buildings: Comparison of decision-making criteria between developing and developed regions. *Journal of Building Engineering*, *97*, 110957. DOI: 10.1016/j.jobe.2024.110957

issues such as the legal complications surrounding the SR process and the social challenges associated with the change management of building users (Al Dakheel et al., 2020) are few of the key sources of conflict in SR.

SR is typically thought to be costly (Sun et al., 2018), and many building contractors are unwilling to participate in SR projects due to concerns about undertaking sophisticated work tasks, which would increase project risk and expenses (Yang and Peng, 2001). The ambiguities in SR literature, too, trigger confusion among practitioners and researchers. While previous studies have reviewed the concept of SBs and their development, no work has been fully focused on reviewing the concept of SR and its complexities. For instance, some studies have only focused on the technical components of SBs (Li et al., 2021, O'Grady et al., 2021) while some have briefly examined the challenges of SR, such as implementation complexity and stakeholder coordination (Al Dakheel et al., 2020). However, to date, a proper comprehension of this topic and its current state is still lacking (Jaspert et al., 2021), while urgent attention to the complex issues of SR is needed given the dramatic increase in the demand for smartness in existing buildings (Aliero et al., 2021).

In view of the above, it is imperative to understand the past development and the status quo of SR so as to pave proper pathways for the future of SR. To this end, the following research questions (RQs) arise:

- RQ1: Who are the prominent contributors and what are the prominent keywords in SR research?
- RQ2: What are the past and recent research areas in SR research?
- RQ3: What are the potentially useful future research directions in SR research?

To answer the above question, a systematic literature review exercise bearing the following objectives was initiated: firstly, to conduct a quantitative study on SR-related journal articles using the bibliometric analysis technique to identify the prominent contributors and keywords in the SR field; secondly, to qualitatively review a rigorously-selected set of journal articles to identify the past and recent research areas in the field; and finally, to identify the gaps in SR research and hence the potentially useful future research directions.

2.3 Materials and methods

Towards the above objectives, a three-stage methodology was developed with reference to the interpretivist epistemological design adopted in past review studies such as Chamberlain et al. (2019) and Adegoriola et al. (2021). Central to this methodology is a systematic literature review, which follows a mixed-methods approach that combines a bibliometric analysis and a qualitative analysis to synthesize and evaluate the existing literature on the topic under study (Hargen and Thomas, 2010). Qualitative analysis is a powerful tool for facilitating in-depth understanding and finding gaps in literature (McGowan and Sampson, 2005). While subject to personal judgment and biases (He et al., 2017), this shortcoming of the qualitative analysis can be minimized using the mixed-methods approach (Heyvaert et al., 2016) as the bibliometric literature analysis is quantitative and objective. Hence a mixed-method systematic review produces fruitful yet unbiased results when compared to the 'mono-method systematic review' (Heyvaert et al., 2016).

The three main stages of the methodology are: Stage 1 – data collection; Stage 2 – quantitative analysis using bibliometric analysis and visualization; and Stage 3 – qualitative analysis. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) framework, which facilitates transparent and complete reporting of systematic reviews, was applied to select and screen publications in Stage 1 (See Figure 2-1).

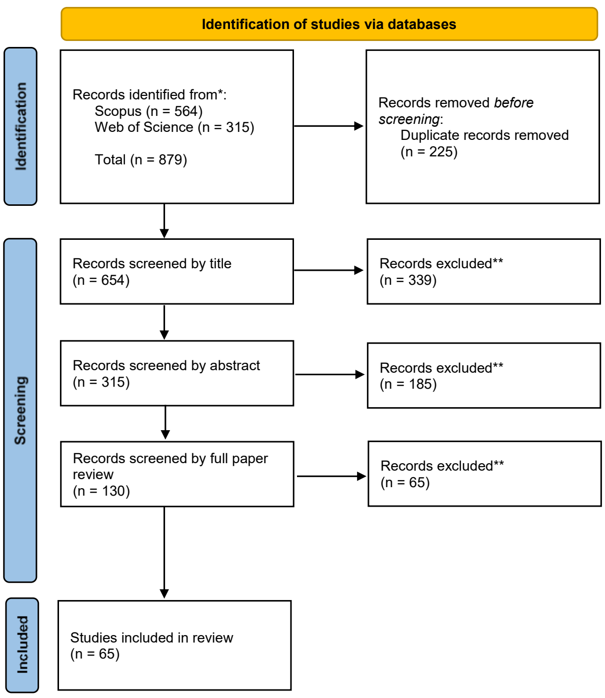

Figure 2-1: The PRISMA process

At the initial stage of this study, search terms were developed and used to gather data from well-established literature databases, namely, Web of Science (WoS) (Sedighi and Jalalimanesh, 2017) and Scopus (Aghaei Chadegani et al., 2013). A search term, comprising of a set of words that may best capture the relevant literature, was formulated based on the author keywords of previous similar studies (Al Dakheel et al., 2020, Capeluto, 2019, Engelsgaard et al., 2020). An iterative search strategy was used beginning with broad keywords (e.g., retrofitting, decision-making, facility management, sustainability, smart technologies) and refining based on keyword co-occurrence and snowballing from seminal papers. The search terms used in this study comprise SR-related keywords combined with Boolean operators: *building* AND (retrofit* OR renovation* OR refurbishment*) AND (smart OR intelligen*).*

The search process was conducted using the 'TITLE-ABS-KEY' field in Scopus and the 'Topic' field in Web of Science. The resultant dataset was then refined to articles published between 2003 and 2022 because the field of study is rapidly evolving and studies from the past 20 years should be sufficient to answer the RQs of this review. All publications except journal articles were excluded in order to limit the dataset to articles that contain an appropriate level of detail and required information (Butler and Visser, 2006). Empirical research articles and review papers were both included in the review because, similar to empirical research, knowledge captured in review papers are important for further development of the field. The dataset was further refined to articles written in English. The search process was completed in December 2022 and a total of 879 records were exported from the databases (see Figure 2-1).

These records were then exported to an MS Excel Spreadsheet and duplicates were removed. The remaining records were screened by title and abstract review. The following inclusion/exclusion criteria were used in the screening.

Inclusion criteria:

- Papers mainly focused on retrofitting smart technology to existing buildings
- Papers introducing smart innovative technology that can be retrofitted to existing buildings
- Papers discussing the integration of Renewable Energy (RE) technologies that can communicate with the grid
- Papers on post SR performance evaluation

Exclusion criteria:

- Papers focusing on smartification of the retrofit process only
- Papers introducing smart technology that can be incorporated only into new buildings
- Papers focusing on structural retrofitting

A high-quality bibliometric analysis is useful for explaining and visualizing the growing scientific knowledge and progression of research fields (Donthu et al., 2021b). 'VOSviewer', a bibliometric analysis and visualization software (Van Eck and Waltman, 2013), was used in Stage 2 to analyse the dataset of 130 records in order to answer RQ1. Prominent keywords and prominent contributors were thus identified in terms of authors, countries, organizations and journals.

In Stage 3, a qualitative review of selected publications was conducted to find answers for RQ2 and RQ3. The full-texts of the 130 articles were screened by the same inclusion/exclusion criteria, and this resulted in having 65 articles shortlisted. Content analysis was made on these articles; their main contents identified were summarized using a manual coding process and the content of each article was coded into discernible categories.

2.4 Number of annual publications and citations

The 130 journal articles, which were identified through the bibliometric search, were analysed based on the number of annual publications and annual citations. The results in Figure 2-2 indicate an increasing trend of publications in the period 2005 - 2022. Initially, there was moderate growth in publications between 2005 and 2016 with slight drops in between. Only 19% of the 130 articles were published over that period. From 2016 to 2017, the number of publications showed a significant increase which was maintained until 2019. However, in 2020 the number of publications show an increase of 136% which is the highest among all years. A minor drop can be observed from 2020 to 2022. However, 53% of the 130 publications were published in the period of 2020 to 2022.

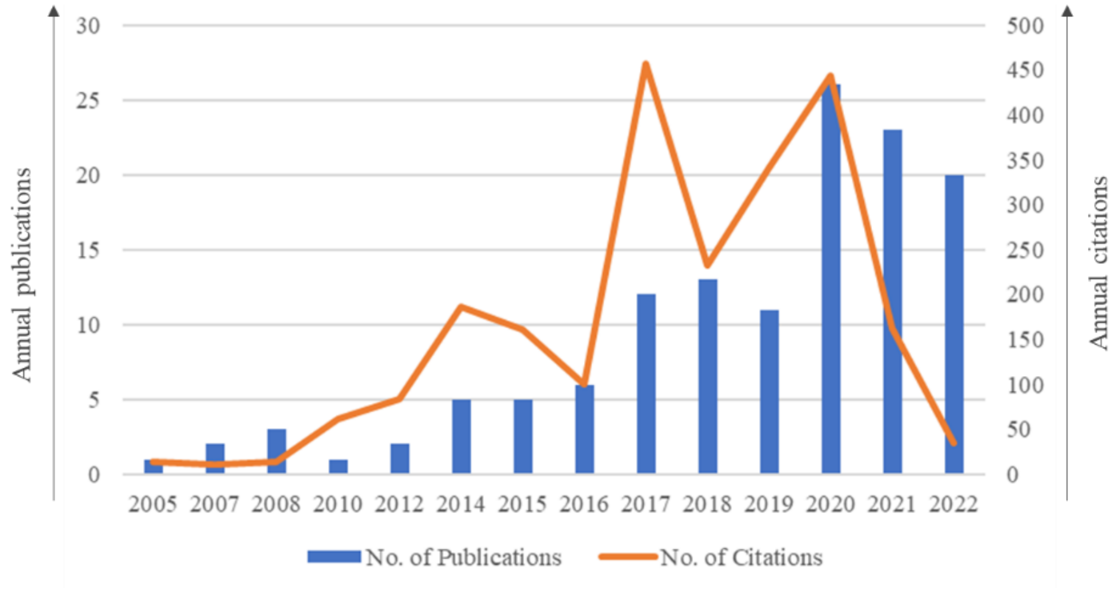

Figure 2-2: Annual publications and citations

As evidenced by the increasing trend in the annual number of publications, the main reason for the overall rise could be the increased interest of researchers in SR. This could be attributed to the new rules enforced by various governments in the pursuit of nZEB, including the Energy Performance of Buildings Directive (EPBD) targets (Al Dakheel et al., 2020). The majority of papers related to SR were published between 2020 and 2022, indicating that research in this area has grown in popularity and that there is more ground to be explored.

Figure 2-2 further shows that there is no obvious trend in the number of citations received by the journal articles published each year, particularly between the years 2014 and 2020. Over the years, the fluctuating trend has continued, with substantial surges in several cases. However, following 2020, there is a significant and continuing reduction. This could be due to two factors: (1) the significant time it takes for new publications to be cited, and (2) the interest in this topic not reaching maturity yet. This echoes the findings of Al Dakheel et al. (2020) and Jaspert et al. (2021) that deeper research is needed in the field.

2.5 Prominent contributors

When investigating a research field, particularly its current condition and evolution, it is critical to identify and recognize its contributors because such findings can provide insights and inform implications of research collaboration between the experts in the related fields. In this review, the VOSviewer software was used to analyse the contributors using different attributes such as item, publications, links, Total Link Strength (TLS), Average Citations (AC), Average Publication Year (APY), and occurrences. These attributes are defined as follows: (i) item - the objects of interest in a map which may for example be publications, researchers, or terms; (ii) publications - the number of documents published by a source, an author, an organization, or a country/place; (iii) links - a link is a connection or a relation between two items. Between any pair of items, there can be no more than one link; (iv) TLS - the strength of a link may for example indicate the number of publications two researchers have co-authored (when the strength of links owned by an item is totalled, it is the TLS); (v) AC - the average number of citations received by the documents in which a keyword or a term occurs or the average number of citations received by the documents published by a source, an author, an organization, or a country/place; (vi) APY - the average publication year of the documents in which a keyword or a term occurs or the average publication year of the documents published by a source, an author, an organization, or a country/place; and (vii) occurrences - the number of documents in which a keyword occurs.

Five types of contributors were identified based on prominence: (1) authors, (2) countries/places, (3) organizations, (4) journals, and (5) keywords and are reported in the following.

Co-authorship analysis of literature was used to identify academic collaborations, collaborative behaviours, or schools of thought in a research field by observing the authors and their affiliations (Liu et al., 2005). Such findings could be valuable for research and policy that seeks to approach the subject with the assistance of specialized groups (Donthu et al., 2021a).

2.5.1 Co-authorship analysis

When analysing the bibliometric data using VOSviewer, certain parameters need to be set in order to analyse the dataset in accordance with the objectives of the study. These parameters include the thresholds for the minimum number of documents and citations of the subjects undergoing analysis. In the case of authors, the threshold limit for the minimum number of documents of an author and the minimum number of citations were set at ‘2’ and ‘1’ respectively. Of the 264 authors, only nine (3.4%) met the threshold, as visualized in Figure 2-3.

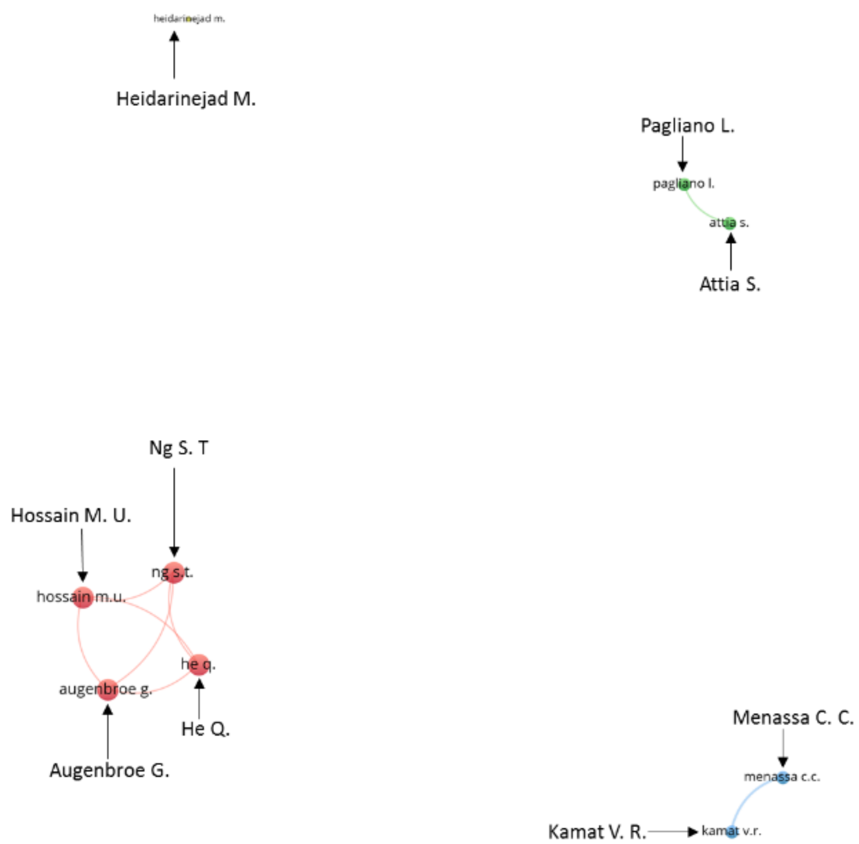

Figure 2-3: Co-authorship analysis (network visualization based on links)

In Figure 2-3, the size of a node represents the number of co-authorship links with other authors and the node colours represent the collaboration clusters. Of the four collaboration clusters, the only cluster with more than two authors comprises authors ‘S.T. Ng’, ‘M.U. Hossain’, ‘G. Augenbroe’, and ‘Q. He’. These authors have the strongest network with a total link strength of eight out of 14 (57%). Researchers’ influence on each other is shown by their distance and connectivity. As the clusters are dispersed and the number of links is small, more collaboration between researchers should be encouraged for addressing any key concerns in SR research.

Table 2-1, generated using the ‘save as’ option in VOSviewer, summarizes the findings of the analysis, with the authors ranked based on the AC. It shows that even though some authors have a relatively low link strength, their publications have been frequently cited. Possible reasons for this include: (1) those publications contain fruitful findings; and (2) they are relatively old publications which had more time to be cited. For example, ‘L. Pagliano’ and ‘S. Attia’ have co-authored a highly cited paper titled “Overview and future challenges of nZEB design in Southern Europe” (Attia et al., 2017). This is a useful reference for SR researchers who need to identify key components of the background including threats, opportunities for SR implementation and research gaps.

Table 2-1: Quantitative measurements of the author network

Rank	Authors	Documents	Links	Total Link Strength	Average Citations (AC)	Average Publication Year (APY)
1	Attia S.	2	1	1	83	2017
2	Pagliano L.	2	1	1	75	2018
3	Kamat V.R.	2	1	2	23	2018
4	Menassa C.C.	2	1	2	23	2018
5	Heidarinejad M.	2	0	0	8	2019
6	Augenbroe G.	2	3	2	1	2021
7	He Q.	2	3	2	1	2021
8	Hossain M.U.	2	3	2	1	2021
9	Ng S.T.	2	3	2	1	2021

2.5.2 Analysis of publications (by country)

The threshold limit for the minimum number of documents of a country and the minimum number of citations were set at '2' and '1' respectively. Of the 54 countries, only 21 (38%) met the threshold. Among these 21 countries, only 16 were connected, as visualized in Figure 2-4 and Figure 2-5.

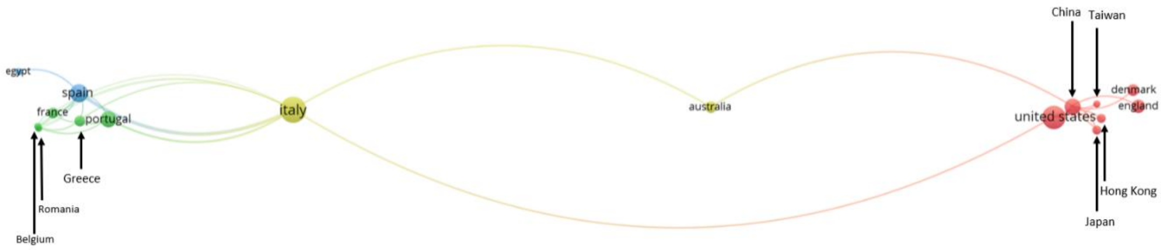

Figure 2-4: Network visualization based on documents (by country)

In Figure 2-4, the size of the nodes represents the number of publications. A larger node implies a larger contribution to publications from that country. Four scientific clusters in SR research have been distinguished with four different colours. Italy, Spain, Portugal, France, the US and China have produced relatively more publications. In terms of co-authorship, the US, China, Taiwan, Hong Kong, and Japan as well as Italy, Spain, Portugal, France, Greece and Romania show intense collaboration. Australia is active in maintaining co-authorship links with other countries in different clusters. Overall, Italy is the most active country in publication and collaboration.

Figure 2-5: Overlay visualization based on citations and APY scores (by country)

In Figure 2-5, the size and the gradient colour of the nodes represent the number of citations and the APY of countries (as per the legend). Publications by many countries have received high citations, which could be from strong co-authorship links of these countries with countries in other regions. The older APY of Taiwan, the US and France could be another contributor to their high number of citations. The most recent SR publications have been produced by Hong Kong and Egypt, implying that these places are active in this emerging research area.

2.5.3 Analysis of publications (by organization)

The threshold limit for the minimum number of documents of an organization and the minimum number of citations were set at '2' and '1' respectively. Of the 189 organizations, only 14 (7.4%) met the threshold and among these 14 organizations, 13 were connected (Figure 2-6).

Figure 2-6: Overlay visualization based on citations and APY scores (by organization)

The node size represents the number of citations, and the line between two nodes demonstrates the academic link between the two organizations connected. Hence, a shorter line indicates a closer relationship. Only seven organizations have collaborated with at least one other. In terms of collaboration, only one cluster shows the existence of strong links, with a total of 14 links among five universities: Georgia Institute of Technology (GIT), Purdue University (PU), The University of Hong Kong (HKU), City University of Hong Kong (CityU), and Nanjing Tech University (NTU). Figure 2-6 indicates that the organizations are doing well independently in terms of research output, but there is a lack of collaboration links among the research organizations. This suggests a need for researchers from the various institutions to collaborate, which would boost research productivity and quality. In terms of number of publications, there is no significant difference between the organizations.

The gradient colours of the nodes demonstrate the APY of organizations according to the legend. It is clear that the numbers of citations received by the University of The Basque Country (UBC) and Politecnico Di Milano (PDM) are significantly higher than the other organizations. A main reason could be their informative publications in SR. Furthermore, their APY is comparatively less recent, allowing more time for researchers to recognize and reference those publications. Universities such as NTU, GIT, PU, HKU, CityU, and Universitat Politècnica de Catalunya (UPC) have the most recent average publication years, implying that they are the relatively more influential organizations in the latest SR research.

2.5.4 Analysis of keywords

The threshold limit for the co-occurrence of keywords was set at '2'. Twenty-eight (28) keywords that met this condition (after merging duplicates and similar words) are illustrated in Figure 2-7, where the frequency of occurrences of keywords is represented by the size and density of the nodes. The more a keyword was co-selected among the SR publications, the larger and more solid the node. The difference in distance between two keywords reveals the relative strength and topic similarity. The node colour, varying from purple to yellow (see legend), indicates the APY of each keyword.

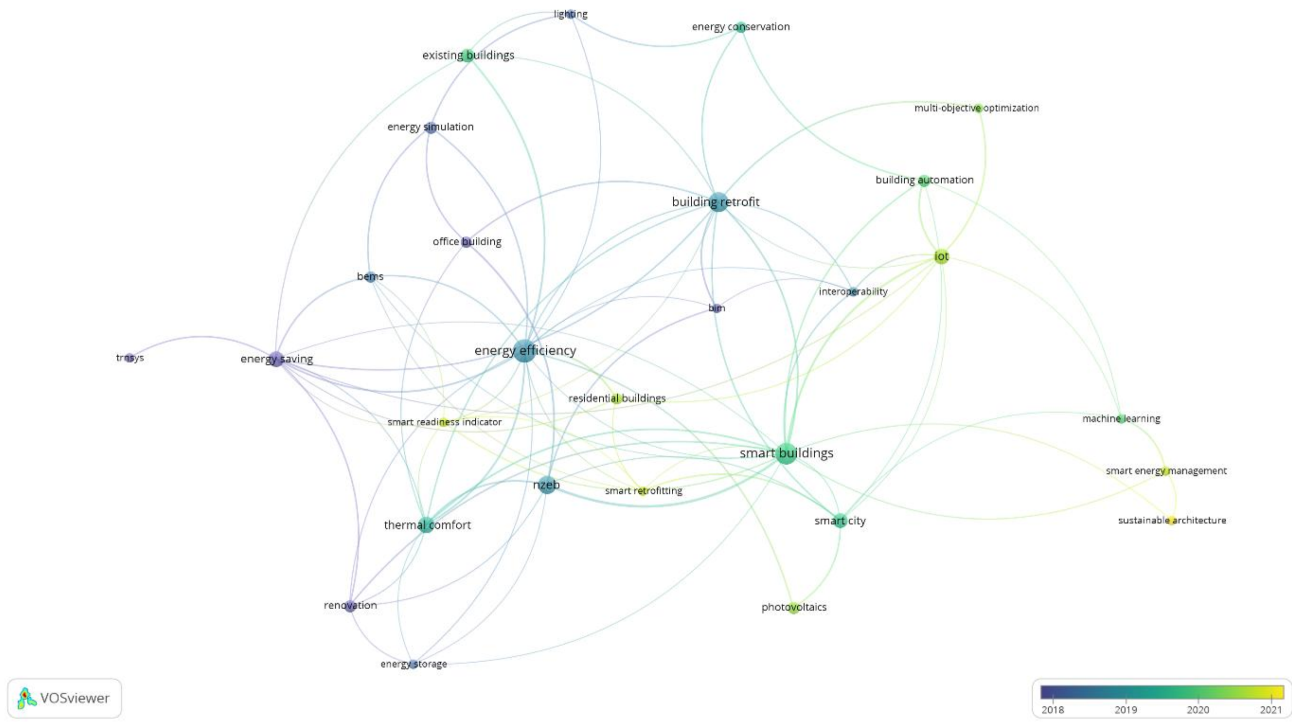

Figure 2-7: Overlay visualization based on links between keywords

The keywords are ranked based on the number of occurrences (Table 2-2). 'Energy efficiency' has the highest number of occurrences and links. There are cases where keywords with high occurrences do not have high citations and vice versa. For instance, 'renovation' has a relatively high average citation of 60 but the occurrence value is low: 5. The high AC could be because studies with these keywords were undertaken in earlier years.

Based on the APY (from the yellow nodes in Figure 2-7 and Table 2-2), keywords such as 'internet of things', 'smart energy management', 'smart readiness indicator', 'smart retrofitting', 'sustainable architecture', and 'residential buildings' appeared in most of the recent publications, indicating that they are becoming significant topics in this discipline.

Table 2-2: Quantitative measurements of the keyword network

Rank	Keywords	Occurrences	Links	TLS	AC	APY
1	Energy Efficiency	17	16	13	21	2019
2	Smart Buildings	15	16	14	20	2020
3	Building Retrofit	13	13	11	21	2019
4	nZEB	10	7	8	29	2019
5	Thermal Comfort	9	9	7	33	2019

6	Energy Saving	8	11	8	24	2018
7	IoT	8	9	7	21	2021
8	Smart City	7	8	5	7	2020
9	Existing Buildings	6	4	3	25	2020
10	Building Automation	5	5	4	11	2020
11	Energy Simulation	5	4	4	22	2018
12	Photovoltaics (PV)	5	2	2	6	2020
13	Renovation	5	6	4	60	2018
14	BEMS	4	6	4	29	2019
15	Energy Conservation	4	3	3	8	2020
16	Office Building	4	4	4	17	2018
17	Residential Buildings	4	4	3	10	2021
18	Building Information Modelling (BIM)	3	4	3	18	2018
19	Energy Storage	3	5	2	15	2018
20	Interoperability	3	5	3	37	2019
21	Lighting	3	4	3	12	2018
22	Machine Learning	3	4	2	20	2020
23	Multi-Objective Optimization	3	2	2	23	2020
24	Smart Energy Management	3	3	2	7	2021
25	Smart Readiness Indicator (SRI)	3	7	3	30	2021
26	Smart Retrofitting	3	6	3	30	2021
27	Sustainable Architecture	3	2	1	2	2021
28	TRNSYS	3	1	1	22	2018

The network of prominent keywords consists of key reasons for SR such as aiming for improvement in Smart Readiness Indicator (SRI) score and the drive towards the smart city concept. Apart from the above, energy management being one of the key drivers of SR, the keyword network consists of several building energy related terms: ‘energy efficiency’, ‘photovoltaic’, ‘energy storage’, ‘energy saving’, ‘energy simulation’, ‘energy conservation’, ‘nZEB’, ‘smart energy management’ and ‘BEMS’. The network also consists of different SR facilitators such as ‘IoT’, ‘Building Information Modelling (BIM)’, ‘Machine Learning’, ‘building automation’, and their ‘interoperability’.

It is evident that the most studied themes in SR research are key drivers of SR including development of a SRI, smart city realization and the use of SR for energy management in buildings. And to ensure their effectiveness, the facilitators of SR are also studied.

2.5.5 Analysis of journals

The thresholds for the minimum number of documents and citations of a journal were each set as '3'. Out of the 130 journals, only 11 influential journals met this criterion, as visualized in Figure 2-8. The node size there represents the number of journal publications. The connecting lines were determined by the relationship or closeness of journals in terms of mutual citations. The node colour, varying from purple to yellow (see legend), indicates the APY of each journal.

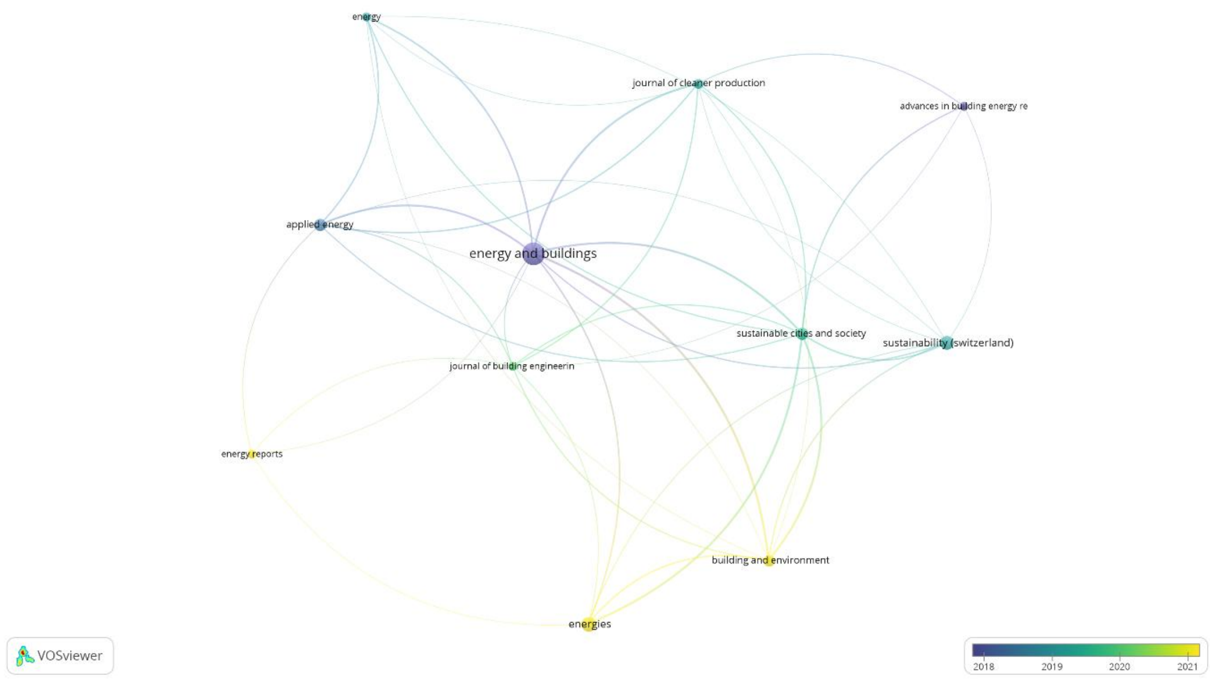

Figure 2-8: Overlay visualization based on links between journals

In Table 2-3, the journals are ranked based on number of publications. Together with the findings shown in Figure 2-8, it can be seen that the journal with the highest number of publications (nearly 30%) is 'Energy and Buildings'. This journal also showed strong links with all other 10 influential journals.

Table 2-3: Quantitative measurements of the journal network

Rank	Journal Title	Publications	Links	TLS	AC	APY
1	Energy and Buildings	19	9	72	33	2018
2	Energies	8	6	30	6	2021

3	Sustainability (Switzerland)	7	8	23	10	2019
4	Applied Energy	6	8	35	32	2019
5	Sustainable Cities and Society	6	9	66	29	2020
6	Building and Environment	5	8	43	6	2021
7	Journal of Cleaner Production	4	8	33	33	2019
8	Advances in Building Energy Research	3	4	10	10	2016
9	Energy	3	6	21	19	2019
10	Energy Reports	3	4	5	2	2022
11	Journal of Building Engineering	3	8	24	23	2020

Regardless of their number, the articles published in journals such as ‘Energy and Buildings’, ‘Journal of Cleaner Production’ and ‘Applied Energy’ were cited the most. ‘Energy and Buildings’ takes the lead probably because of its multidisciplinary scope. It covers a wide range of topics such as energy efficiency, ICT integration in building energy management, all of which being relevant to the topic of this paper. The most cited journals are mostly concerned with efficient energy generation and usage in buildings, as well as the application of modern ICT throughout the building lifespan, to promote ecologically sustainable and socially resilient communities. SBs and SR evolve around these key themes. Because the APY of the journals is 2016 or after (i.e. recent), there is room for more SR research in the years ahead.

2.6 Past and Recent Research Areas of SR

As Figure 2-1 shows, 65 journal articles were shortlisted as eligible for the in-depth qualitative review, which sought to identify the past and recent research areas, research gaps and potentially useful future research directions. The 65 papers comprise 61 empirical research papers and 4 review papers. The main contents of each journal article were coded and then grouped into four categories: (1) research methodology, (2) research context and findings, (3) future research directions and (4) study conclusions and implications. The codes identified from the articles were then carefully compared, contrasted, and differentiated. Eventually, six research areas representing the key themes/ideas covered in the articles were identified.

2.6.1 Area 1: Smart retrofit performance evaluation

Retrofit performance measurement is crucial for determining whether the SR project produced the desired benefits. The performance of low energy SRs in Lyon, Munich, and Vienna were monitored as part of the EU ‘Smarter Together’ project (Hainoun et al., 2022), using a novel Integrated Monitoring Methodology (IMM) covering three main steps: monitoring infrastructure, data collection, impact assessment, and following a co-creation process involving key stakeholders. Key Performance Indicators (KPIs) that address energy-efficiency improvement, local RE contribution, and the associated CO_2 emission reduction at the district scale were used to evaluate performance. According to the findings, zones within a building should be studied independently for better results. Furthermore, it was stated that various projects cannot be quantitatively compared without additional effort (for example by carrying out further interviews).

Oh et al. (2020) compared the indoor air temperature profiles of a smart thermostat between the pre and post retrofit periods in a single-family residence. Binned, weather-adjusted quartile analysis was used for the comparison of the zone-by-zone electricity use before and after the smart thermostat installation. Pritoni et al. (2016) evaluates the effectiveness of occupancy responsive learning thermostats for energy conservation in university dormitories. A similar study was done by De Bock et al. (2021).

Che et al. (2019) investigated the energy consumption and indoor environment performance of a HVAC system retrofitted to a commercial office building. A sensor-based intelligent Building Management System (BMS), outdoor air dehumidification, and a two-stage particle filter system were among the retrofitting solutions. Performance was analysed based on the pre and post retrofit energy data.

Santos et al. (2021) proposes AUSTRET, a tool that can test the automatic step response of a retrofitted Building Automation Control System (BACS), considering its integration and interactions with the building's energy supply systems.

Engelsgaard et al. (2020) introduced 'IBACSA', a unique holistic instrument for BACS assessment and smartness evaluation based on a qualitative-based multi-criteria approach. Using the points grading principle, the suggested tool may measure the consequences of the specified control capabilities in the building systems based on five criteria (energy efficiency, maintenance and fault prediction, energy flexibility, comfort, and information to occupants).

The SRI concept has appeared in an increasing number of journal articles since its launch in 2018. Among these articles, Ramezani et al. (2021) conducted a study to investigate the use of SRI in retrofitting actions for Mediterranean structures. Ramezani et al. (2021) undertook a study to explore the application of SRI in retrofitting options for Mediterranean structures. The SRI was applied to two case studies and its effects on Indoor Air Quality (IAQ) and energy performance were examined between the case studies by comparing the measurement and energy simulation outcomes. Canale et al. (2021) devised a method for estimating the SRI for the Italian residential construction stock under three scenarios: (a) base scenario (as-is); (b) “energy scenario” (basic energy retrofit); and (c) “smart energy scenario” (energy retrofit from a smart perspective). The study by Apostolopoulos et al. (2022) examined the retrofitting cost towards smartification for typical residential buildings, using the SRI technique to measure the change in smartness when alternative retrofitting scenarios are performed.

Different other strategies are also utilized to evaluate post-retrofit performance. The Emergy-based methodological approach employed in Kumar et al. (2022) is one such method. Developed by ecologist Howard Odum (Li et al., 2021), Emergy Analysis (EA) is an energy accounting method that “incorporates the energy, economic costs, and environmental work expended in material formation to assess the total energy inputs and outputs in any system based on the net thermodynamic balance”. This research examines the true environmental cost of incorporating IoT-based sensor devices into a building using the notion of ‘Emergy Neutrality’.

The aforementioned technologies and approaches enable the analysis of retrofitting efforts through a clear side-by-side comparison of the performance retrofitted systems, providing useful information for future retrofitting.

2.6.2 Area 2: SR applications for building envelop optimization

This study identified a number of papers that introduced various smart technology that can be retrofitted to building envelopes. Capeluto (2019) presented a prefabricated retrofit system based on solar air heating and solar-tracking blinds for building envelopes, allowing it to be adapted to diverse climate zones. This system can be installed on the exterior of the façade and roof and is adaptable to the specific needs of each building, providing constructive advantages in retrofitting by reducing interruption times for occupants. Psomas et al. (2017) proposed an automatic roof window control system to prevent temperature climate overheating in retrofitted buildings. James and Bahaj (2005) investigated Holographic Optical Elements (HOE) for solar management in office buildings via glare control and maintaining vision through the window or switchable electrochromic. Basso et al. (2017) presented an innovative facade module that facilitates adaptability and heat exchange of buildings and is composed of two main parts: an adaptable Smart Modular Heat Recovery Unit (SMHRU) that can preheat ventilation air in winter while precooling it in summer; and a Latent Thermal Heat Energy Storage System (LTHES) that is based on Phase Change Materials (PCM).

Dynamic electrical-driven glazing to retrofit windows of historical buildings was mentioned in Scorpio et al. (2020). Shaik et al. (2022) investigated Polymer Dispersed Liquid Crystals (PDLCs) films, which are intelligent glazing materials that change between translucent and transparent states in response to an electric stimulation. Mahmoudian and Sharifikheirabadi (2020) discussed many uses of smart materials for facades such as diverse varieties, architectural needs, and the beneficial impacts of smart materials. One of the most important systems explored in this research was PCM, which can cut energy usage by 20% if the right type is chosen, and, in addition to natural ventilation, minimizes the building's reliance on mechanical equipment. Gallo and Romano (2018) explored the development of unique adaptive envelope systems for incorporating power generation technologies in the façade (such as PV modules) and innovative materials capable of dynamically aligning with the climatic conditions. Panopoulos and Papadopoulos (2017) evaluated the state of the art in facade building technology, including double skin facades, façade operation automation, PV integrated smart facades, and facades with smart material. Various façade smartification retrofit solutions that have previously been deployed are also explored. Habibi et al. (2020) presented a 'Modelo Integrado de Valor para una Evaluación Sostenible (MIVES)'-Delphi evaluation model that can estimate the long-term viability of Intelligent Façade Layers (IFL). According to the study findings, optimum IFLs evaluated in the Spanish school setting should be dynamic, cost-effective, energy efficient, environmentally friendly, and provide secure, healthy, and comfortable inner classroom conditions.

2.6.3 Area 3: Renewable energy integration through SR applications

Todeschi et al. (2020) presented an approach based on Geographical Information Systems (GIS) to estimate the roof areas that may be converted to produce RE. Tsoumanis et al. (2021) described the installation of Building-Integrated Photovoltaics (BIPV) solutions in Évora's Historic Centre. Circular insulating materials, solar roofs and facades, PV canopy, PV skylight, PV thermal panels, thermo-acoustic heat pumps, and hybrid wind/solar generation systems were all part of the project. Fiorentini et al. (2015) proposed a solar-assisted HVAC system in a ducted system that comprises of an air-based Photovoltaic-Thermal (PVT) collector and a PCM thermal storage unit connected with a reverse cycle heat pump. The heat stored in the PCM can later be used to condition the room or prepare the air entering the air handling unit. Analytical models for the PVT collector and PCM unit were created so that they could be easily integrated into a practical BMS.

Yousif et al. (2020) used system advisor model software to do a full analysis and concluded that battery energy storage systems have the capacity to match RE supply to demand, however this technique is still far from cost-optimal. Given the high costs of direct energy use, storage, and load matching, the research suggested that RE incentives should shift away from feed-in tariffs and instead subsidize direct energy use, storage, and load matching. Furthermore, to ensure a holistic approach to building upgrading, the cost-optimal analysis should estimate the costs of thermal discomfort, energy poverty, and grid mismatch (Yousif et al., 2020).

2.6.4 Area 4: SR applications for demand side management

Previous studies have explored and introduced different smart technology that can manage the energy demand of the building. ‘Overgrid’, a new decentralized load management architecture for balancing the energy output changes created by the adoption of renewable sources, is one such kind of load controlling technology (Croce et al., 2020). Without a centralized server, the ‘Overgrid’ Demand Response (DR) architecture calculates aggregated power demand and forms a virtual “community” of SBs. Overgrid simplifies SR by eliminating the need for a centralized controller in favour of a low-cost software controller that integrates local energy data (smart-plug/smart-meter) and external input to implement DR control mechanisms. As a result, there is no need for redundancy because there is no single point of failure. There are no constraints on the type of hardware or wireless connection either: new smart-plug/smart-appliances can be gradually added and connected via WiFi, Bluetooth, ZigBee, or any other wireless technology.

Another example is Lin et al. (2012)’s power factor correction controller, which can execute power factor adjustment without causing harmonic resonance under changing demand conditions. The controller does not require any additional measurements because it is based on standard low-cost sensing devices. As a result, the suggested controller can be built as a retrofitting device to easily replace conventional power factor correction controllers.

Syed Ali et al. (2021) proposed a Model Predictive Control (MPC) framework-based automatic radiator control system that may be utilized to retrofit low pressure steam heating systems in existing buildings. Bird et al. (2022) discussed another comparable MPC application. Naji et al. (2020) offers an energy management system based on a Wireless Sensor Network (WSN) that is deployed and tested on a university campus. It can control the heaters and efficiently implement the energy policy with the incorporation of ICT. Gonçalves et al. (2020) introduced and implemented a new generation of adaptable Intelligent Supervisory Predictive Control

(ISPC) systems, which include a building thermal simulation and multi-objective optimization algorithm that interact with traditional machine-level controllers of HVAC systems to define optimized setpoints based on current and forecasted operation conditions. Dey et al. (2020) presented a method for detecting defective HVAC Terminal Unit (TU) and diagnosing them, automatically and remotely, using a big data framework. Gattuso et al. (2016) discusses the use of a unique non-invasive retrofit technology called the Wireless Pneumatic Thermostat (WPT) that requires less installation time while providing the same degree of functionality.

Basu et al. (2014) introduces a sensor-based intelligent lighting system for future grid-integrated buildings. Based on predictive models of indoor light distribution created by sensing, the technology is intended to ensure participation of lighting loads in the energy market.

Some research investigated demand side management through influencing a variety of systems. Kawasaki et al. (2016) presented a smartification project in a building that aimed for a 50% reduction in energy use compared to before the retrofit. The retrofitted systems include a newly developed Light Emitting Diode (LED) light system that can be controlled remotely via a wireless connection, multiple intelligent human detection sensors, a smart distribution board for each floor, Variable Air Volume (VAV) controllers, inverter type air conditioners, and RES such as solar and wind. Beccali et al. (2018) evaluated the impact of some retrofit scenarios dealing with the utilization of RES and BACS to address energy consumption fluctuations on small islands. Among the possibilities under consideration are appropriate sizing of the power storage combined with the PV plant, LED lighting systems connected with building automation technologies. Yang et al. (2022) proposed a mechanism for using energy generated by user interactions to power automation systems such as motion-triggered doors, remote-control window blinds, and contactless toilet lids.

2.6.5 Area 5: Stakeholder engagement in SR

Stakeholder engagement is another important yet often overlooked part of SR. Preston et al. (2020) investigated two separate EU-funded smart city research projects to uncover practical insights for citizen involvement in low-carbon smart cities. According to the findings, a proper approach should include occupants as active agents (actors) in the development process of smartification projects. Occupants can also add value to these projects by participating in the design and innovation processes.

Lee et al. (2012) investigated the end-user impacts of automated electrochromic windows in a retrofitting project. H. Ahmed et al. (2021a) conducted a post-occupancy evaluation of three schools in the UK that underwent HVAC retrofits. The findings suggested that building users wanted more control over the indoor environment, which contradicted the prevailing trend of automated 'intelligent systems'. Mooses et al. (2022) investigated how occupants with varying attitudes towards the environment and technology evaluated a SR intervention in a smart city project in Estonia. The findings revealed that pro-technology occupants reported strong interest and trust in SR interventions, whilst ecologically inclined occupants expressed more critical views. Based on semi structured interviews, six categories of meaning that respondents gave to the SR intervention were identified: (1) environmental consequences, (2) health consequences, (3) technological issues, (4) financial considerations, (5) utility and personal comfort, and (6) symbolic and emotional values. Kim et al. (2017) discovered that early and extensive occupant involvement in lighting retrofit planning, design, and commissioning phases may better facilitate 'levels of occupant satisfaction' and 'tolerance of construction delays' in a lighting retrofit of an administrative building that included wireless lighting controls and photometric sensors.

Alberg Mosgaard et al. (2016) investigated the issues that stakeholders experience in the SR of buildings and how these challenges lead to alterations in stakeholder constellations. According to the findings, a central stakeholder is required to oversee the major stakeholders and resolve potential conflicts of interest.

Vendors should look for a variety of maintenance solutions and work to improve the system handover process by developing supporting documentation and training materials (Kim et al., 2017).

2.6.6 Area 6: Planning for effective SR implementation

As emphasized by most studies, proper planning is crucial for successful SR implementation. From the studies reviewed, their findings on barriers and enablers for SR, cost effectiveness planning, technology planning, and process planning in SR are discussed below.

2.6.6.1 Barriers and enablers for SR

As with other retrofit types, the most common barrier in SR is the lack of communication and integration among stakeholders (Hainoun et al., 2022). Another barrier is the high investment cost, which discourages building owners who support SR (D'Oca et al., 2018, Kokkaliaris and

Maria, 2015). The majority of investors and building occupants are also concerned about the personal data and privacy issues associated with the post-SR stage (Kokkaliaris and Maria, 2015). These challenges can be addressed by establishing a good communication foundation and more extensive planning from the start of the SR project (Hainoun et al., 2022).

On the other hand, SR is facilitated by certain enablers. For example, smart meters enable consumers to have easier access to more information about their electricity consumption, so is expected to raise their awareness and understanding of the importance of energy efficiency, as well as help encourage them to invest in improving the energy performance of their buildings (Kokkaliaris and Maria, 2015).

A set of review papers covered knowledge on SR enabling technologies and some associated challenges. O'Grady et al. (2021) highlighted the features and benefits of Building Automation System (BAS) - building modelling software, building automation architecture and their benefits, motivations and interactions with occupants (IAQ, daylighting and glare). Al Dakheel et al. (2020) reviewed the concept of smartness in the built environment, emphasizing the fundamental features, functions, and technology of SBs while also analysing potential problems for SR applications. The second section of the article examines the existing KPIs that measure the performance and success of SBs in meeting its goals. Two review papers examined the use of BIM in buildings to achieve smartness. Yang et al. (2021) emphasized the benefits of BIM for reaching various levels of smartness, BIM applications in multiple phases of SBs, and SB functions that can be accomplished with BIM. According to Panteli et al. (2020), the lack of BIM utilization in retrofitting is due to the challenges that still exist in this practice, such as the modelling effort required to convert building data into BIM objects, model information updating, and the handling of uncertain data and objects with existing building models.

2.6.6.2 Planning for cost effectiveness

By comparing two situations, Schäuble et al. (2020) evaluated the cost-effectiveness of smart thermostats (households with smart thermostats vs. households without smart thermostats). Smart thermostats were found to be cost effective, with both CO_2 concentrations and payback durations falling as relative savings increased.

He et al. (2021) stated that the cooling system, BEMS, and thickness of wall insulation are the most influential retrofitting aspects in Hong Kong for the best Net Present Value (NPV) and energy saving. Felius et al. (2020) investigated the cost-effective retrofitting combinations of building envelope, energy systems, and BACS measures in accordance with EN 15232 automation standard.

2.6.6.3 Planning for proper technology

Cho et al. (2021) carried out a study for the EU that emphasized the causal relationship between building attributes, retrofit procedures, and energy performance. The study, for example, discovered that the shape of the roof and the type of façade influenced the energy-saving effectiveness when PV panels were added. The overall findings can be used to choose/plan the best solutions for SR.

According to Roberta et al. (2018), the first step in building smartification is to equip buildings with sensors, actuation, and data transmission systems: a centralized diagnostics and optimization system that allows energy and economic savings at low cost, based primarily on automation and ICT infrastructure. For remote monitoring and control of SB systems, Reddy and Kumar (2021) suggest a retrofitted IoT-based communication network with Hot Standby Router Protocol (HSRP). This suggested network provides a redundant way during link failures, ensuring secure network communication. Chien and Wang (2014) presented a smart partitioning system that may be used for better and more convenient room level integration of smart technologies into existing structures.

Woo and Menassa (2014) introduces the Virtual Retrofit Model (VRM), a cost-effective computational platform that can connect buildings to a smart grid environment in which building energy data can be shared for intelligent decision making. Fernandes et al. (2022) introduced the adaption of the SmartLVGrid metamodel for SR, allowing for gradual technical improvements to obtain new functionalities while retaining old ones to the greatest extent feasible.

To address interoperability concerns in IoT integration, the World Wide Web Consortium (W3C) created a set of protocols known as the Web of Things (WoT). Ibaseta et al. (2021) shows how the W3C WoT specifications may be used to effectively integrate heterogeneous IoT-enabled devices in a BEMS. The W3C WoT recommendations provide a mechanism for designing and implementing a network of sensors, actuators, and other devices for SR of buildings.

2.6.6.4 Planning for proper retrofitting process

Kim et al. (2017) recommended cautious scheduling and monitoring of activities during SR implementation to avoid scheduling slippages and minimize interruptions to living conditions. It is further recommended that any software reporting function that comes with a lighting retrofit should be simple and useful for users to justify the investment, as well as work as a decision-support system for assessing the worth of future retrofits.

Wang (2008) stated that retrofitting for smartness is a difficult process that requires a systematic approach that includes vision, assessment, funding, planning, technology considerations, and collaboration with various other parties. Arbizzani et al. (2015) evaluated current governmental and/or private policies aiming at retrofitting towards smartness to determine their energy saving potential in reference to the European Directive 20-20-20 in a study on smart devices for Mediterranean low-income housings. In a second phase, technical solutions and innovative financing mechanisms for increasing energy efficiency were identified, considering the specific characteristics of low-income families as well as the characteristics of Mediterranean countries in terms of identified weather conditions and building types.

Table 2-4 consolidates the findings from the manual qualitative review, with the research area and research subject of the publications summarized.

Table 2-4: Summary of findings from the qualitative review

Research Area	Research Subject	Identified Publications
Research Area 1: Smart retrofit performance evaluation	Post SR performance measurement methodologies	Hainoun et al. (2022), Oh et al. (2020), Pritoni et al. (2016), De Bock et al. (2021), Che et al. (2019), Santos et al. (2021)
	Application of tools such as SRI, IBACSA	Engelsgaard et al. (2020), Ramezani et al. (2021), Canale et al. (2021), Apostolopoulos et al. (2022)
	Application of different strategies such as ‘Emergy Neutrality’	Kumar et al. (2022)
Research Area 2: SR applications for building envelop optimization	Smart retrofit applications for heat gain control	Capeluto (2019), Psomas et al. (2017), James and Bahaj (2005), Basso et al. (2017), Diallo et al. (2017)
	Smart window applications for retrofitting	Scorpio et al. (2020), Shaik et al. (2022), Mahmoudian and Sharifikheirabadi (2020), Gallo and Romano (2018), Panopoulos and Papadopoulos (2017)
	Smart envelop performance assessment methods	Habibi et al. (2020)

Research Area 3: Renewable energy integration through SR applications	Estimation of roof area for RES installation	Todeschi et al. (2020)
	Solar-assisted HVAC systems	Tsoumanis et al. (2021), Fiorentini et al. (2015)
	Battery energy systems for RES applications	Yousif et al. (2020)
Research Area 4: SR applications for demand side management	Smart load controlling technologies for retrofitting	Croce et al. (2020), Lin et al. (2012)
	Smart retrofits for improving HVAC performance	Syed Ali et al. (2021), Bird et al. (2022), Naji et al. (2020), Gonçalves et al. (2020), Dey et al. (2020), Gattuso et al. (2016)
	Smart retrofits for improving lighting performance	Basu et al. (2014)
	Smart retrofits for improving overall system performance	Kawasaki et al. (2016), Beccali et al. (2018), Yang et al. (2022)
Research Area 5: Stakeholder engagement in SR	Stakeholder involvement in SR projects	Preston et al. (2020), Lee et al. (2012), Kim et al. (2017),
	Stakeholder perceptions on SR projects	H. Ahmed et al. (2021), Mooses et al. (2022), Alberg Mosgaard et al. (2016)
Research Area 6: Planning for effective SR implementation	Barriers and enablers for SR	Hainoun et al. (2022), D'Oca et al. (2018), Kokkaliaris and Maria (2015), O'Grady et al. (2021), Al Dakheel et al. (2020), Yang et al. (2021), Panteli et al. (2020)
	Planning for cost effectiveness in SR	Schäuble et al. (2020), He et al. (2021), Felius et al. (2020)
	Planning for proper smart technology	Cho et al. (2021), Roberta et al. (2018), Reddy and Kumar (2021), Chien and Wang (2014), Woo and Menassa (2014), Fernandes et al. (2022), Ibaseta et al. (2021)
	Planning for proper retrofitting process	Kim et al. (2017), Wang (2008), Arbizzani et al. (2015)

2.7 Research Gaps and Future Research Directions

The codes explained at the beginning of Section 2.6 were further examined in Stage 3 to identify the prevailing research gaps and potentially useful future research directions. This was achieved through a critical analysis of the codes documented under the 'future research directions' category, which were then systematically mapped against the previously identified past and recent research areas. Accordingly, a conceptual framework was developed (Figure 2-9) to illustrate how insights from existing literature informed the derivation of corresponding future research directions.

These directions were derived through an evidence-based assessment of the gaps and limitations associated with each research area. The use of directional arrows in Figure 2-9 reflects this traceable link between each 'past and recent research area' and its related research opportunities. However, it is also acknowledged that some new research directions, particularly those emerging from the development and validation of the Smart Retrofitting Decision-

Support System (SRDSS) in later stages of this study, extend beyond the boundaries of existing research themes. These emergent areas represent novel contributions that were not directly apparent in the early-stage literature review but arose from methodological insights and practical challenges encountered during model development.

Figure 2-9: Framework of the existing research areas and future research directions

2.7.1 Area 1: Smart retrofit performance evaluation

According to Kumar et al. (2022), Emergy Neutrality computations are susceptible to non-specific Unit Emergy Values (UEV), data uncertainty, missing values, multiple UEV values for the same process, and a lack of standardized databases. Furthermore, data loss and lack of interoperability between various modelling tools such as BIM, Building Energy Modelling

(BEM), and EA are significant limitations for computing Emergy neutrality. As a result, these modelling tools must be integrated into a meta-model for seamless semantic integration of building sustainability assessment approaches while using reliable and current databases.

Some of the achieved KPIs on post retrofit performance can only be explained in relation to specific user behaviour, e.g., rebound effects, higher room temperature, tilted windows (Hainoun et al., 2022). In this direction future research on KPI measurement should include a qualitative analysis of occupancy behaviour to assess its impact on the monitored data as well on the resulting project impact.

Current performance measurement tools such as IBACSA do not consider the impact on the investment cost and the related returns (Engelsgaard et al., 2020). Hence, future studies can consider integrating provisions to measure economic performance of retrofits to such tools. These additions could ultimately improve the retrofit decision-making of building owners, managers and consultants.

Past studies have not considered SRI improvement as a retrofit objective (Ramezani et al., 2021). However, an SRI-based multi-objective selection approach could aid the selection of the possible SR actions based on their effectiveness on SRI. A potential future research direction is therefore to develop a SR decision making model by incorporating SRI improvement.

Studies have also highlighted certain limitations in the SRI calculation methodology. They include the inability of the SRI to capture different climate conditions (Al Dakheel et al., 2020), building construction date, systems type (autonomous or centralized) and the building users' activities (Apostolopoulos et al., 2022) and the lack of clarity in calculating the overall functionality level and the impact of personal judgement (Ramezani et al., 2021). Future studies could therefore consider further development of the current SRI methodology.

2.7.2 Area 2: SR applications for building envelop optimization

Studies highlight that despite the many technological advances, there is a lack of policies encouraging smart envelope retrofits (Capeluto, 2019). Further, the current regulations fail to identify all the possible occupant discomfort issues (Psomas et al., 2017) that need to be addressed through smart envelop retrofits. Hence, an important future research direction is to promote the establishment/improvement of policies and regulations in this regard.

Apart from the introduction of different technology for building envelop smartification, the impact of user behaviour on the performance of these technologies is yet to be established (Psomas et al., 2017). This could be a potential research direction in the future.

Despite the introduction of smart glazing systems, its cost-effectiveness compared to external shades have not been studied before (Krarti, 2022). Hence, this can be explored in future studies for both residential and commercial buildings.

2.7.3 Area 3: Renewable energy integration through SR applications

It was observed in this review that all RE related studies mostly considered the onsite integration of solar energy. Hence, future studies can explore the feasibility of integrating other RES such as wind, geothermal and biogas.

While the technology aspects of onsite RE integration have been widely studied, the research areas such as the management aspect including the proper communication between the building systems/demand can be studied further to propose better strategies.

The current cost-optimal analyses related to onsite RE does not quantify the costs of thermal discomfort, energy poverty and grid mismatch (Yousif et al., 2020), to ensure a holistic approach to retrofitting of buildings. Hence, future research should focus on applying the multi-criteria approach covering the above aspects to consider a more comprehensive macroeconomic analysis.

2.7.4 Area 4: SR applications for demand side management

The smart applications for demand side management can constantly be improved to obtain the perfect balance between performance and energy savings (Syed Ali et al., 2021). Hence, future studies can be focused on further improving these applications with the integration of complex techniques of machine learning etc.

These smart applications which are highly dependent on occupant and building data but still susceptible to security threats (Ibaseta et al., 2021). Future work can therefore be focused on establishing and improving security mechanisms for these smart applications.

The novel technologies and applications introduced should be properly investigated in future work for different building and occupant populations with different capabilities, frequency of uses in different environments and applications, and beyond (Yang et al., 2022). This investigation will further improve understanding on the performance gaps and the necessary improvements required.

2.7.5 Area 5: Stakeholder engagement in SR

Different previous work on stakeholder engagement in SR projects have been carried out in an isolated manner. Meanwhile, combining and comparing results of stakeholder engagement and management in large organizations could be helpful to small and medium scale organizations to streamline their approaches (Alberg Mosgaard et al., 2016, Preston et al., 2020). Hence, future work could be focused on addressing this gap.

Further studies are needed on a more extensive application of the introduced smart technology with measured environmental data and subjective response data to better understand user acceptance and satisfaction with these technologies (Lee et al., 2012).

It was also apparent that occupants were semi-divorced from the design stage of the contract and perhaps greater involvement could have allayed the concerns raised during the post occupancy stage (Ahmed et al., 2021a). Further work is required to explore this phenomenon in greater detail by conducting cost-benefit analysis between greater investment and higher occupant satisfaction. Such work could establish the cut-off point at which further financial investment produces minimal increases in occupant satisfaction.

2.7.6 Area 6: Planning for effective SR implementation

Smart retrofit applications need to prove their benefits in terms of investment costs by achieving desirable smartness and/or energy efficiency levels with attractive payback times (Apostolopoulos et al., 2022, Yang et al., 2021). Therefore, further research in this field should define the cost-effectiveness of the various smart technologies in buildings retrofitting, according to the building typology or the year of construction.

Empirical data on relative savings through SR applications is scarce while it has a strong impact on mitigation costs and payback times (Schäuble et al., 2020). In this direction, statistically relevant databases of empirical data are needed not only to document realized savings but also to investigate determinants for savings through these smart applications.

As there were no studies considering the indirect benefits of SR for decision-making models (He et al., 2021), future studies could focus on establishing such a holistic SR decision making model incorporated with both direct and indirect benefits of SR.

Although a fully automated environment would maximise energy savings, this approach would be received negatively by certain end users. Occupants feel dissatisfaction when decision making for functions is automated and thus removed from their control (O'Grady et al., 2021). While full automation of buildings may be considered normal in the future, a link between technology and acceptance must be developed. With qualitative and quantitative feedback loops present in BAS, the iterative operational engagement process needs to be further developed. This could lead to adaptable and scalable technologies being modelled and tested. The added benefits from smart decision-making logic with integrated feedback loops will be a great asset to SR, its users, and hence, society.

2.8 Discussion of Review Findings

One key finding of this review is that the past and recent research areas fall into six groups. Research area 6, 'Planning for effective SR implementation' is relatively more prominent, with 20 out of the 65 journal articles falling into this group. Following the identification of the past and recent research areas, potentially useful future research directions of research areas were also identified. Figure 2-10 depicts a mapping of the nexus of different potentially useful future research directions. For illustrative purpose, it also indicates some examples of interrelationships between various domains of the six research areas that have been identified above. Such interrelationships are delineated as follows.

Introducing SRI as an SR objective and improving SRI calculation methodology will be helpful to develop holistic SR decision making models in Research Area 6. Qualitative analysis of occupant behaviour in Research Area 1 is important to compare and contrast occupant engagement and response data in Research Area 5. Cost effectiveness of various smart technologies identified in Research Area 6 and investigating the analysis between greater investment and higher occupant satisfaction in Research Area 5 is important for incorporating economic performance aspects to different tools in Research Area 1. Occupant impacts on smart envelop performance identified in Research Area 2 is useful to conduct qualitative analysis of occupant behaviour in Research Area 1.

Comparison of cost effectiveness of smart glazing systems in Research Area 2 is helpful for cost effectiveness analysis of various smart technologies in Research Area 6. Occupant impacts on smart envelop performance identified in Research Area 2 is useful for comparing different stakeholder levels and collecting occupant response data in Research Area 5. Developing a link between smart technology and user acceptance in Research Area 6 is helpful for identifying occupant impacts on smart envelop performance in Research Area 2.

Findings of Research Areas 3 and 4 are important for cost effectiveness analysis and understanding benefits for SR decision making model development in Research Area 6. Application of SR technology for various building populations in Research Area 4 could aid the comparison of different stakeholder engagements and satisfaction levels in Research Area 5.

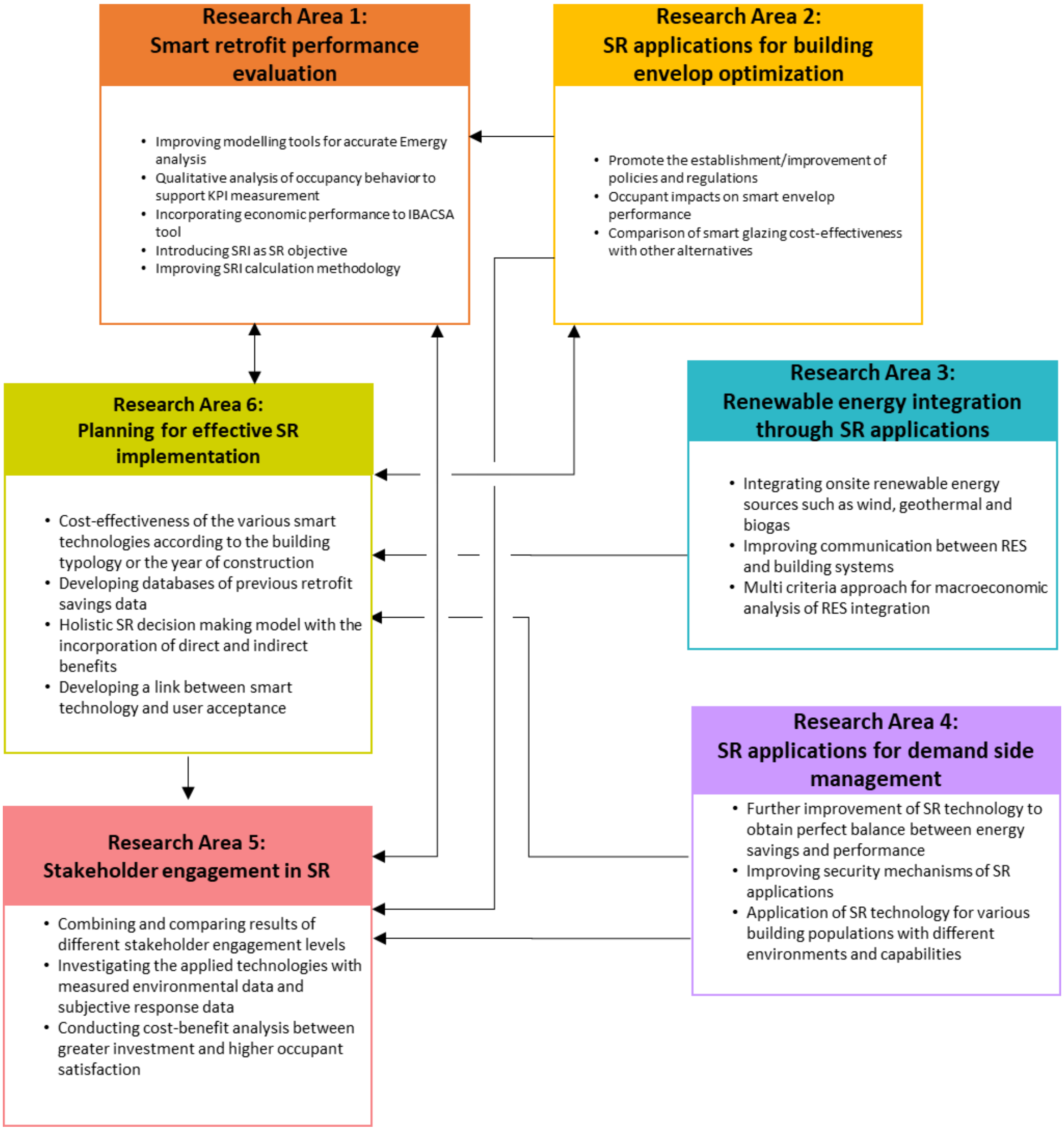

Figure 2-10: Nexus between future research directions

It is interesting to observe that while some research areas only have unilateral links with one another, some have bilateral and multiple interrelationships, showing a high potential for collaboration and shared contribution. In particular, Research Area 6 exhibits the largest number of interrelationships with the other research areas, implying that it is the most influential, complicated and challenging area for future research.

Overall, it is worth noting that the potentially useful future research directions identified above are consistent with the findings of the bibliometric analysis, viz. keywords including ‘energy,’ ‘smart grid,’ and ‘IoT’ have been featured in recent papers, indicating that they are becoming significant topics in this discipline. The diverse nature of the research areas in this field and the significant gaps in these areas indicate that SR research has yet to be developed in proper directions. One likely cause for this is the lack of a standard definition for SR, based on which authors can properly formulate their research studies in this field. Another factor could be that neither researchers nor practitioners have paid heed to the difference between ordinary retrofits and . A further cause could be the difficulty in executing and managing SR for existing buildings where user demands are ever-changing. Despite these hurdles, the future research directions drawn from the above systematic literature review should help promote SR research studies for contributing to SBs and the sustainability of the built environment.

Offering insights into theoretical and practical implications, the review results allow researchers to unveil the significant gaps in SR research, hence highlighting the urgent need for pragmatic SR solutions. The review findings emphasize the current difficulties encountered in SR implementation, inspiring practitioners and policymakers to create solutions in cooperation with researchers. Stakeholders of SR can also identify relevant prominent resources, including active journals and impactful studies, which can be referred and tapped into in tackling SR-related issues.

While the intended research outcomes have been attained, the review is not without limitations. First, the bibliometric analysis method adopted in this review may be considered as straightforward when compared with advanced techniques such as centrality measurement of networks, clustering (e.g., exploratory factor analysis, hierarchical clustering, k-means clustering) using other visualization software such as ‘Bibliometrix R’ (Donthu et al., 2021a, Raza and Hameed, 2021). Second, while the search terms were carefully chosen from prior research in this field, publications without these keywords might not have been found through the literature search process. Third, non-academic SR-related reports of public organizations were not included in this review. Fourth, the literature reviewed was confined to the publications contained in the two databases, viz. Scopus and Web of Science. Further review work is planned after addressing these limitations, after which the expanded review results are expected to extend to those reported above, with further in-depth insights too.

Among the identified potentially useful future research directions, '**development of a holistic SR decision-making model**' under *Research Area 6: Planning for effective SR implementation* was selected as the research gap to be addressed in this study. Accordingly, the subsequent sections of this chapter present a focused analysis of literature relevant to SR decision-making.

2.9 Decision-making process for SR

A typical SR project follows a structured decision-making process involving six stages that addresses the needs of the building (Figure 2-11). The first stage involves evaluating the existing building conditions through energy audits, operational performance assessments and occupant feedback surveys (Ma et al., 2012, Albatici et al., 2016). This step identifies inefficiencies, such as outdated systems, excessive energy consumption or poor indoor environmental quality. A pre-retrofit survey can also highlight building operational problems and define the scope, objectives and expected outcomes of the retrofit project (Hong Kong Green Building Council, 2023). Key factors considered include building typology, energy consumption trends, operational challenges and regulatory compliance requirements. This phase ensures that retrofit projects align with financial, environmental and functional objectives (International Energy Agency, 2022).

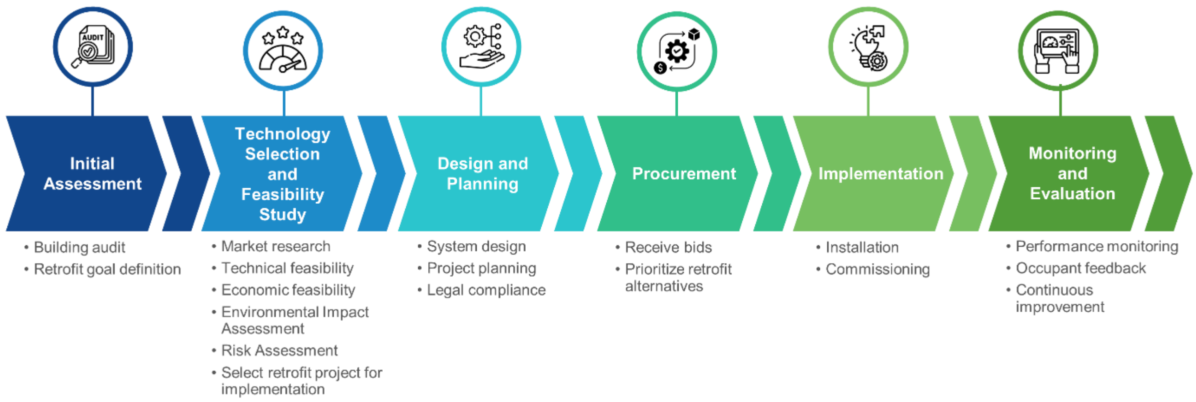

Figure 2-11: SR decision-making process

Once the building's baseline performance is established, the next step is to identify and evaluate feasible SR measures based on building systems and technologies. This involves conducting a market study of available retrofit technologies and assessing them based on key decision criteria such as energy efficiency, technical feasibility, economic viability, environmental impact and operational risks (Ma et al., 2012). At this stage, multiple types of retrofit measures are considered, and the most viable is selected for implementation based on performance benchmarks and cost-effectiveness (Albatici et al., 2016).

After selecting the type of SR measure, the system design and project planning phase ensures its seamless integration with existing building systems (Lu et al., 2021). This stage involves developing the technical specifications and configurations of the chosen retrofit measure, establishing timelines, resource allocation and budgetary constraints, ensuring that the project meets building energy codes, environmental regulations and other legal requirements (Hong Kong Green Building Council, 2023) and including coordination between building owners, facility managers and regulatory bodies, plays a crucial role in refining the implementation strategy (International Energy Agency, 2022).

During the next phase, the procurement process is initiated by inviting suppliers to submit bids based on the defined technical and financial specifications (Ma et al., 2012). The different SR alternatives in the received proposals are evaluated considering criteria such as cost, quality, reliability, energy savings and compatibility with existing building systems (Kolokotsa et al., 2011). In the context of this study, an 'SR alternative' refers to a distinct technical proposal or system configuration submitted by a vendor under a single selected SR measure (e.g., smart lighting, smart car park management system). These proposals, each differing in aspects such as technology type, integration capability, cost and performance, constitute the alternatives to be evaluated within the Decision-Support System (DSS). The decision-makers prioritize the most suitable SR alternative, ensuring alignment with project goals and long-term sustainability (Albatici et al., 2016).

In the next phase, the selected SR alternative is installed, tested and commissioned. System calibration and performance tuning ensure operational efficiency, with minimal disruption to building occupants (International Energy Agency, 2022). During the last phase, post-retrofit performance is tracked using smart sensors, energy meters and automated systems. Measurement and verification protocols confirm energy savings, and adjustments are made based on occupant feedback (Albatici et al., 2016).

2.10 Gaps in previous Decision-Support Systems (DSSs) for SR

A review of previous studies on SR decision-making revealed that most of them are focused on the 'technology selection and feasibility study' phase in the decision-making process (Table

2-5). Detailed analysis of the contents showed that there are certain gaps in these studies that need to be addressed.

Table 2-5: Summary of previous studies on SR decision-making

Source	Study aim	Building type	Criteria considered	SR measures considered	Decision-making methods	Research gaps identified
Pinto et al. (2023)	Develop an investment decision-making framework for selecting the most suitable solar shading system	Office	Energy, environment, economic, social	Intelligent solar shading system	Energy simulations with Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) II	Narrow focus on specific criteria, limited scope of SR measures considered, limited applicability across regions, not scalable and adaptable
Yang and Peng (2001)	Propose a method for decision-making related to intelligent building system selection	Office	Economic, technical	Building automation system, energy management system	Life cycle cost and magnitude of system integration calculation	Narrow focus on specific criteria, limited scope of SR measures considered, limited applicability across regions
Si et al. (2016)	Demonstrate the applicability of MCDM to select green retrofit technologies	University	Different sub-criteria under economic, environmental, social, technical aspects	Motion sensors, BMS	Analytical Hierarchy Process (AHP)	Limited scope of SR measures considered, limited applicability across regions
Kaashi and Vilventhan (2023)	Develop a framework for integrating BIM with green retrofitting to obtain suitable green retrofitting measures for existing buildings	Hostel	Energy, water optimization, occupant needs, saving potential, time of installation, difficulty in installation, shutdown requirement, initial investment, payback period	Occupancy sensors	BIM - energy and water usage analysis Pairwise comparisons - selecting the most suitable retrofitting measures	Narrow focus on specific criteria, limited scope of SR measures considered, over-reliance on complex methodologies, limited applicability across regions, not scalable and adaptable
Abidin et al. (2019)	Develop a retrofit decision-making model that directly indicates the type of practice for different retrofit options	University	Technical, economic, physical, occupants' comfort, design, environmental, visual comfort	Motion sensors, Smart lighting	Retrofit option categorization using the steps of sustainability to suggest type of practice (i.e. best practice, good practice etc.)	Narrow focus on specific criteria, limited scope of SR measures considered, limited applicability across regions
Jradi (2020)	Evaluate the trade-off between implementing deep energy retrofit techniques and improving building intelligence measures	University	Energy	Daylight sensors, motion sensors, smart ventilation and temperature control	Energy simulations	Narrow focus on specific criteria, limited scope of SR measures considered, limited applicability across regions, not scalable and adaptable
Ibn-Mohammed et al. (2014)	Integrate economic considerations with both operational and embodied emissions to produce optimal	University	Economic, operational emissions savings, embodied emissions, net	BEMS	Marginal abatement cost curves and Pareto optimization	Narrow focus on specific criteria, limited scope of SR measures considered, over-reliance on complex

	decisions for building retrofit options		emissions savings, cost-effectiveness			methodologies, limited applicability across regions, not scalable and adaptable
Foldager et al. (2019)	Demonstrate a decision-making tool called DanRETRO for energy retrofit design and assessment	Residential and office	Technical, economic, environmental	Daylight sensors, motion sensors, smart ventilation control, adaptive heating	Energy simulation	Narrow focus on specific criteria, limited applicability across regions, not scalable and adaptable
Zhao et al. (2019)	Develop a Case-Based Reasoning (CBR) approach to support decision-making in building green retrofits	Office	General building information, component information, energy, cost information	Smart lighting	CBR, AHP, Entropy	Narrow focus on specific criteria, limited applicability across regions, not scalable and adaptable
Hong et al. (2021)	Identify optimal retrofit solutions that achieve set energy performance targets for low-rise buildings in Shanghai	Office	Energy consumption, CO_2 emissions, cost indicators, retrofit development level, energy reduction impact	Energy Management Systems (EMS), BMS	Data mining (agglomerative hierarchical clustering), building performance modeling, life cycle cost, environmental assessment	Narrow focus on specific criteria, limited scope of SR measures considered, over-reliance on complex methodologies, limited applicability across regions, , not scalable and adaptable
Lu et al. (2021)	Propose an integrated decision-making framework for optimal energy retrofit options	University	Upfront cost, net present value, benefit-cost ratio, uncertainty	Occupancy sensors, variable speed drive, BMS	Energy simulation, cost-benefit analysis, multi-objective decision-making	Narrow focus on specific criteria, limited scope of SR measures considered, limited applicability across regions, not scalable and adaptable
Jradi et al. (2023)	Design, develop, and demonstrate a digital twin solution called DanRETwin intended to facilitate optimal decision-making, retro-commissioning, and performance optimization of Danish buildings	Non-residential	Technical, Economic, environmental	Clamp-on IoT sensors	Real-time data collection from IoT sensors, machine learning-based data-driven energy models, and dynamic building energy models to develop a digital twin	Narrow focus on specific criteria, over-reliance on complex methodologies, limited applicability across regions, not scalable and adaptable

Most DSSs presented in Table 2-5 focus on selecting between different SR measures (e.g., smart lighting, HVAC, or BMS) in the 'technology selection and feasibility study' phase but they often neglect the subsequent and equally critical step of comparing SR alternatives within the chosen measure in the 'procurement' phase. In practice, organizations must evaluate and compare specifications from various suppliers to identify the best option for implementation and justify the decision to top management. This step is not only challenging but also highly un-systemized, leaving a significant gap in practical DSSs for SR projects.

Most criteria in Table 2-5 focus on energy efficiency and environmental impacts, often neglecting critical aspects unique to SR. While the study by Jradi (2020) evaluate environmental sustainability, it fails to address issues such as user convenience, data privacy, and system adaptability which are key factors in SB technology. Similarly, while Ibn-Mohammed et al. (2014) integrates economic and emission criteria, it overlooks operational flexibility and stakeholder preferences. Studies like Abidin et al. (2019) and Lu et al. (2021) consider factors such as occupant comfort and aesthetics but fail to address broader aspects such as system usability and maintenance ease. One key reason for the poor consideration of a holistic approach towards the SR decision problem in the said studies is the inability of the DSS to consider multiple criteria. The most common methods used in previous studies are simulation-based methods, multi-objective optimization, cost-benefit approaches and BIM. The use of MCDM methods, which enhances decision-making processes, is significantly lacking.

By structuring complex problems, balancing multiple criteria, providing comprehensive evaluations, handling interdependence and enhancing transparency, MCDM methods significantly improve the quality and reliability of decision-making processes (Nielsen et al., 2016). And it has been proven to be very successful in other types of building retrofitting decision-making studies other than SR (Ongpeng et al., 2022, Pinto et al., 2023, Seddiki et al., 2016, Villalba et al., 2024). Only a very few studies such as those by Pinto et al. (2023), Si et al. (2016), Kaashi and Vilventhan (2023) and Zhao et al. (2019) have considered MCDM methods in SR decision-making. Yet, they have only considered a single method or not the most advanced method available for its purpose. Furthermore, while MCDM techniques such as AHP (Si et al., 2016) and 'ELimination Et Choix Traduisant la REalité – Tri' (ELECTRE Tri) (Daniel and Ghiaus, 2023) have been previously employed, integrating and evaluating subjective and objective criteria in the same DSS still remains unexplored. Studies often lack mechanisms to balance competing priorities, such as initial investment costs versus reliability, or energy efficiency versus user convenience.

Many studies (e.g., Si et al. (2016), Daniel and Ghiaus (2023)) put more emphasis on green or energy-efficient systems in their DSS but limit the scope of SB technologies, which encompasses benefits beyond green and energy efficiency, to a few options such as motion sensors. Several DSSs rely on advanced simulation tools or optimization techniques that require significant technical expertise and resources, making them difficult to adopt for practical decision-making. For instance, Kaashi and Vilventhan (2023) and Ibn-Mohammed et al. (2014) employ high-fidelity simulations and optimization algorithms, which may not be feasible for smaller-scale or budget-constrained SR projects. Hong et al. (2021) utilizes machine learning algorithms to predict energy outcomes but lacks an interface that allows non-expert users to interpret results effectively.

Existing DSSs are often rigid and not easily scalable or adaptable. For instance, Lu et al. (2021) highlights IoT-enabled retrofitting options but does not provide a flexible framework that can be customized for different building sizes or stakeholder needs. Similarly, Jradi et al. (2023) and Foldager et al. (2019) focus on highly specific scenarios, which limits their broader applicability. Most of these studies have been conducted and applicable to a specific geographic area. But it is important to have DSSs that are applicable across different regions.

Addressing these gaps is essential to advancing the field of SR and ensuring that DSSs align with the practical and dynamic needs of modern building environments. Figure 2-12 graphically summarises the context of the DSSs reviewed above.

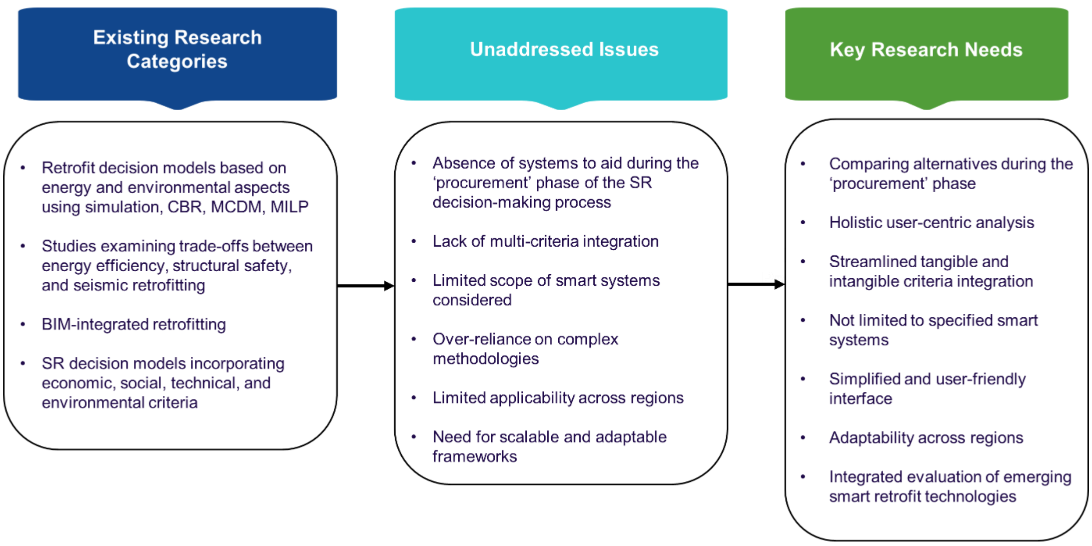

Figure 2-12: Overview of literature findings

Figure 2-12 explicates that an SRDSS addressing existing gaps must offer a comprehensive, user-friendly and adaptable framework. It should include tools for comparing alternatives within selected measures, enabling organizations to evaluate supplier specifications and justify decisions effectively. The DSS must incorporate multi-criteria analysis, balancing technical, economic, environmental and social factors, while being able to consider a wide range of smart measures, including emerging technologies such as Artificial Intelligence (AI)-based energy management. Scalability across regions and adaptability to evolving technologies are essential for broader applicability. A transparent, user-centric design is crucial for enhancing stakeholder understanding and confidence, while streamlined integration of MCDM methodologies such as ANP, TOPSIS and Entropy ensures efficiency in decision-making. By addressing these aspects, the SRDSS can provide a holistic, scalable, and future-ready tool for SR projects.

2.11 Chapter Summary

Aimed at improving the SR knowledge base, this is the first systematic literature review that combines a bibliometric analysis and an in-depth qualitative review to uncover the past and recent developments of SR research. Covering 130 journal articles published between 2003 and 2022, the bibliometric analysis identified the prominent contributors and keywords in the SR research domain.

The qualitative review of the 65 shortlisted journal articles further identified the key pieces of SR literature and categorized them into six research areas: (1) SR performance evaluation, (2) SR applications for building envelop optimization, (3) RE integration through SR applications, (4) SR applications for demand side management, (5) stakeholder engagement in SR, and (6) planning for effective SR implementation. The framework consolidating the major findings and deficiencies in these research areas, which signposts potentially useful future research directions for plugging the current gaps in SR research, is a significant outcome of this review. The nexus of the various future research directions, as mapped and illustrated with examples of interrelationships between the key elements in the six research areas, is a further resource for future researchers in this field.

Following the selection of one of the identified future research directions as the focus of this study, a subsequent review of relevant literature revealed the specific needs and gaps to be addressed within the chosen area.

CHAPTER THREE

3 RESEARCH METHODOLOGY

3.1 Introduction to the Chapter

This chapter outlines the methodological framework adopted to address the research objectives of this study, which aims to develop a Smart Retrofitting Decision-Support System (SRDSS) for office buildings. The chapter presents the philosophical foundations, research approach and research design, including data collection and analysis methods employed throughout the study. Each methodological choice is justified in alignment with the research aim and objectives, ensuring rigor and validity in the development and application of the SRDSS.

3.2 Research Philosophy

The philosophical underpinning of this study is grounded in pragmatism, which supports the integration of both qualitative and quantitative methods to address complex, real-world problems (Creswell and Creswell, 2023). As Saunders et al. (2023) assert, pragmatism acknowledges the existence of multiple realities and recognizes that no single method or perspective can fully capture the complexities of the world. This orientation is particularly relevant for addressing the diverse and often conflicting interests inherent in SR decision-making. Pragmatism encourages researchers to focus on the research problem itself and to employ whichever methods that are most effective in facilitating understanding and generating practical solutions (Morgan, 2007). By supporting the use of multiple methodologies, pragmatism ensures that research outcomes are both robust and applicable to practice (Kaushik and Walsh, 2019). Consequently, this philosophical basis is well-suited to this study, which aims to develop a Decision-Support System (DSS) that integrates expert judgment with quantitative data to enhance SR decision-making.

3.3 Research Approach

Research approaches refer to the broader overarching plans, as well as the procedures that guide the conduct of research, encompassing decisions from broad philosophical assumptions to detailed methods of data collection and analysis (Creswell and Creswell, 2023). Typically, research approaches are classified into three main categories: (1) qualitative, (2) quantitative and (3) mixed-methods.

The qualitative approach involves the non-numerical and descriptive examination of phenomena, focusing on reasoning articulated through words and narratives (Rajasekar et al., 2006). In contrast, the quantitative approach generates numerical data that are subject to formal and systematic analysis, enabling statistical evaluation and hypothesis testing (Kothari, 2004). The mixed-methods approach represents a deliberate combination of qualitative and quantitative strategies within a single study, leveraging the strengths of both paradigms.

3.3.1 Qualitative Approach

Qualitative research is particularly suitable for addressing "what," "why" and "how" types of research questions (Ritchie et al., 2013). It aims to capture in-depth insights into the experiences, attitudes and behaviours of respondents, thereby facilitating a comprehensive understanding of complex social phenomena (Dawson, 2002).

3.3.2 Quantitative Approach

Quantitative research is best suited for questions that seek to determine "how many" or "to what extent," and it typically involves testing objective theories through the examination of relationships among variables (Creswell and Creswell, 2023, Yilmaz, 2013). This approach is grounded in numerical data and emphasizes statistical rigor and generalizability.

3.3.3 Mixed Approach

The mixed-methods approach integrates both qualitative and quantitative methodologies within a single study or research program. As defined by Tashakkori and Creswell (2007), mixed-methods research involves the collection and analysis of both qualitative and quantitative data, the integration of findings and the drawing of inferences that synthesize these multiple forms of evidence. The use of mixed-methods enhances the credibility, validity, and depth of research findings by combining the strengths of both paradigms, thereby improving the robustness of the conclusions (Gilbert and Stoneman, 2015).

3.3.4 Selected Approach for the Study

Given the complex and multifaceted nature of SR, this study adopts a mixed-methods approach to effectively address its research objectives. The study is structured into two primary phases (Peiris et al., 2020):

1. Identification of decision-making criteria relevant to SR, including the exploration of enablers, challenges and regulatory considerations within the context of SB and retrofitting.
2. Determination of the interrelationships and relative importance of these criteria and establishing the SRDSS.

The first phase necessitates an in-depth qualitative exploration of the SR landscape, including a systematic literature review, focus group discussions and expert interviews, to identify and refine the relevant decision-making criteria. The second phase necessitates quantitative methods to establish the criteria weights and prioritize retrofit alternatives. The integration of qualitative insights with quantitative analysis is essential to capture both the subjective judgments of the experts and the objective characteristics of retrofit alternatives, thus enhancing the validity and practical relevance of the developed SRDSS. Consequently, the mixed-methods approach offers the most appropriate and comprehensive research strategy for this study.

3.4 Research Design

The methodological framework of this study is based on the integration of the Analytic Network Process (ANP), Entropy and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods proposed in previous MCDM studies (Si et al., 2016, Chen, 2021). This integrated approach was selected for its ability to address the complexities inherent in SR decision-making, where multiple, interrelated criteria and stakeholder perspectives must be considered. While traditional expert-driven MCDM methods often assume independence among decision criteria, ANP offers a mechanism to account for interactions and interdependencies (Lai et al., 2022), which is essential in the context of SR. To complement the subjectivity of expert judgments, the Entropy method provides an objective assessment of data variability, enhancing the robustness of the weighting process (Shadman Roodposhti et al., 2016). Finally, TOPSIS enables a systematic and transparent ranking of retrofit alternatives based on their relative closeness to Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS), facilitating clear and justifiable decision outcomes (Çelikbilek and Tüysüz, 2020). The combination of these three methods ensures methodological rigor, balancing subjective expert inputs with objective data analysis, and is thus well-suited for developing the SRDSS. This research adopts a five-phase sequential design (Figure 3-1) to systematically develop, apply and validate the SRDSS, with each phase described in detail below.

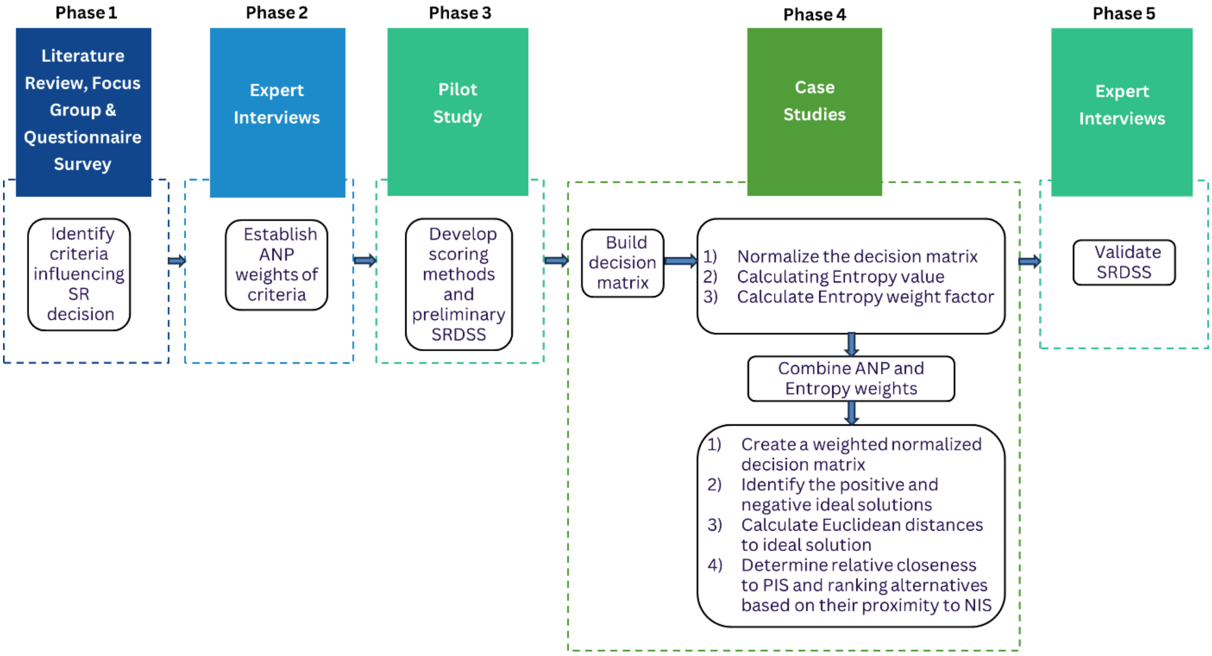

Figure 3-1: Five-phase research design

3.4.1 Phase 1: Criteria Identification

The first phase focused on identifying key decision-making criteria for SR. Given the multifaceted nature of SR, this phase was crucial in ensuring that the developed SRDSS would address all relevant dimensions including financial, technical, user-centric, environmental, legal, safety and security-related aspects. A systematic literature review was conducted across major databases, including WoS and Scopus, to identify existing criteria used in SR and related fields. The preliminary list of criteria derived from the literature was refined and validated through a focus group discussion. It was conducted with FM industry experts from Hong Kong to assess the relevance and applicability of the identified criteria. Their feedback provided insights, suggesting the addition, modification or removal of certain criteria to better reflect real-world decision-making processes.

Subsequently, an industry-wide questionnaire survey was conducted among FM professionals in Hong Kong to further validate the criteria. Respondents rated the importance of each criterion, and the results were statistically analysed using mean score ranking and non-parametric tests, including the Mann-Whitney U and Kruskal-Wallis H tests. Criteria that received importance ratings above a defined cut-off point were selected for the final list. This multi-layered process ensured that the final set of criteria was both comprehensive and contextually relevant, forming the foundation for the subsequent phases of the study. The detailed procedures and findings related to this phase are elaborated in Chapter 4.

3.4.2 Phase 2: ANP Weighting

The second phase established the relative importance weights of the finalised SR criteria. Recognizing that SR decisions involve interrelated and often conflicting criteria, this study employed the ANP method, which allows for the modelling of interdependencies and feedback loops among criteria. To derive ANP weights, 24 expert interviews were conducted across two regions: Hong Kong (developed) and Sri Lanka (developing). This ensured that the model captured regional variations in priorities and decision-making practices, reflecting the diverse economic, regulatory and cultural settings in which SR projects are implemented. Expert opinions on the pairwise comparisons of criteria were collected using a questionnaire. The collected data were imported into a specialised software, 'Super Decisions', to calculate the ANP weights. Subsequently, the ANP-derived criteria weights from Hong Kong and Sri Lanka were compared using Spearman's rank correlation to examine the degree of alignment in prioritisation across the two regional contexts. In addition, the expert interviews findings were thematically analysed to identify contextual factors influencing SR decision-making in each region. The detailed procedures and findings related to this phase are elaborated in Chapter 5.

3.4.3 Phase 3: Scoring Methods and Preliminary SRDSS Development

The third phase focused on the development of scoring methods for evaluating SR alternatives under each identified criterion, as well as the construction of the preliminary SRDSS framework. This phase served as a critical bridge between criteria identification and weighting (phases 1 and 2) and the application of the SRDSS in real-world scenarios (phase 4).

The scoring methods were devised through a hybrid approach. Some scoring mechanisms were directly adapted from established literature. Others were self-developed to ensure context-specific applicability where no suitable methods existed. This blended strategy ensured that the scoring methods reflected both theoretical rigor and practical relevance, aligning with the diverse nature of SR decision-making. To validate the applicability and clarity of these scoring methods, feedback was sought from two FM experts each from Hong Kong and Sri Lanka, ensuring that the scoring methods were interpretable, consistent, and aligned with industry expectations.

Following the development of the scoring methods, these were integrated into a preliminary SRDSS framework within a MS Excel-based platform. This initial version of the SRDSS incorporated the conceptual and mathematical structure of the ANP-Entropy-TOPSIS framework, laying the foundation for subsequent SRDSS application. The preliminary MS

Excel platform was refined iteratively, ensuring that it was not only methodologically sound but also operationally feasible for the case study applications that followed. The detailed procedures and findings related to this phase are elaborated in Chapter 6.

3.4.4 Phase 4: SRDSS Development and Case Study Application

The fourth phase focused on operationalising the SRDSS by applying the developed framework to real-world scenarios. To demonstrate the applicability, robustness, and versatility of the SRDSS, the system was applied to four case studies, two office buildings each from Hong Kong and Sri Lanka. These case studies were strategically selected to reflect diverse building characteristics, stakeholder priorities and regulatory environments, enabling a comprehensive evaluation of the system across both developed and developing regional contexts.

For each case study, the SRDSS facilitated a structured assessment of SR alternatives, allowing facility managers to evaluate options based on criteria using the scoring methods. The ranked outputs generated through the SRDSS were then subjected to comparative analysis across the four cases. This comparative evaluation enabled the derivation of context-specific insights, highlighting regional differences in decision-making priorities and adaptability of the SRDSS framework. The detailed procedures and findings related to this phase are elaborated in Chapter 6.

3.4.5 Phase 5: Model Validation

The final phase involved validating the SRDSS to assess its usability, reliability and practicality. A series of semi-structured interviews were conducted with ten FM industry experts from Australia, offering a third regional perspective beyond the initial case study contexts. The validation process focused on assessing the relevance and comprehensiveness of the criteria, evaluating the clarity and functionality of the MS Excel-based tool and identifying potential improvements for user experience and decision transparency.

Feedback from the validation phase informed refinements to the SRDSS, including enhancements to the user interface, automation of calculations through VBA macros, and improvements in the presentation of results. The SRDSS was subsequently refined into an automated MS Excel-based tool, incorporating VBA macros to enhance its operational functionality, user-friendliness and practical application. The detailed procedures and findings related to this phase are elaborated in Chapter 7.

3.5 Data Collection Techniques

This research employed both primary and secondary data sources to ensure a comprehensive exploration of the complex decision-making processes associated with SR. According to Saunders et al. (2023), primary data refers to original information collected directly from first-hand sources, providing unique, context-specific insights (Salkind, 2010). The primary data sources for this study included focus group discussions, questionnaire surveys, expert interviews and case studies. In contrast, secondary data refers to information previously gathered and analysed by others (Salkind, 2010). In this research, the systematic literature review served as the key secondary data source. The integration of both data types ensured that the study benefited from both depth and breadth, covering theoretical foundations as well as practical perspectives.

3.5.1 Systematic Literature Review

A systematic literature review was conducted to identify the key decision-making criteria for SR. This method provides a transparent, structured and replicable process for synthesizing existing research, reducing potential bias and ensuring rigor (Tranfield et al., 2003). It forms a strong foundation for research by generating a comprehensive understanding of the current state of knowledge (Saunders et al., 2023). The review followed the guidance of Oxman and Guyatt (1993), ensuring the data collected were precise and comprehensive as well as adhering to pre-established eligibility parameters. Such rigour is vital for supporting evidence-based decision-making (Snyder, 2019). The findings of the systematic review were essential for identifying SR criteria that served as the preliminary input for the development of the SRDSS.

3.5.2 Focus Group Discussion

Following the systematic literature review, focus group discussions were conducted to validate and refine the identified SR criteria. Focus group discussions are widely recognized for their ability to explore diverse perspectives through structured, interactive dialogue among selected participants (Nyumba et al., 2018). This method is particularly effective for developing research instruments and generating new insights based on group dynamics. In this study, focus group discussions were organized with FM experts in Hong Kong, who critically evaluated the literature-derived criteria. These discussions ensured that the criteria reflected both practical relevance and contextual applicability within the SR decision-making environment. This step was vital in bridging theoretical constructs with real-world practices, ensuring that the final criteria set aligned with industry expectations.

3.5.3 Questionnaire Survey

After refining the SR criteria through focus group discussions, a questionnaire survey was conducted to quantitatively assess the validity of these criteria across a broader population of industry professionals. Questionnaire surveys are a widely used method for collecting structured data from a larger audience, facilitating standardization, comparability and statistical analysis (Buckingham and Saunders, 2004, Saunders et al., 2023). By distributing the survey among practitioners and academics involved in FM, the study ensured a diverse range of perspectives, capturing both theoretical and practical viewpoints on SR decision-making.

The survey instrument employed Likert-scale items, allowing respondents to rate the importance of each SR criterion. This approach enabled the collection of quantitative data suitable for prioritization and statistical analysis. Techniques such as mean score ranking were used to establish initial rankings of the criteria, while the Mann–Whitney U and Kruskal–Wallis H tests were applied to assess group differences across demographic or professional sub-groups. These statistical tests ensured that the prioritization of SR criteria reflected consensus across diverse stakeholder groups, enhancing the robustness and generalizability of the findings. The questionnaire survey also contributed valuable data for subsequent criteria weighting and model development, ensuring that the SRDSS was grounded in empirical stakeholder inputs.

3.5.4 Expert Interviews

To supplement the quantitative findings and deepen the qualitative understanding of SR decision-making processes, expert interviews were conducted in phase 2 and phase 5 of this study. Expert interviews are a well-established qualitative research method designed to extract specialized knowledge from individuals with significant experience and authority within a field (Libakova and Sertakova, 2015). Their semi-structured format allows for flexibility in probing complex topics while maintaining a consistent thematic focus across interviews.

In phase 2, expert interviews were conducted with FM professionals in Hong Kong and Sri Lanka to capture their experiences and insights regarding current SR decision-making practices, prevailing challenges and context-specific nuances. Additionally, these interviews provided the pairwise comparison data required for applying the ANP method to derive subjective criteria weights.

In phase 5, following the development of the SRDSS, expert interviews were used to validate the system's usability, reliability and practical applicability. This phase involved industry experts from Australia, ensuring the inclusion of perspectives from a developed economy beyond the initial case study regions. The interviews focused on evaluating the transparency, user-friendliness and relevance of the SRDSS framework, gathering feedback to refine and enhance the system.

Through these two phases of expert engagement, the study ensured that both the weighting process and the validation of the SRDSS were informed by practical expertise across different geographical regions and market contexts.

3.5.5 Case Studies

To demonstrate the practical applicability of the SRDSS and to evaluate its performance across diverse contexts, four case studies were conducted: two office buildings in Hong Kong and Sri Lanka each. The case study is a robust empirical research strategy that investigates phenomena within their real-life context, using multiple sources of evidence for triangulation and validation (Robson, 2002, Yin, 2009). Case studies are particularly effective for complex decision-making environments like SR, where contextual factors such as regulatory frameworks, market conditions and stakeholder priorities play a crucial role.

By selecting multiple cases across developed and developing regions, this study enabled cross-case comparisons, offering insights into regional differences in SR decision-making. The diversity of the case studies ensured that the SRDSS was evaluated under varied economic, regulatory and operational conditions, enhancing the generalizability and applicability of the system.

Each case study involved the application of the SRDSS to a SR project, using actual retrofit alternatives and project-specific data. The outputs generated by the SRDSS, including the ranking of retrofit alternatives, were analysed to assess the system's effectiveness and decision-support capabilities in real-world settings. This approach ensured that the SRDSS was not only theoretically robust but also practically validated.

3.6 Data Analysis Techniques

This study employed a mixed-methods data analysis strategy, integrating both qualitative and quantitative techniques to ensure a comprehensive, rigorous examination of the data collected. The analysis techniques were selected to align with the research objectives and the complex, multi-criteria nature of SR decision-making. Each analytical method was applied at the appropriate stage of the study, ensuring that subjective expert insights and objective data were both systematically evaluated to support the development and validation of the SRDSS.

3.6.1 Content Analysis

For the qualitative data derived from the systematic literature review, focus group discussions, and expert interviews, content analysis was employed. Content analysis is defined as "a systematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding" (Stemler, 2000). This method enables the researcher to extract themes, patterns and categories from qualitative data, providing a structured interpretation of textual information (Drisko and Maschi, 2016).

In this study, content analysis was applied in the three contexts. During the systematic literature review, content analysis was used to identify recurring SR criteria. For the focus group discussions, the method facilitated the extraction of key insights and consensus points regarding the practical relevance of SR criteria. In the expert interviews conducted in phase 5, content analysis allowed for the identification of recommendations related to SR decision-making and the validation of the SRDSS. This approach ensured that qualitative data were analysed systematically, contributing valuable insights to criteria development, context identification and model validation.

3.6.2 Statistical Analysis of Survey Data

For the quantitative data collected through the questionnaire survey, several statistical techniques were employed to analyse and interpret the responses. **Mean score ranking** was utilized to shortlist SR criteria based on Likert-scale responses. This method is widely used in built environment research for prioritizing variables and offers a simple yet effective approach to ranking (Altomonte and Schiavon, 2013, Darko et al., 2017, Ho et al., 2021b). **Cronbach's alpha** was calculated to assess the internal consistency and reliability of the survey instrument (Tavakol and Dennick, 2011). Ensuring that the scale items were consistent in measuring the intended constructs enhanced the credibility of the survey findings. To explore differences in perceptions across stakeholder groups, **Mann–Whitney U** and **Kruskal–Wallis H tests** were applied. These non-parametric tests are appropriate for ordinal data, such as Likert-scale responses, and do not require assumptions of normality (Teplow, 2018, Smalheiser, 2017). The Mann-Whitney U test was used for comparing two independent groups (e.g., different genders), while the Kruskal–Wallis H test facilitated comparisons across three or more groups (e.g., varying work experience levels). These analyses ensured that the prioritization of SR criteria was robust and accounted for stakeholder diversity.

Together, these statistical techniques provided a solid empirical basis for refining the criteria shortlist and informed the weighting and ranking processes in subsequent stages.

3.6.3 Thematic Analysis

The qualitative expert insights gathered in phase 2 were analysed using thematic analysis, a widely adopted method for identifying, analysing and interpreting patterns of meaning within qualitative data. Boyatzis (1998) broadly describes thematic analysis as a way of "seeing" and "making sense out of seemingly unrelated material." Braun and Clarke (2006) define it as a flexible method for detecting recurring themes or patterns across a textual dataset, facilitating the organisation and interpretation of rich qualitative content. As noted by Brough and Neuendorf (2018), the process ultimately aims to construct a coherent narrative from the data. In this study, thematic analysis enabled the identification of context-specific challenges, stakeholder perspectives, and expert recommendations related to SR decision-making, offering deeper insight into the real-world dynamics influencing SR implementation.

3.6.4 Analytic Network Process (ANP)

The ANP method was employed to derive the subjective weights of SR decision-making criteria. Developed by Professor Thomas L. Saaty in 1996, ANP is an extension of the AHP method, designed to address complex decision environments where interdependencies and feedback loops exist among decision elements (Saaty, 2004). Unlike AHP, which assumes a hierarchical structure and independence among criteria, ANP models the relationships among criteria in a network, allowing for the capturing of interactions between decision factors (Lai et al., 2022).

In the context of SR decision-making, where financial, technical, environmental and occupant-related criteria often influence one another, ANP was particularly suitable (Peiris et al., 2024). Its pairwise comparison mechanism facilitated the systematic elicitation of expert judgments, enabling the derivation of relative importance weights that reflect real-world complexities (Saaty, 2004). The use of Super Decisions software ensured consistency and accuracy in the pairwise comparison matrices (Saaty and Vargas, 2006).

ANP was selected over other subjective weighting methods, such as the Simple Multi-Attribute Rating Technique (SMART), Weighted Sum Model (WSM) and the Delphi method, due to its unique ability to model interdependencies and feedback relationships (Saaty and Vargas, 2006, Ishizaka and Labib, 2011). These alternative methods assume criteria independence or focus solely on achieving expert consensus, limiting their applicability in dynamic decision environments like SR. The proven application of ANP in FM decision-making further justified its use (Ahmed et al., 2021b, Jin et al., 2018, Albayrak et al., 2009, Shao et al., 2018, Tseng, 2009).

3.6.5 Spearman's Rank Correlation

The Spearman rank correlation is a non-parametric statistical test used to measure the strength and direction of association between two sets of ranked data (Abedi et al., 2019, Leon, 1998). In this study, the ANP-derived criteria weights from Hong Kong and Sri Lanka were further analysed using the Spearman rank correlation test to assess the degree of alignment in the prioritisation of SR criteria between the two regions.

3.6.6 Entropy Method

The Entropy method was applied in this study to derive objective criteria weights for SR criteria. Grounded in information theory (Shannon, 1948), the Entropy method evaluates the uncertainty and information content within a dataset, providing a data-driven mechanism for weighting criteria (Bai et al., 2018). The fundamental principle underpinning this method is that the greater the variability in the data associated with a criterion, the more informative that criterion is considered to be, thus receiving a higher weight (Zou et al., 2006). Conversely, criteria with less variability, or higher entropy, are deemed less informative in the decision-making process, receiving lower weights (Zavadskas et al., 2014).

In the context of SR decision-making, relying solely on subjective expert judgment (via ANP) may introduce biases or inconsistencies, particularly across regional contexts. The Entropy method complements the subjective weights by introducing an objective dimension, derived from data distributions across retrofit alternatives. This integration enhances the robustness, credibility and balance of the weighting framework within the SRDSS.

Compared to other objective weighting methods, the Entropy method offers distinct advantages. The Standard Deviation (SD) method assigns weights based solely on the degree of dispersion in the data, but it does not account for uncertainty or information richness (Peldschus, 2008). Similarly, the Coefficient of Variation (CV) normalizes dispersion relative to the mean but is sensitive to scale effects and outliers (Huang and Nguang, 2010). Principal Component Analysis (PCA), while useful for data dimensionality reduction, does not directly generate criteria weights but focuses on explaining variance structures (Jolliffe and Cadima, 2016).

An alternative approach, the Criteria Importance Through Intercriteria Correlation (CRITIC) method, considers both variability and inter-criteria correlations (Diakoulaki et al., 1995). While CRITIC offers an effective mechanism for addressing redundancy among criteria, its correlation-based weighting adjustments would overlap with the interdependencies already modelled via ANP in this study. Introducing CRITIC alongside ANP could result in methodological redundancy, as both approaches address criterion relationships through different methods.

In contrast, the Entropy method focuses solely on data variability and uncertainty, providing a clear, complementary role within the ANP-Entropy-TOPSIS framework. This non-overlapping function ensures that subjective insights from the experts (via ANP) and objective variability from data (via Entropy) are balanced without redundancy, enhancing the rigor and robustness of the SRDSS.

3.6.7 Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Method

To establish the final ranking of SR retrofit alternatives, the TOPSIS method was employed. Developed by Hwang and Yoon (1981), TOPSIS is an MCDM method that ranks alternatives based on their closeness to the PIS and farness from the NIS. The PIS represents the best attainable values across all criteria, while the NIS represents the worst (Zavadskas et al., 2016). The alternative with the shortest distance to the PIS and farthest distance from the NIS is deemed the most favourable.

TOPSIS is particularly suited for decision-making scenarios involving conflicting criteria and offers a transparent, mathematically robust framework for ranking alternatives. Unlike subjective methods, the distance-based logic of TOPSIS relies purely on quantitative calculations, ensuring consistency and objectivity in the final rankings (Peng et al., 2021).

This method has been widely applied in construction management, energy retrofitting and sustainability assessments due to its simplicity and interpretability (Aye et al., 2018, Chen, 2021, Tiwari et al., 2020). In this study, where SR alternatives needed to be evaluated based on multiple, often conflicting criteria, TOPSIS provided a logical and practical solution for prioritizing options.

When compared to other ranking MCDM methods, TOPSIS offers unique advantages. The Simple Additive Weighting (SAW) method aggregates weighted scores linearly but assumes perfect compensability between criteria, which may oversimplify complex trade-offs (Zanakis et al., 1998). The Weighted Product Model (WPM), while maintaining multiplicative relationships, is sensitive to scaling issues (Yoon, 1987). ELECTRE and 'VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)', both outranking methods, introduce complex threshold settings and additional parameters, reducing their transparency and practical applicability (Govindan et al., 2015). In contrast, TOPSIS strikes a balance between computational simplicity and methodological rigor, requiring no subjective threshold settings while maintaining clear interpretability.

Therefore, within the ANP-Entropy-TOPSIS framework, TOPSIS served as the ranking mechanism, integrating seamlessly with the subjective (ANP) and objective (Entropy) weighting processes. This ensured that the prioritization of retrofit alternatives was methodologically sound, transparent and practically applicable, reinforcing the decision-support capabilities of the SRDSS across diverse SR scenarios.

3.7 Chapter Summary

This chapter presented the methodological framework adopted to achieve the research aim of developing an SRDSS for office buildings. It commenced by outlining the research philosophy, which is grounded in pragmatism. The mixed-methods research approach was justified as the most appropriate strategy for capturing both subjective expert insights and objective data, thereby enhancing the robustness and applicability of the SRDSS.

The chapter then detailed the research design, which followed a five-phase sequential structure. This design facilitated the systematic development, application and validation of the SRDSS. The data collection methods employed across these phases included both primary and secondary sources. Primary data were collected through focus group discussions, questionnaire surveys, expert interviews and case studies, while secondary data were obtained from the systematic literature review. Each method was justified based on its suitability for addressing specific research objectives and its execution was described in detail to ensure methodological rigor.

The chapter further elaborated on the data analysis techniques employed. Content analysis was used to systematically evaluate qualitative data from the literature review, focus groups and interviews. Statistical analyses, including mean score ranking, Cronbach's alpha, the Mann-Whitney U test and the Kruskal-Wallis H test, were applied to the survey data to shortlist SR criteria and ensure data reliability. Thematic analysis was used to explore contextual insights related to SR. The ANP method was employed to derive subjective criteria weights, accounting for interdependencies among decision criteria along with Spearman rank correlation to identify any associations between the criteria ranks. The Entropy method was integrated to provide objective weighting based on data variability. Finally, the TOPSIS method was used to rank retrofit alternatives, offering a transparent, quantitative approach to prioritizing SR alternatives.

Collectively, these methodological choices ensured that the SRDSS was developed through a rigorous, systematic process, grounded in both theoretical rigor and practical relevance. The integration of subjective and objective weighting methods within an MCDM framework allowed for a holistic evaluation of retrofit alternatives, ensuring that the system is adaptable across diverse regional and contextual settings. This chapter thus provided a comprehensive foundation for the application and validation of the SRDSS, which are detailed in the subsequent chapters.

CHAPTER FOUR

4 IDENTIFICATION OF SR DECISION-MAKING CRITERIA[4]

4.1 Introduction to the Chapter

This chapter presents the systematic process undertaken to identify and prioritize the key decision-making criteria for SR, which serve as the foundational input for developing the Smart Retrofitting Decision-Support System (SRDSS). Given the complex, multi-criteria nature of SR, where financial, technical, human, environmental, legal and safety factors are involved, this chapter describes the structured, four-stage approach employed in this research phase. This includes an initial literature review, a focus group discussion with industry experts, an extended literature review and a questionnaire survey to validate and refine the criteria. The chapter outlines the methods, analyses and findings from each stage, culminating in a finalised set of criteria that reflects both academic insights and practical stakeholder perspectives, thereby ensuring the relevance and robustness of the SRDSS in subsequent stages.

4.2 Multi-Criteria Decision-Making (MCDM) in SR

While a variety of modelling and empirical research have been undertaken on building energy retrofits (e.g., Ho et al. (2021a); Sing et al. (2021)) and a large number of buildings require upgrading (International Energy Agency, 2021), the uptake of retrofitting is still low. For instance, the annual retrofitting rates in the European Union range from 0.4% to 1.2% (Pohoryles et al., 2022). Some of the key reasons for this are: system compatibility and interoperability related complexities (Al Dakheel et al., 2020), cyber security risks (Lawrence et al., 2016), lack of competent staff to handle the retrofits and operations (Yang and Peng, 2001), resistance from the occupants and most significantly the disapproval from investors due to the significant investment required for SR (Wong et al., 2005).

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[4]The core research and findings in this chapter have been peer-reviewed before publication in:

Peiris, S., Lai, J. H. K. & Kumaraswamy, M. M. (2023). *Smart retrofitting decision-making criteria for buildings: shortlisting via a questionnaire survey* [Paper presentation]. The 46th Australasian Universities Building Education Association (AUBEA) 2023 Conference. Auckland, New Zealand.

Peiris, S., Lai, J., & Kumaraswamy, M. M. (2023). Establishing criteria for smart retrofitting decision-making for buildings. *IOP Conference Series: Earth and Environmental Science*, *1176*, 012004. IOP Publishing. https://doi.org/10.1088/1755-1315/1176/1/012004.

This makes SR decision-making a very complex problem, which depends on different criteria spanning the financial, technical, user comfort, environmental and legal aspects. To ensure rational decision-making, decision-makers should understand the criteria upon which they should base their judgements. Despite the existence of certain criteria identified from prior retrofit-related studies (Ma et al., 2012, Miller et al., 2018, Ismaeel and Mohamed, 2022), there remains a need to identify criteria that are specifically applicable to the SR decision-making process. Consequently, the goal of this phase of study is to respond to a problem that SR decision-makers frequently encountered: "What are the most important criteria that need to be considered when selecting the most appropriate SR alternative?" To this end, a bespoke MCDM method is needed.

MCDM is a method that "considers different qualitative and quantitative criteria that need to be fixed to find the best solution" (Taherdoost and Madanchian, 2023). Among the most prevalent criteria in many decision-making scenarios, for instance, are cost and quality (Shahsavarani and Azad Marz Abadi, 2015). Additionally, expert groups assign weights to the criteria based on the significance of each criterion in that particular situation (Taherdoost and Madanchian, 2023). The main steps for developing an MCDM framework are shown in Figure 4-1.

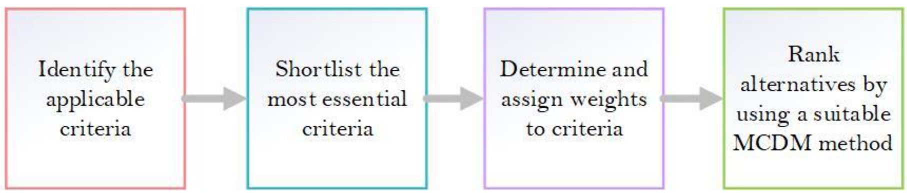

Figure 4-1: Steps for developing an MCDM

The MCDM method has been previously used for other types of retrofitting studies such as energy retrofitting, green retrofitting and seismic retrofitting (Dangana et al., 2013, Formisano and Mazzolani, 2015, Si and Marjanovic-Halburd, 2018). However, the distinctive nature of SR decision-making has not been comprehensively addressed. Aimed at addressing this research gap, the processes and findings of the first and second steps of Figure 4-1 are reported below.

4.3 Research Methods

The research process adopted in this part of the study consists of four stages as shown in Figure 4-2. Firstly, an initial literature review was conducted followed by a focus group discussion to validate the findings. Based on the findings of the focus group discussion, the literature review was further extended. Criteria identified from the second stage of literature review was shortlisted through a questionnaire survey.

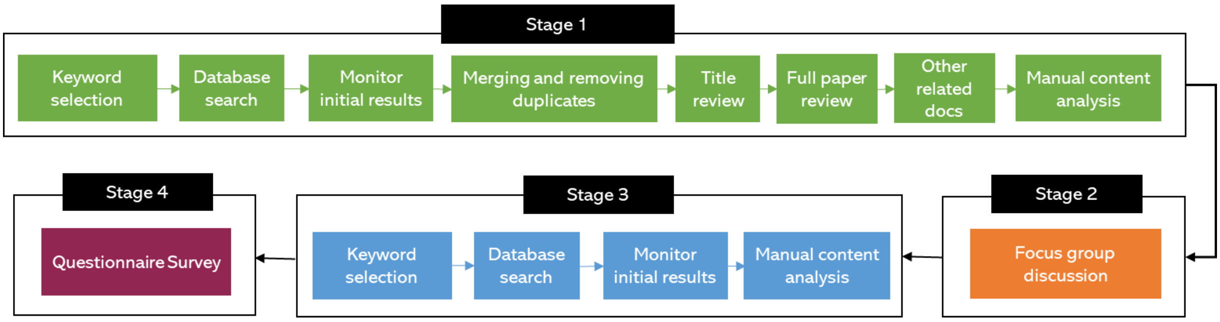

Figure 4-2: Four-stage methodological approach used to identify SR decision-making criteria

4.3.1 Stage 1 – Initial Literature Review

An initial extensive literature review was undertaken following an interpretivist research philosophy. Due to the limited previous research work on SR decision-making, a qualitative review approach similar to those of Adegoriola et al. (2021) and Ho et al. (2021a) was taken, allowing flexibility to manually locate, analyse, and interpret the data and materials needed.

Through a series of keyword searches on the WoS database, Stage 1 identified previous works that provide insights for establishing the envisaged SR decision-making criteria. The searches in the present study were made on the 'Topic' field in the WoS, using the following keywords: (1) ("smart building" OR "intelligent building") AND selection, (2) ("smart building" OR "intelligent building") AND criteria, and (3) ("smart building" OR "intelligent building") AND decision. The initial searches resulted in 419 papers. Before a final, clean dataset was acquired, the initial dataset was checked for duplicates and errors, thus resulting in 357 papers. The dataset then underwent title and full paper reviews, from which the most pertinent 12 papers were identified. Added to this dataset were two other highly relevant documents (UL Solutions, 2022, Verbeke et al., 2019) that were manually located through a focused web search. The criteria used to shortlist these 14 documents from the rest fall into two sets, namely, (1) Inclusion: a) papers or documents on SB related selection/assessment criteria, b) papers or documents on building retrofitting related criteria, and c) the criteria mentioned in the papers are useful for SR decision making; and (2) Exclusion: papers or documents on the technical aspects of a particular SB technology. Afterwards, the contents of these 14 documents were manually analysed to identify the SR decision-making criteria.

4.3.2 Stage 2 – Focus Group Discussion

During Stage 2 of this criteria identification phase of the study, a group of experts were invited to participate in a focus group discussion and their views sought on the relevance of the decision-making criteria identified in Stage 1. As the comprehensive literature review offered a broad set of criteria, a focus group discussion was necessary as certain criteria identified in the literature were theoretical in nature and not always practically relevant for facility management contexts.

Through the implementation of a focus group methodology, participants are given the opportunity to engage in a collaborative exchange of perspectives (Slovák et al., 2023). A focus group session facilitates the exploration of participants' perspectives in a thorough manner, allowing for the gathering of comprehensive data (Minichiello and Kottler, 2009). Hence, they are highly appropriate for the identification of the relevance of decision-making criteria, as well as any additional important criteria that may not have been addressed in Stage 1.

To address the problem under consideration, the focus group participants needed to be well experienced in initiating and implementing SR. Accordingly, nine facility management professionals with a minimum 5 years of experience, direct involvement in retrofitting projects and seniority in decision-making were invited through purposive sampling. The focus group size chosen is within the ideal range indicated by Kamberelis and Dimitriadis (2005) and Lazar et al. (2017) which is six to twelve individuals.

The demographic details of the focus group participants are shown in Table 4-1.

Table 4-1: Demographic details of focus group participants

Participant	Designation	Years of Experience	FM Sectors of Experience							
			Commercial	**Residential**	**Hotels**	**Hospitals**	**Shopping Complex**	**Construction Projects**	**Educational Institutes**	**Academia**
A	Senior Facilities Manager	14	√	√						
B	Head of Energy and Sustainability	15	√	√	√	√	√			
C	General Manager	22	√	√			√	√	√	
D	Vice President	29	√							
E	Head of Property FM	30+	√	√	√	√	√			

F	Assistant Professor	20+	√					√		√
G	Operations Director	20	√	√						
H	Director	40	√	√			√			
I	Vice President - Facilities Operations	20+	√	√	√		√	√	√	√

As shown in Table 4-1, the focus group was composed of nine highly experienced facility management professionals, each bringing between 14 and 40 years of industry experience. The group included senior decision-makers such as Vice Presidents, Directors and Heads of Departments, alongside a representative from academia, ensuring a balance between practical industry insights and research-oriented perspectives. Their collective expertise covered a diverse range of facility sectors, including commercial, residential, hospitality, healthcare, shopping complexes, educational institutes and property management. This sectoral diversity allowed the study to capture decision-making considerations relevant to different building types rather than being limited to a single sector. The inclusion of professionals directly responsible for sustainability, property and operations ensured that both strategic and operational perspectives were incorporated. Such a composition provided not only the breadth of viewpoints needed for comprehensive validation of criteria but also the depth of authority required to reflect the realities of decision-making in smart retrofitting practice.

The focus group discussion was held online via the Zoom platform. Presentation slides were prepared with the required details and a copy was sent to the participants two days prior to the discussion. This allowed the participants to preview and get familiar with the contents before attending the discussion. At the beginning of the focus group meeting, the host explained the requirement for the consent of the experts to participate in the discussion. Afterwards, the background of the study was introduced along with the objective of the focus group discussion. Once the participants were clear on the background and the arrangement, the discussion was conducted in the following sequence:

- For each criterion:
    - Explanation of the definition and scope, to avoid misinterpretation
    - Voting for relevance of each criterion and discussion
- Discussion on any important criteria to be added

Data of the focus group discussion was collected by recording the oral discussion using the ‘record’ feature on zoom and immediate note taking of the matters discussed. At the end of the discussion, the host requested the participants to provide personal particulars via an online form. The personal particulars include their job title, work experience in years, FM sector they are involved in, professional qualifications/memberships and academic qualifications. The duration of the focus group discussion was one and a half hours.

4.3.3 Stage 3 – Extended Literature Review

The focus group feedback highlighted shortcomings in the criteria identified from the literature review in Stage 1. Therefore, in Stage 3, a second round of literature review was conducted to cover papers with a broader scope. For this purpose, papers were searched again from the WoS and the search terms used were: building AND (renovat* OR retrofit* OR refurbish*) AND decision*. These searches were conducted on the 'Title' field in the WoS, resulting in 121 papers in addition to the 14 papers identified in Stage 1. The contents of all these papers were manually reviewed by a qualitative content analysis process (Zhao and Taib, 2022), where their main contents identified were summarized using a manual coding process and the summarized content of each article was qualitatively coded into discernible categories. The findings were cross-checked to minimize bias due to subjective judgement during the content analysis process.

Due to the dearth of publications specifically on SR, the set of 121 papers mentioned above include certain papers focusing on conventional, energy, or green retrofits that are relevant to SR. In addition to papers on retrofit decision-making criteria, papers on post-retrofit performance evaluation criteria were also included in the set of 121 papers.

4.3.4 Stage 4 – Questionnaire Survey

The criteria finalized at the end of Stage 3, were then presented to professionals via a questionnaire survey in order to shortlist the most important and relevant ones. The questionnaire consisted of five sections. Section 1 sought the consent of respondents to participate in the survey while providing them additional information on the study including Human Subjects Ethics approval. Section 2 facilitated the indication of the personal particulars including their job level, work experience, professional qualifications/memberships, academic qualifications and gender. These details served to portray the backgrounds of the respondents, allowing for comparisons between groups to be made when analysing the survey results. Section 4 solicited the importance ratings of the SR decision making criteria on a five-point scale (1: very low; 2: low; 3: moderate; 4: high; and 5: very high). Section 5 asked the participants to suggest any other criteria they consider important and any other comments they have based on their experience. The online questionnaire is provided in Appendix A4.1 (page 184)

Pilot tests on the questionnaire were conducted with two FM experts. These tests assisted in detecting and eliminating any potential inaccuracy or misunderstanding of the survey questions. The results were used to finalize the questionnaire before it was officially distributed. The industry-wide online survey was officially launched in August 2022 during a webinar conducted for FM professionals in Hong Kong. The webinar was jointly organized by the Building Services Operation and Maintenance Executives Society (BSOMES), the Hong Kong Institute of Facility Management (HKIFM), the International Facility Management Association (IFMA) – Hong Kong Chapter, and the Department of Building Environment and Energy Engineering (BEEE) of The Hong Kong Polytechnic University. The participants were invited to complete the survey during the interim break of the webinar.

A total of 165 survey responses were received. To assure data quality, responses were carefully checked, and those with incomplete information were eliminated. As a result, 160 responses were deemed qualified for further data analysis.

Among these responses, the majority were male respondents. Further most of the respondents were well-experienced with over 20 years of experience in the field. The respondents were accomplished with the majority holding middle level jobs such as 'manager', 'engineer' and also well educated, with more than half of the respondents possessing a degree at the master level.

4.3.4.1 Statistical Analysis

The data collected were analysed using the SPSS version 25.0 software. Initially, the Cronbach's alpha was calculated, which is a statistic often used to assess the internal consistency of a survey instrument (Collins, 2007). In this study, this test was used to assess the consistency of ranking items included in Section 4 of the questionnaire. The purpose of ranking the items in Section 4 is to reveal the importance levels of SR decision making criteria. If each question in Section 4 assesses the same construct (i.e. importance levels of SR decision making criteria), the ratings on each should be correlated with one another. A perfect correlation would have a Cronbach's alpha value of 1.0, whereas no correlation would have a value of 0.0 (Adamson and Prion, 2013). Hence, Cronbach's alpha can range from 0.0 to 1.0.

After testing the Cronbach's alpha, statistical tests were performed on the response data to obtain the required answers. There are two types of statistical tests such as 'parametric tests' and 'nonparametric tests' (Chan, 2003). Parametric tests are based on the assumption that the data are continuous and have a normal distribution (Mishra et al., 2019). However, since the data collected in this study were based on a Likert Scale, the data cannot be considered as continuous. Nonparametric tests are reliable when dealing with ordinal data since they do not presume a normal distribution (De Winter and Dodou, 2010). Hence, the nonparametric tests that were used in this study are Kruskal–Wallis H test (H) and Mann–Whitney U test (U).

Respondents were divided into five groups to investigate any variations between groups of responses. As shown below, each of these groups were further divided into subgroups:

- G1: Gender: male (G1a) and female (G1b);
- G2: Work experience: less than 10 years (G2a), 10 - 19 years (G2b), 20 - 29 years (G2c), and 30 years or above (G2d);
- G3: Job level: senior (G3a), middle (G3b), junior (G3c);
- G4: Professional qualification: The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (G4a), BSOMES (G4b), The Chartered Institution of Building Services Engineers (CIBSE) (G4c), The Hong Kong Institution of Engineers (HKIE) (G4d), HKIFM (G4e), IFMA (G4f), The Royal Institution of Chartered Surveyors (RICS) (G4g);
- G5: Academic qualification: bachelor (G5a), and postgraduate (master's degrees or doctorate degrees) (G5b)

As the first step in the statistical analysis process, group analyses were conducted using the Kruskal–Wallis H test (H) and the Mann–Whitney U test (U) to analyse whether the samples originate from the same distribution (Teplow, 2018). In other words, they test whether the importance ratings of criteria perceived by respondents differ between groups. The H test can compare more than two samples, but the U test can only compare two independent or unrelated samples (Smalheiser, 2017). These tests are carried out based on hypotheses testing. Two additional values, such as the significance level (α) and the p-value, are applied in order to rule out one of the hypotheses (Greenland et al., 2016). The significance level is selected by the researcher, whereas the p-value is a calculated number.

The U test was used for the inter-group comparisons between G1a and G1b and between G5a and G5b. For each of the comparisons, a null hypothesis (H_o) and an alternative hypothesis

(H_a) were set (H_o: the median of the two groups are the same; H_a: the median of the two groups are different). The α value for the U test was set as 0.05.

The H test was applied to make comparisons between different sample groups in G2, G3 and G4. For each of the comparisons, a null hypothesis (H_o) and an alternative hypothesis (H_a) were set (H_o: medians of each group are the same; H_a: at least one of the groups has a different median). The α value for the H test was set as 0.05.

Finally, for each evaluated criterion, a mean score was calculated, and the overall ranking of the criteria was established to aid in shortlisting the most relevant criteria.

4.4 Findings and Discussions

4.4.1 Stage 1 – Initial Literature Review

The 14 documents identified in Stage 1 were reviewed in depth and the contents found to be in the SR decision-making context were manually coded. Codes sharing the same meaning were merged to create larger themes. Accordingly, 14 themes of SR decision-making criteria were identified and also noted to fall into five categories: (1) financial, (2) technical, (3) human, (4) environmental, and (5) legal (see Figure 4-3).

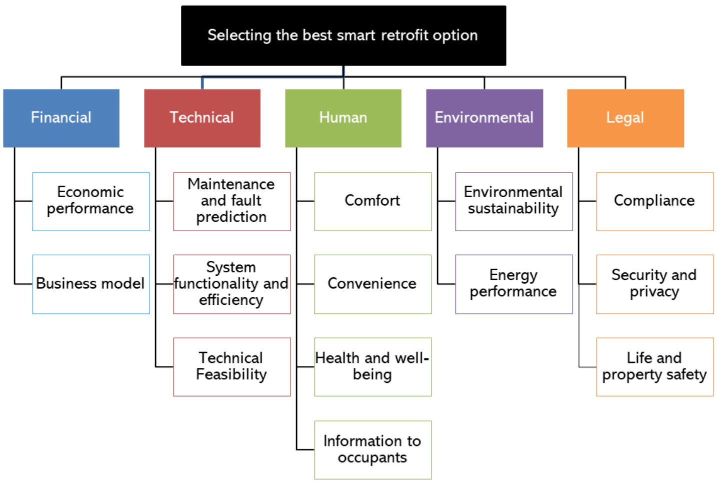

Figure 4-3: SR decision-making criteria identified from Stage 1

4.4.2 Stage 2 – Focus Group Discussion

The above criteria were presented to the industry experts during the focus group discussion. Their feedback is presented and discussed below under three sections:

- Voting for the relevance of criteria
- Recommended changes to the criteria
- Suggestions for additional criteria

4.4.2.1 Voting for the relevance of criteria

All 14 criteria were voted as highly relevant to the SR decision making problem by all nine participants. Participant I further elaborated that, *"Since these are results of a literature review, it is very hard to prove these wrong or vote a 'no' for any of these criteria."* Participant B seconded this point. Hence, all 14 criteria were established as relevant to SR decision making.

4.4.2.2 Recommended changes to the criteria

However, the participants highlighted that the criteria need to be more specific. In the words of Participant B, "*The important point is how each criterion is defined. The thing is, now the criteria titles are quite broad. Initial cost, running cost, and even cost-saving are all combined under one criterion. I think it is better if a future review could separate such criteria and make it clearer. Otherwise, all criteria seem similar.*" Participant F added, "*I suggest developing some sub-criteria under the existing criteria to make it more specific and clearer.*" This point was noted for further improvement of the set of criteria.

4.4.2.3 Suggestions for additional criteria

The participants were also asked whether they would like to recommend any other relevant criteria to the list. As the first concern, Participant H raised that, "*Since occupied buildings are considered, a major consideration would be the potential disruption to existing occupants and the protection offered to them.*" This point was emphasized by participants as the retrofit work would need to conducted simultaneously with the current daily operations of tenants. In addition to tenants, important guests of tenants or the landlord may visit the office building during this period. Hence, these parties may not prefer being disturbed or inconvenienced. Participant G also highlighted, "*One should see whether the building owner may consider making the whole building vacant for the retrofit work, since, new leases of a renovated building should have higher rent than the old building. However, it all depends on the size of the building along with the number of tenants being affected and the lease terms. So, this idea of vacating the whole building will be more applicable for relatively smaller size buildings.*" In this case, if the whole building is vacated, the concerns on disturbance and inconvenience may be less.

In addition to inconvenience, the safety of the building and its occupants during the retrofit implementation was pointed out as a crucial criterion. Fire safety was mentioned as an often-overlooked aspect. Hence, Participant E highlighted that risk assessment of the SR implementation should be conducted to safeguard occupants as well as building systems from any potential harm.

Participant E further pointed out that design and construction quality of the retrofitting works is a major determining criterion of the post-retrofit performance of the systems. Hence, it is important to see as to whether there are competent staff with the necessary know how to oversee the retrofitting project. It was emphasized that, as the required know how varies between different SR measures, this is one of the criteria to be added for further study.

Retrofitting work scheduling was also brought forward as an important criterion by the participants. Participant H mentioned, "*I have experience in working on a retrofit project of an old commercial building. One of my key observations is the hectic, prolonged program of retrofitting work, mainly because work cannot be carried out during day time and it must be done during night time, weekends or at times when the building is not occupied. This was one of the problems for the implementation of the whole project which consequently caused cost escalations.*"

While the contribution of the SR measures towards energy conservation and carbon reduction was already considered under the 'Environmental' category, participants highlighted that current landlords, tenants and investors are particularly interested about the ability of SR to achieve Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM) certifications or Environmental, Social and Governance (ESG) targets. It was emphasized that this is a key driving factor of SR and hence needs to be separately considered in decision-making.

To summarize, the addition of five criteria were recommended: (1) disruption and inconvenience to existing occupants, (2) safety of existing occupants, (3) overseeing design and construction quality of retrofitting work, (4) retrofitting work scheduling, and (5) ability to achieve environmental certification and targets.

The views of focus group participants demonstrate that most decision makers prefer a specific, and suitably detailed basis when making decisions. This can be understood by their suggestion to expand the list of criteria. As highlighted by Si and Marjanovic-Halburd (2018), due to various backgrounds, the retrofit decision-making perspectives differ from person to person. Further, all retrofit scenarios are unique by nature (de Oliveira Fernandes et al., 2021). Hence, if the criteria are specific and comprehensive, it will cater to almost all retrofit scenarios and the concerns of the different decision makers.

Another finding is that the criteria identified from literature are mainly about the features of SBs that can be achieved after the retrofit. Certain comments/suggestions from the participants are about what would happen (i.e., concerns, impacts) when implementing the retrofits. Hence, the criteria should be divided into two main groups, (1) during retrofit and (2) after retrofit, for further analysis. The criteria to be considered during retrofits are often overlooked in many studies. However, they are critical as they contribute to determining the cost of retrofit and the satisfaction of the existing building occupants (Hwang et al., 2015). If the retrofit implementation stage is not effectively planned, it may cause negative impacts such as occupant dissatisfaction due to inconvenience, cost overruns and, even worse, accidents that could have been avoided (Miller and Buys, 2008). While these criteria are not only applicable for SR but also for any kind of building retrofit, due to the reasons above, it is imperative that these criteria are included in the decision-making stage.

Another important aspect highlighted by the participants is the need of building owners to obtain environmental and wellness certifications. With the current carbon neutrality targets set by Governments (for example, Hong Kong's Climate Action Plan 2050, EU's 2030 Climate Target Plan), the need to achieve environmental and human wellness goals are a key driver for SR (EU Directorate-General for Climate Action, 2020, Hong Kong Environment and Ecology Bureau, 2021). Where office buildings are concerned, not only the landlords but the tenant organizations too are striving to maintain their status in the market as leaders in sustainability. Hence, tenants mostly look for buildings that are certified in the same aspects (Gou et al., 2013). To become a building on demand, and keep up with the competitors, landlords commit to SR to achieve these goals (O'Mara and Bates, 2012). Even though not explicitly stated, the need to achieve such certifications should therefore be a major criterion of SR decision making.

To address the above comments, a further literature review process was undertaken in Stage 3 and the findings are presented below.

4.4.3 Stage 3 – Extended Literature Review

A total of 121 papers identified in this stage were reviewed manually to identify codes and thereby themes of SR decision-making criteria. These review findings combined with those obtained in Stage 1 resulted in 32 themes of SR decision-making criteria, which fall into 14 sub-categories under five main categories, as depicted in Figure 4-4.

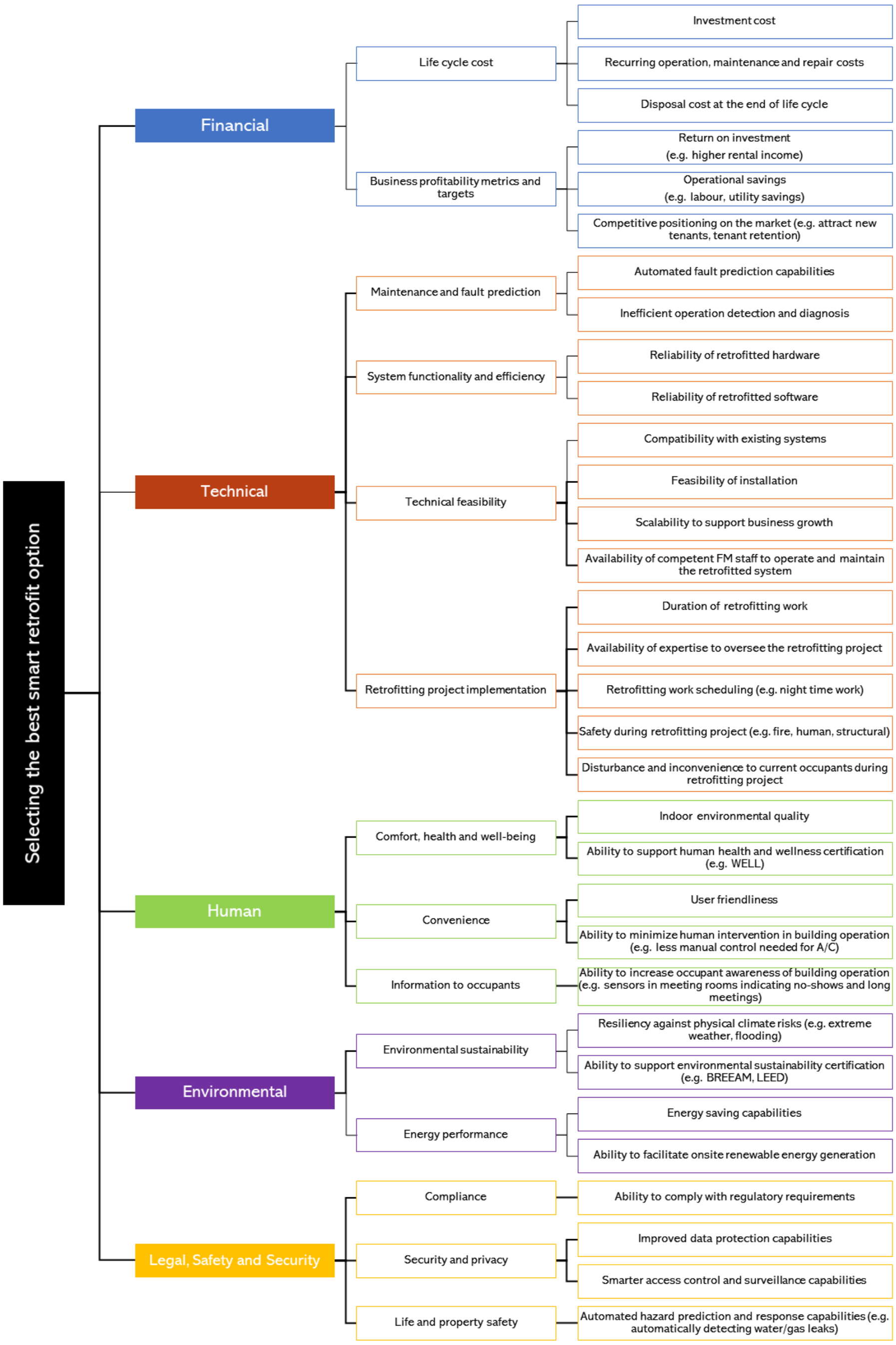

Figure 4-4: SR decision-making criteria finalized after Stage 3

Based on the review findings, this section elaborates the influence of the identified criteria on SR decisions. The discussion is presented under the five main criteria categories shown in Figure 4-4.

Financial Criteria. Previous research has demonstrated that initial costs of retrofits are more important to building owners than anticipated future savings. Therefore, regardless of the extent of their long-term benefits, retrofits with low initial costs are preferred (Anderson and Newell, 2004). The majority of owners aim to attain the highest acceptable quality standards while simultaneously minimizing the likely costs of the retrofit project (de Vasconcelos et al., 2016). In this context, one of the most popular methodologies used to assess the initial investments and long-term benefits of retrofit alternatives is Life Cycle Cost (LCC) analysis (Jafari and Valentin, 2017).

Because tenant organizations want to provide effective and spacious environments for their employees (Fisk, 2000), a well-thought-out SR project can lead to not only energy savings, lower operating costs, and reductions in equipment maintenance, but also improved rental rates, higher tenant retention, and higher occupancy rates (Kontokosta, 2016). Another financial incentive for SR is its capacity to ensure continuous building operation through predictive fault detection and maintenance; such a decision also depends on the building owner's views towards sustainability and environmental responsibility (Kontokosta, 2016). These values could reduce worries about financial returns and raise their willingness to pay for more SB features.

Technical Criteria. SR has the potential to offer multiple benefits, including the utilisation of innovative technology to provide more flexibility, convenience and comfort to occupants while reducing operation and maintenance expenses. If chosen wisely, smart building features can anticipate or identify some potential faults in building systems and suggest preventive and predictive actions to avoid system failure (Wong et al., 2005). To make all these a reality, the retrofit measures must be technically fit for the existing systems, making technical feasibility a key criterion to be considered during the decision-making process.

SB operation is mainly enabled through IoT, Radio-Frequency Identification (RFID), WSN, middleware platforms, cloud computing, and user-specific software applications (Lee and Lee, 2015). Given the sophisticated networking and communication requirements of these state-of-the-art applications, reliability, compatibility, standardization, practicality, user convenience, and scalability to enable business growth are key considerations before spending a substantial amount of money (Yang et al., 2020).

Similar to the technical expectations in the post-retrofit stage, the challenges during retrofit project implementation should also be considered (Gallo et al., 2022). Building users/occupants may fear disruptions (e.g., discontinuation of elevator services, air conditioning shutdowns). To minimize such disruptions in busy buildings, scheduling retrofit work to be executed at night or on weekends is preferable. The extra cost incurred for implementing the work during non-business hours can be recovered by the potentially higher rental income after the retrofit.

Human criteria. Improvements to the human element is another main factor considered by building owners (Alcalá et al., 2005, Wong et al., 2008a, Wong et al., 2005). This may be related to enhancements in information to occupants, convenience, and comfort brought about by SB technologies. Examples include altering room temperature and lighting levels based on occupancy, and increasing occupant productivity and satisfaction while saving energy (Hong Kong Green Building Council Limited, 2021). Through their building automation features, SB management systems can also improve car parking experiences, effectively manage water use, optimize elevator and escalator operations, regulate occupancy of spaces such as meeting rooms, and continuously provide information to occupants on the current status of the building. However, these benefits are often disregarded because it is challenging to measure or foresee their scope during the decision-making stage (Wong et al., 2008b).

Environmental Criteria. The environmental component, often more broadly referred to as sustainability, has been a popular topic in the field of built environment. The extreme scarcity of the Earth's resources is continuously emphasized in many of global platforms. As a result, building owners are beginning to understand the significance of sustainability as a social responsibility, a legal requirement, and a key to their business success. According to studies (Fasna and Gunatilake, 2019), one of the primary drivers of SR is the possibility of earning sustainability certifications such as LEED and BREEAM. It is also generally known that tenant organizations prioritize buildings that promote sustainability (Yang et al., 2020). An important aspect of a building's sustainability is its effective energy management. Since the building sector is the largest energy consumer, it is necessary to control its energy usage (Mir et al., 2021), thus improving the effectiveness of its resource utilization.

The smart grid, IoT, and renewable energy sources are crucial facilitators of efficient building energy management. The smart grid ensures proper two-way communication between all parties involved in energy production, distribution, and consumption (Al Dakheel et al., 2020). Additionally, the inclusion of cloud and fog computing architectures with smart metering will make it easier for IoT devices to monitor real-time building energy use (Kafıloğlu et al., 2021). Given the foregoing, it is clear that the incorporation of sustainability features, particularly for energy management, is a crucial criterion of SR that should be considered when making retrofit decisions.

Legal, Safety and Security Criteria. While SR has many benefits, its systems and technologies are interconnected and hence, complicated, creating concerns about privacy and data security. In an IoT environment, users must be connected via the same standard communication technology to exchange information (Liu et al., 2011). However, sensitive information such as personal information or vital organizational information may attract hackers. Therefore, it is key that IoT applications be equipped to provide equal or higher levels of security to its inherent components. Thankfully, the field of cybersecurity is growing alongside new developments of IoT (Pinch, 2022); hence it is becoming easier to secure data, especially for companies that prioritize smart digital processes.

The life safety features of SB systems, such as automated emergency alert systems, are another critical point of consideration. These systems use overhead alarms, speakers and strobes to inform residents of an emergency or incident (Mallikarjuna and Kozin, 2019). These systems coordinate a building's systems to speed up evacuations and shelter-in-place arrangements. Emergency notification systems are used to alert large crowds to take rapid action. In an emergency, a BMS integrates door access controls, video feeds, and Voice over Internet Protocol (VoIP) telephones for a faster response. Given these many benefits of smart safety and security systems, appropriate decision-making that carefully identifies and evaluates all available options, is necessary before choosing optimal solutions. Lack of good decision-making might cause noncompliance with regulations and hamper the implementation of SR projects.

4.4.4 Stage 4 – Questionnaire Survey

This section presents the results of the questionnaire survey conducted to shortlist the most important criteria out of the 32 finalized in Stage 3. The demographic details of the respondents are given in Figure 4-5.

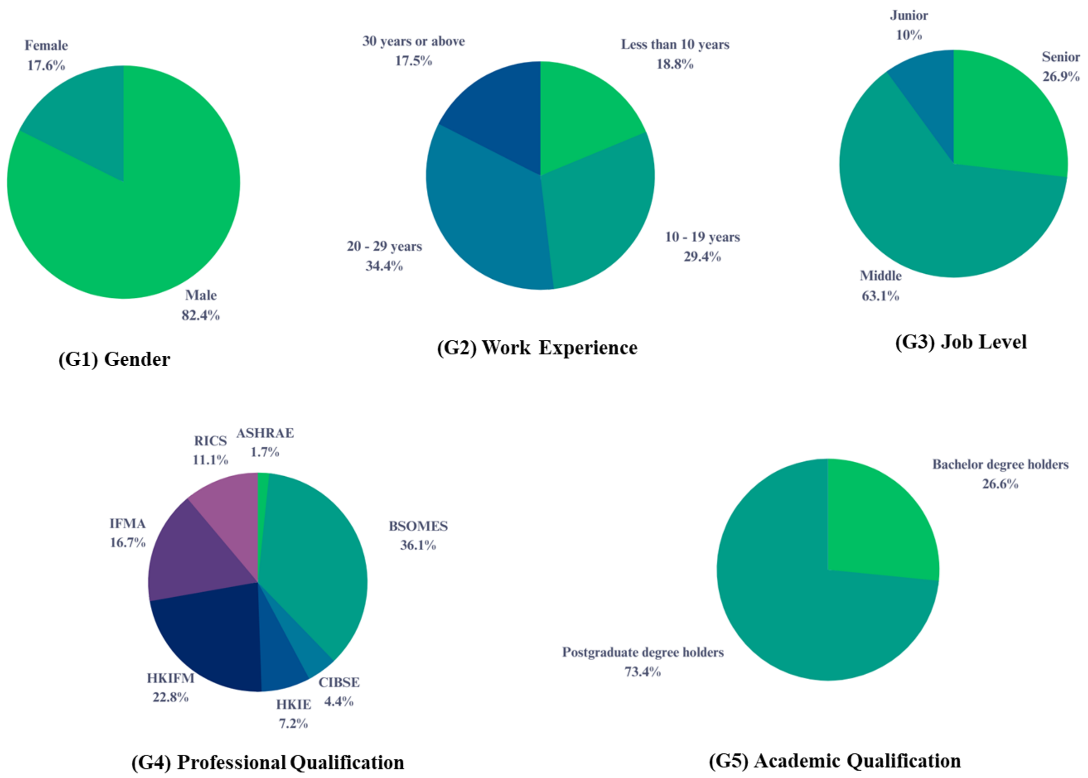

Figure 4-5: Demographic details of survey respondents

The findings are presented in three parts as follows:

- Cronbach's alpha measurement results
- Significant differences in perceived importance levels
- Overall mean ranking of criteria importance

4.4.4.1 Cronbach's alpha measurement results

SPSS resulted a Cronbach's alpha of 0.922 for the questionnaire responses under 32 criteria. As explained in Section 4.2.4, the recommended value for Cronbach's alpha is between 0.0 to 1.0, where 1.0 represents a perfect correlation. Since, 0.922 is a value which is nearly 1.0, it can be concluded that the ranking items are highly consistent.

4.4.4.2 Significant differences in perceived importance levels

This section presents the results of the Kruskal-Wallis (H) tests and Mann-Whitney (U) tests conducted on different respondent groups G1 – G5. Referring to the results shown in Appendix A4.2 (page 193), the respondent groups that belong to G1, G2, G3 and G4 did not show significant differences in the way they perceived the importance of criteria. However, four significant observations from G5 are worth noting. A significant difference was observed between bachelor degree holders and postgraduate degree holders for the criterion '*Availability of competent FM staff to maintain the retrofit*'. It means that bachelor degree holders and postgraduate degree holders had different perceptions of the importance of '*Availability of competent FM staff to maintain the retrofit*' for SR decision making. Their perceptions were also significantly different with regard to '*Duration of retrofitting work*', '*Safety during retrofitting project*' and '*Ability to comply with regulatory requirements*'. The corresponding values are given in Table 4-2.

Table 4-2: Criteria with significantly different importance ratings between respondent groups

Criterion	**Mean Rank**		**U Value**	**P Value**
	Bachelor	Postgraduate		
Availability of competent FM staff to maintain the retrofit	68.67	83.42	1981	0.047
Duration of retrofitting work	68.14	83.61	1959	0.039
Safety during retrofitting project	68.17	83.60	1960	0.041
Ability to comply with regulatory requirements	67.40	83.88	1928	0.026

At a time when most engineering graduates pursue a degree up to master's level (Okahana and Hao, 2019), respondents having only a bachelor's degree may be the fresh graduates who have just entered the field. Hence, due to their comparatively low experience, they may perceive certain criteria are less important while the well experienced perceive them as important (mean rankings of bachelor's degree holders' respondents are lower than postgraduate degree holders). Further, the knowledge on aspects such as 'regulatory requirements of retrofitting', 'planning for retrofitting safety and duration' develops with hands-on experience in managing such projects and from learning from mistakes (Alfaiz et al., 2021). Especially if they have never encountered situations in which things failed due to incompetent human resources, recent graduates may not appreciate how crucial it is to have competent personnel to manage the SR measure after installation. This resonates with the findings of Ho et al. (2021a) that with different levels of experience, the perceptions of importance could also differ.

Aside from the aforementioned exceptions, the importance rankings are consistent across all respondent categories, with no significant differences.

4.4.4.3 Importance Levels and Ranks of SR Decision Making Criteria

Based on all the valid responses, a mean rating was calculated for each criterion, and the calculation results in Table 4-3 show that the ratings range from 3.05 to 4.4. The Likert scale in the questionnaire was set as follows: 1 – Very Low Importance; 2 – Low Importance; 3 – Moderate Importance; 4 – High Importance; 5 – Very High Importance. Hence, to shortlist the criteria with high importance to use in SR decision making, 4.00 was taken as the cut-off mean rating and criteria with a mean rating of less than 4.00 were not shortlisted. Thus, a total of 20 criteria, covering all five categories (i.e. financial, technical, human, environmental and legal) were shortlisted.

Table 4-3: Mean ratings of decision-making criteria

No.	Criterion	Mean	Rank	Shortlisted
1	Investment Cost	4.21	6	Yes
2	Recurring O&M cost	4.26	4	Yes
3	Disposal cost at the end of life cycle	3.05	27	-
4	Return on Investment	4.15	=9	Yes
5	Operational Savings	4.18	=7	Yes
6	Competitive positioning on the market	3.84	=25	-
7	Automated fault prediction capabilities	4.08	12	Yes
8	Inefficient operation detection and diagnosis	3.95	18	-
9	Reliability of retrofitted hardware	4.23	5	Yes
10	Reliability of retrofitted software	4.16	8	Yes
11	Compatibility with existing systems	4.18	=7	Yes
12	Feasibility of installation	4.10	10	Yes
13	Scalability to support business growth	3.86	=24	-
14	Availability of competent FM staff to maintain the retrofit	4.02	14	Yes
15	Duration of retrofitting work	3.94	19	-
16	Expertise to oversee the retrofitting project	3.92	20	-
17	Retrofit work scheduling	3.84	=25	-
18	Safety during retrofitting project	4.29	3	Yes
19	Disturbance and inconvenience to current occupants	4.15	=9	Yes
20	Indoor environmental quality	4.06	13	Yes
21	Ability to support human health and wellness certification	3.86	=24	-
22	User friendliness	4.09	11	Yes
23	Ability to minimize human intervention	3.99	17	-
24	Ability to increase occupant awareness of building operation	3.80	26	-
25	Resiliency against physical climate risks	4.01	=15	Yes
26	Ability to support environmental sustainability certification	3.88	23	-
27	Energy saving capabilities	4.34	2	Yes
28	Ability to facilitate onsite renewable energy generation	3.89	22	-
29	Ability to comply with regulatory requirements	4.40	1	Yes
30	Improved data protection capabilities	4.01	=15	Yes
31	Smarter access control and surveillance capabilities	4.00	16	Yes
32	Automated hazard prediction and response capabilities	4.18	=7	Yes

As shown in Table 4-3, the top 5 ranked criteria are: (1) Ability to comply with regulatory requirements; (2) Energy saving capabilities; (3) Safety during retrofitting project; (4) Recurring O&M cost; and (5) Reliability of retrofitted hardware. It is not surprising that regulatory compliance is ranked highest, as it is something that the building owners cannot compromise (Tan et al., 2018). Further, there is no point of considering a particular SR alternative if it does not meet the regulatory requirements. Another important finding is that

‘Energy saving capabilities’ is highly regarded in SR. Unlike in general energy retrofits, energy conservation is not the sole focus of SR (Al Dakheel et al., 2020). However, since the features of smart technology such as intelligent and automated operation based on IoT sensors are a promising method to achieve savings in energy, it is still a primary goal of SR (Rocha et al., 2015). ‘Safety during retrofitting project’ has also entered the top list probably because of the lessons learned from safety related mistakes and its negative consequences which could be even worse as death (Nadhim et al., 2018). The fourth item on the list is ‘recurring O&M costs’, and a primary reason could be that this is a cost factor that can be minimized by making the right decisions. The decision makers can plan well for optimizing the recurring O&M cost if decisions are made well (Wang and Xia, 2015). Furthermore, the reliability of the retrofitted hardware should be regarded as a critical factor; without it, the expected results cannot be achieved, resulting in a waste of the investment (Gao et al., 2007).

It should also be noted that while criteria from legal, environmental, technical and financial categories have reached the top 5, the highest rank received by a criterion from the human category is ‘11’ and it is obtained by ‘User friendliness’. This is a crucial finding that often human aspects are given a very low priority in SR decision making. While the main goal of SR should be occupant satisfaction, because buildings are man-made structures constructed for the betterment, comfort and productivity of the occupants, as observed, it is not considered as very important in usual decision making (Asadian et al., 2023).

To summarize, 75% from the legal criteria, 69.2% from the technical criteria, 66.6% from financial criteria, 50% from environmental criteria and 40% from human criteria have been shortlisted as the final list of criteria to be used in SR decision making. This shows that legal, technical and financial are perceived as the most important criteria in SR, which agrees with the findings of (Tokede et al., 2018).

Correspondingly, a hierarchy for the shortlisted SR decision making criteria is depicted in Figure 4-6.

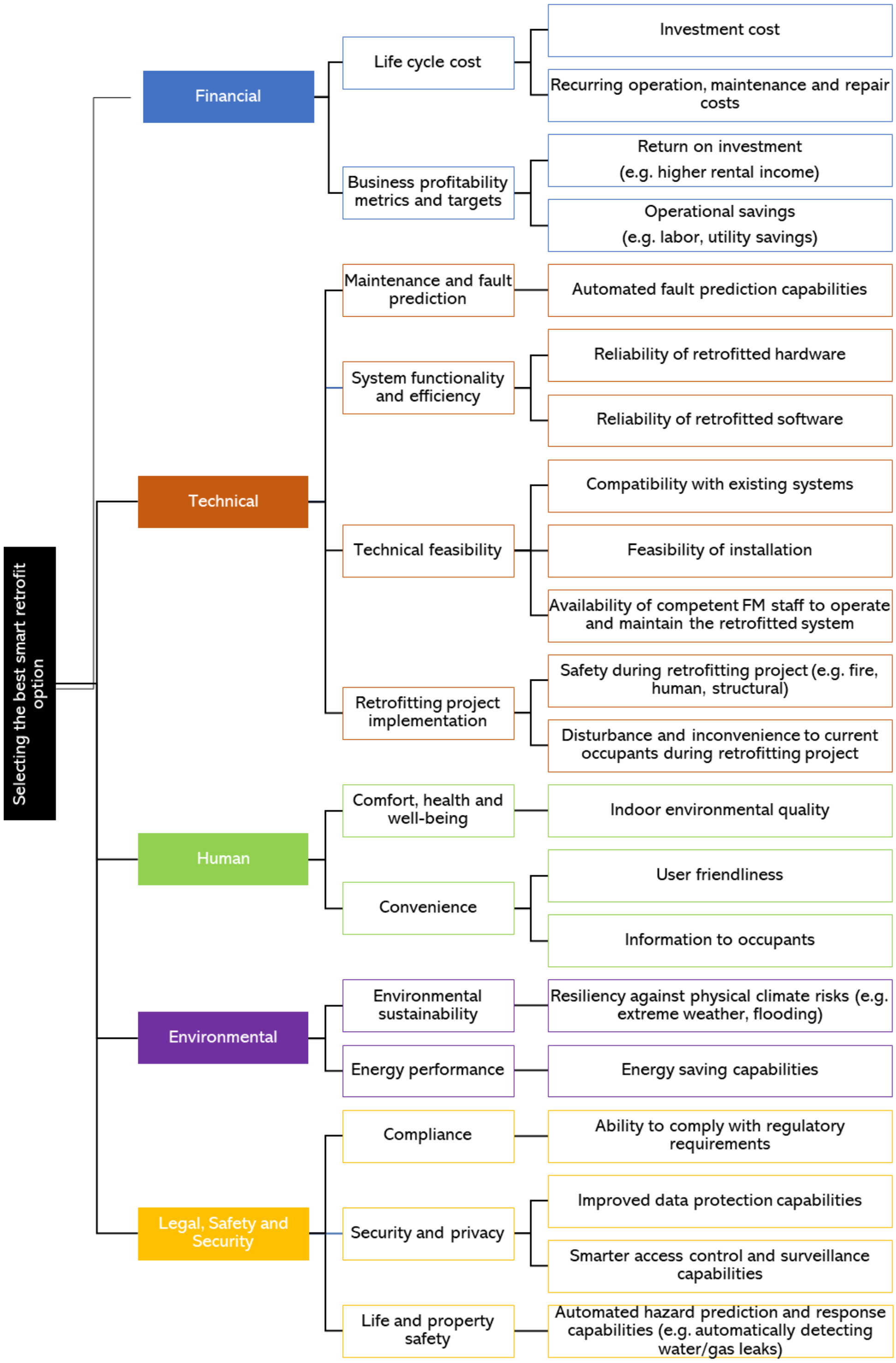

Figure 4-6: Decision-making hierarchy with shortlisted criteria

Notably, all criteria received a mean rating of 3.05 or higher, which, according to the Likert scale, indicates that none of the criteria were deemed to be of ‘low importance’ or ‘very low importance’. This finding suggests that the practice of prioritising only a subset of criteria does not imply the others are unimportant; rather, it reflects the practical constraints faced in real-world decision-making, where considering all 32 criteria simultaneously is often perceived as impractical and overly complex.

4.5 Chapter Summary

This chapter presented the systematic process undertaken to identify and prioritize the key criteria influencing SR decision-making. Recognizing the complex and multi-faceted nature of SR, a four-stage research process was adopted: (1) an initial literature review to establish a foundational set of SR criteria; (2) a focus group discussion with industry experts to validate and refine these criteria; (3) an extended literature review to address gaps highlighted by the focus group and to expand the criteria set; and (4) a questionnaire survey to quantitatively assess the importance of the identified criteria and shortlist those most relevant to SR decision-making.

Through these stages, a total of 32 criteria spanning the financial, technical, human, environmental, legal and safety domains were identified. These criteria reflected both post-retrofit benefits and implementation-stage concerns, including factors such as regulatory compliance, energy savings, occupant safety during retrofitting, hardware/software reliability and human-centred considerations like user-friendliness and occupant comfort.

Following statistical analyses of questionnaire responses, the list was shortlisted to 20 criteria. These final criteria were deemed the most critical for informed SR decision-making across diverse stakeholder groups. The results revealed that legal, technical, and financial criteria were perceived as the most influential, aligning with findings from previous retrofitting studies. Notably, human-centred criteria, although important, were often ranked lower, highlighting a potential gap in prioritizing occupant satisfaction within SR projects.

The decision-making hierarchy developed from these findings serves as the foundational input for the subsequent criteria weighting and ranking stages of the SRDSS. The comprehensive approach undertaken, as described in this chapter ensures that the SRDSS is grounded in both theory and practice, reflecting stakeholder insights, empirical data, and regional contexts.

CHAPTER FIVE

5 CONTEXTUAL ANALYSIS AND CRITERIA IMPORTANCE WEIGHTS DERIVATION FROM EXPERT INTERVIEWS[5]

5.1 Introduction to the Chapter

This chapter presents the analysis of expert interviews conducted to support the development of the Smart Retrofitting Decision-Support System (SRDSS). The expert interviews were conducted for two purposes: (1) to gain a deeper understanding of the current context of SR in the industry, and (2) to obtain, collect and consolidate expert judgments necessary for establishing the relative importance of SR decision-making criteria using ANP. The first part of the chapter presents the findings of a qualitative analysis of the interviews revealing key themes that shape SR decision-making practices in both developed and developing contexts. These include financial and non-financial drivers, stakeholder influence patterns, evaluation approaches and implementation barriers. The second part of the chapter details the methodology and results of the ANP analysis used to derive the criteria weights required for the SRDSS. By combining in-depth qualitative insights with structured expert judgments, this chapter forms the foundation for determining criteria weights within the SRDSS.

5.2 Data Collection Methods

To collect the data required for this part of the study, in-depth expert interviews were conducted with 12 professionals each from Hong Kong and Sri Lanka (representing developed and developing regions, respectively). The choice of these locations allows for a cross-regional comparison, also enabling insights into differences in the contexts of a developing and a developed region on the ‘state of play’ in this domain. The number of experts chosen is within the ideal range for ANP exercises indicated by Lai et al. (2022), Widiastuti et al. (2024) and Topaloğlu (2025) which is eight to fifteen individuals.

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[5]The core research and findings of section 4.4 in this chapter have been peer-reviewed before publication in:

Peiris, S., Lai, J. H. K., & Kumaraswamy, M. M. (2024). Smart retrofitting for office buildings: Comparison of decision-making criteria between developing and developed regions. *Journal of Building Engineering*, *97*, 110957. DOI: 10.1016/j.jobe.2024.110957

Experts were selected based on their expertise in SB technologies and retrofitting projects. The 12 experts from each region represent different stakeholder groups involved in SR projects. These included client's representatives, consultants and contractors (Table 5.1).

Table 5-1: Experts participated in the interviews

Region	Alternative name	Position (Organisation type)	Work experience
Hong Kong	HK-01	Director (Property Management Company)	40+ years
	HK-02	Head of Energy and Sustainability (FM Services Provider)	10+ years
	HK-03	Senior Manager (FM Services Provider)	10+ years
	HK-04	Vice President (FM Services Provider)	30+ years
	HK-05	General Manager (FM Services Provider)	20+ years
	HK-06	Operations Director (FM Services Provider)	20+ years
	HK-07	Manager (FM Services Provider)	10+ years
	HK-08	Executive Director (Building Consultancy Services Provider)	30+ years
	HK-09	General Manager (Building Contractor)	30+ years
	HK-10	Manager (Building Contractor)	7 years
	HK-11	Associate Director (Building Automation Services Provider)	10+ years
	HK-12	Senior Consultant (Building Consultancy Services Provider)	10 years
Sri Lanka	SL-01	Deputy Chief Executive Officer (Property Management Company)	40+ years
	SL -02	Head of Facility Management (Property Development and Management Company)	20+ years
	SL -03	Deputy Head of Facility Management (Property Development and Management Company)	20+ years
	SL -04	Manager – Facilities Management (High-rise Office Building)	10+ years
	SL -05	Managing Director (Building Automation Services Provider)	30+ years
	SL -06	Senior Engineer (Building Automation Services Provider)	20+ years
	SL -07	Chief Operating Officer (Building Automation Services Provider)	20+ years
	SL -08	Director (Building Automation Services Provider)	20+ years
	SL -09	Senior ELV Engineer (Building Consultancy Services Provider)	10+ years
	SL -10	Senior ELV Engineer (Building Consultancy Services Provider)	20+ years
	SL -11	FM/Project Consultant (Independent Consultant)	40+ years
	SL -12	FM Consultant (Independent Consultant)	30+ years

As shown in Table 5-1, the interviewees represented a wide range of stakeholder groups, including property management companies, FM service providers, consultancy organisations, building contractors and automation system providers. While many of the participants hold senior managerial or executive positions such as Vice President, Director or Head of Department, the sample also included professionals with direct technical involvement such as Senior Engineers, ELV Engineers and Project Consultants. These participants contributed practical insights on operational issues, maintenance practices and technical challenges encountered in smart retrofitting projects. The deliberate emphasis on senior professionals was aligned with the purpose of the study, which sought to establish and prioritise decision-making criteria for SR using ANP. Since retrofit investments are typically justified and approved at the managerial or executive level, it was important that the sample reflected individuals with the authority and experience to evaluate such decisions comprehensively. Nevertheless, the contribution of technically oriented participants ensured that operational challenges were not overlooked.

Experts were selected using purposive sampling to ensure diversity in experience, organizational role and technical background relevant to SR. Each interview followed a two-part structure guided by a semi-structured protocol. The first part included open-ended questions to explore current SR practices, decision triggers, stakeholder influence, perceived challenges and evaluation criteria. The second part consisted of structured pairwise comparisons of predefined criteria to facilitate ANP analysis. The interview guide used for both parts is provided in Appendix A5.1 (page 203). Each expert was briefed on the purpose and goals of the research before the interview began.

All interviews were conducted in English, either in person or via secure video conferencing platforms and were audio-recorded with informed consent. Recordings were transcribed verbatim, anonymised and stored securely for subsequent analysis.

5.3 Contextual Insights from Expert Interviews

This section reports the results of the first part of the interview, which involved open-ended questions aimed at exploring current SR practices, decision triggers, stakeholder influence, perceived challenges and evaluation criteria. This contextual investigation was designed to strengthen the analytical grounding of the ANP stage, enabling expert judgements in the second part of the interview to be informed by a clear understanding of local constraints, operational realities, decision-making cultures and criteria. While the decision criteria had already been shortlisted through a rigorous methodological process as explained in Chapter 4, this intermediate step was taken to ensure that the prioritization process was informed by real-world insight. The contextual analysis served to validate the practical relevance of each criterion and uncover regional and stakeholder-specific interpretations.

5.3.1 Contextual Data Analysis

Interview data from the contextual investigation were analysed using Braun and Clarke (2006)'s six-phase framework for thematic analysis. 'Familiarization with the data', which is the first phase out of the six, was conducted by reading the 24 transcripts in detail and taking notes of initial ideas based on meaningful quotes (these quotes are presented in full in Appendix A5.2 (page 210)). The second phase of 'generating initial codes' was conducted by manually coding selected quotes into categories such as 'drivers', 'barriers' and 'stakeholders'. Transcripts were coded and managed using the NVivo 15 software. A coding framework was created on NVivo along with all the experts defined as cases and grouped into case classifications based on their region. An inductive coding approach was followed to capture emergent themes grounded in the interview data. 'Searching for themes', which is the third phase, was carried out by grouping quotes under parent and child nodes on NVivo. Potential themes were compared across regions using NVivo tools such as matrix coding queries. To 'review themes' under the fourth phase, themes were regrouped, refined and merged to avoid overlaps (e.g., certain themes under 'criteria' and 'stakeholder influence' were merged) and quotes were cross-checked for any misattributions or misinterpretation of meaning. This stage resulted in a set of themes that were coherent, distinct and reflective of the data. The resultant themes were defined and named in the fifth phase, and the sixth phase of 'producing the report' was achieved through the analysis presented in this chapter, which relates the findings back to the research objectives and relevant literature.

Several strategies were employed to ensure methodological rigour during this analysis. Data triangulation was established by including perspectives from multiple stakeholder types and two contrasting regions. Auditability was ensured by systematically documenting coding decisions in NVivo, with the corresponding expert interview quotes organised under each node and child node in Appendix A5.2 (page 210). Reflexivity was ensured by maintaining awareness of the researcher's positionality throughout the analysis and by regularly revisiting the original transcripts to verify that emerging interpretations aligned with the experts' actual narratives, rather than being shaped by researcher assumptions. The identified themes are presented and discussed in four sections: (1) drivers and motivators, (2) challenges and barriers, (3) stakeholder roles and influence and (4) decision criteria and evaluation factors.

5.3.2 Drivers and Motivations

This theme captures the underlying incentives and pressures that compel stakeholders to pursue SR initiatives. As illustrated in Figure 5.1, based on the expert interviews, drivers were identified under four core themes: (1) financial performance and market positioning, (2) operational challenges and technology needs, (3) sustainability and policy drivers and (4) tenant-driven factors. Each theme is explored in detail in the following subsections, highlighting the underlying cross-regional differences.

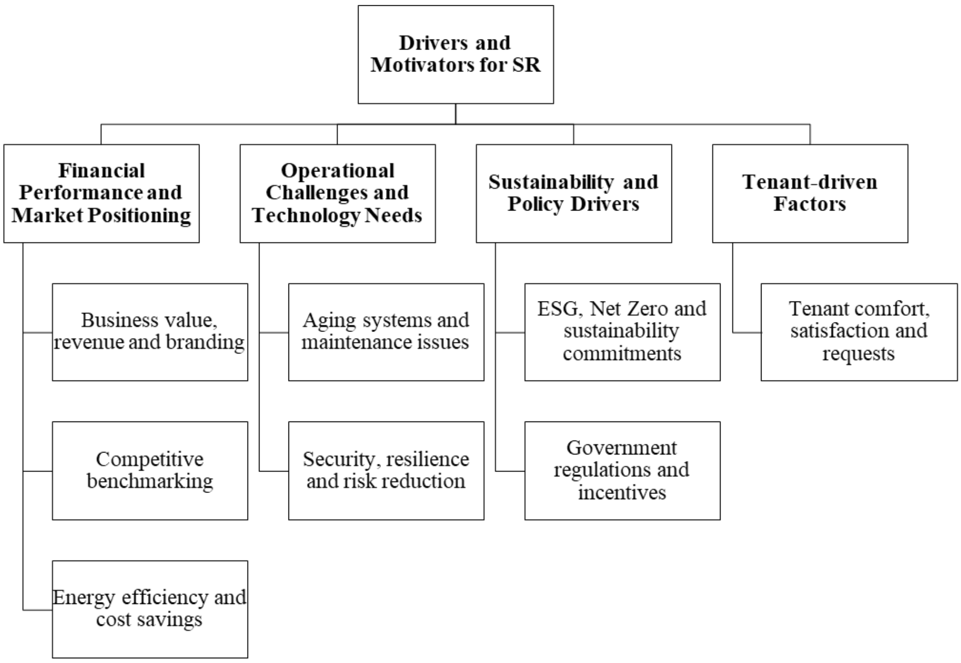

Figure 5-1: Overview of drivers and motivators for SR

5.3.2.1 Financial Performance and Market Positioning

A dominant SR motivator in both Sri Lanka and Hong Kong is its potential to improve financial performance and strengthen market positioning. SR was perceived by the experts not only as an operational enhancement but also a strategic investment to capture competitive and reputational advantages. It was noted that landlords and developers view SR as a lever to increase rental income, attract tenants and improve brand perception. In Hong Kong, participants repeatedly stated that *"marketing"* and *"return"* drive SR decisions. The appeal to ESG branding was particularly strong among developers who are under investor and public pressure to showcase innovation and sustainability. HK-09 noted, *"Developers are more concerned about the image when it comes to ESG."* Sri Lankan experts echoed this sentiment, though often framed within tenant retention and operational affordability, such as reducing service charges through energy savings.

It appeared that benchmarking against competitors is another key driver in Hong Kong. Observing market leaders and adapting successful strategies, such as installing Electric Vehicle (EV) chargers or adopting ESG-aligned upgrades is a frequent practice of developers. According to HK-10, *"Most listed companies release ESG reports because their competitors do, and it's also linked to investment. Investors look at ESG, so even if it's not compulsory, companies voluntarily release these reports. Most developers in Hong Kong, especially big ones, release ESG reports."* In contrast, Sri Lankan stakeholders look externally to global and regional exemplars, especially Singapore, for best practices and efficiency metrics. The findings imply the maturity of Hong Kong's internal market (Hong Kong Green Building Council Limited, 2025), while Sri Lanka seeks inspiration from foreign models to guide SR standards (National Building Research Organisation, 2023).

Energy cost reduction was identified to be a shared motivator, playing particularly a central role in Sri Lanka. Cooling systems and IoT-based automation was highlighted by many experts as pivotal tools to lower high operational costs. SL-02 stated, *"In Singapore, the energy efficiency standard for cooling systems is around 0.3 kW per ton of refrigeration (TR), whereas some buildings in Sri Lanka consume 0.45 kW per TR. This indicates a significant energy loss and an opportunity for improvement through SR."* In Hong Kong, while energy efficiency was also noted, it was often discussed as a secondary benefit to tenant attraction or reputation management.

5.3.2.2 Operational Challenges and Technology Needs

The need to address operational inefficiencies and technology obsolescence in aging buildings was also identified as a dominant barrier. It appeared that aging infrastructure and maintenance challenges prompt stakeholders to seek smart upgrades. In Sri Lanka, frequent breakdowns, unavailable spare parts and inefficient legacy systems, particularly chillers and electrical panels, were attributed to outdated designs. SL-04 noted, *"Most of the building's systems are around 20 years old, and some are no longer in production. If a critical component, such as a control unit fails, we face significant challenges in sourcing replacements. Therefore, we must plan upgrades in advance to prevent failures and ensure building operations remain smooth."* It was also noted by Hong Kong experts that aging buildings *"no longer meet current technical standards"* and that lifecycle-driven retrofits are increasingly necessary (HK-02). This aligns with the findings of Loosemore and Hsin (2001) on lifecycle-based FM where SR becomes a pathway to operational continuity.

Security, resilience, and risk mitigation, especially in mission-critical environments was identified as another driver. Environmental controls protecting high-value server infrastructure was referenced by SL-05 where deviations in temperature or humidity could risk *“$1 million worth of data”*. This underscores how SR is viewed not only as an efficiency enhancer but as a safeguard against operational and financial loss. Table 5-2 presents a selection of illustrative quotes drawn from expert interviews, highlighting stakeholder perspectives related to this theme.

Table 5-2: Quote table on aging systems and maintenance issues

Respondent	**Region**	**Quote**
SL-01	Sri Lanka	“When the systems are outdated, the breakdown rate will be high.”
SL-06	Sri Lanka	“Systems 15-20 years old do not have communication facilities. We need to find alternatives.”
HK-07	Hong Kong	“I think efficiency is one the factors mainly considered in this aspect. If the building is not operated efficiently and there are some inherent efficiency problems, going into smart systems is one way how they can resolve the existing problems.”
HK-10	Hong Kong	“Every system and building component have a lifespan. When they reach the end, retrofitting is necessary.”

Operational drivers for SR are evident in both regions, particularly in response to aging infrastructure and maintenance issues. The focus of the Sri Lankan industry is mostly on technical catch-up (Fasna and Gunatilake, 2020), whereas Hong Kong emphasizes upgrading for resilience and service continuity (Tan et al., 2018).

5.3.2.3 Sustainability and Policy Drivers

The growing pressure to align with sustainability goals, ESG commitments and evolving policy frameworks has become a significant driver for SR implementation, especially in Hong Kong. A rising number of stakeholders are driven by the reputational, compliance and long-term environmental benefits associated with SR initiatives.

A key insight is that corporate ESG objectives are now central to SR strategies, especially among listed companies in Hong Kong. Green certifications like LEED, WELL, and Building Environmental Assessment Method (BEAM) Plus were frequently cited as mechanisms for attracting international investors and signalling environmental stewardship. HK-07 stated, *“If they publicly announced 2030 as their net-zero date, they only have a few more years,”* emphasizing that public declaration of net-zero goals has created urgency.

In contrast, sustainability was positioned by Sri Lankan experts as a long-term aspiration rather than a policy-driven imperative. The importance of reducing energy waste and carbon emissions was emphasized by the experts but sustainability was largely framed in the context of future readiness and global alignment rather than present-day compliance. SL-07 stated, *"Ultimately, the goal is to reduce energy waste, improve operational efficiency, and work toward achieving net-zero emissions."*

In Hong Kong, a special catalytic role is played by government policies and incentives. From Mandatory Building Inspection Schemes (MBIS) (Buildings Department HKSAR, 2025) through statutory energy audit requirements (e.g., Buildings Energy Efficiency Ordinance (The Electrical and Mechanical Services Department of Hong Kong SAR, 2012)) to subsidies through the Eco Building Fund (CLP Power Hong Kong Limited, 2023), regulatory instruments and financial support have become key enablers. HK-09 stated, *"If the government requires them to do so, then there is no excuse."* To better illustrate the regional nuances in sustainability-related motivations for SR, Figure 5-2 presents a Venn diagram comparing the key sustainability drivers in Hong Kong and Sri Lanka.

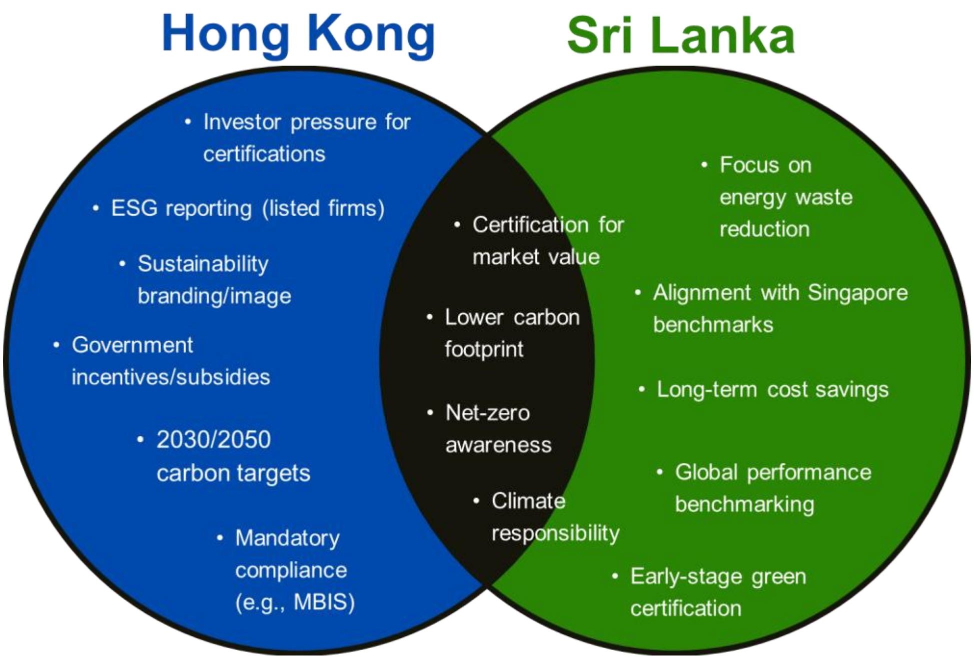

Figure 5-2: Comparison of sustainability drivers for SR

While common goals such as reducing carbon emissions and enhancing property value through certification are shared by both regions, the underlying drivers reflect distinct institutional, economic and policy environments.

5.3.2.4 Tenant Driven Factors

The desire to meet tenant expectations and retain high-value occupants in increasingly competitive real estate markets was also identified as a key motivator and driver for SR. Tenant comfort, satisfaction and specific functional demands were emphasized by the experts across both regions as central to SR decisions.

Tenant-driven feedback mechanisms and user experience were identified as key insights that directly shape retrofit strategies. According to the experts, recurring complaints and surveys help prioritize improvements in Sri Lanka, with comfort linked to tenant retention. SL-10 noted, *"Through discussions, we can identify the shortcomings of the existing design,"* highlighting the importance of participatory input in identifying value-adding improvements. In Hong Kong, tenant demands are more specialized. It was observed that operational needs of high-profile tenants, such as enhanced HVAC, power capacity and indoor air quality, are often catered by SR. The baseline building performance is currently shaped by these expectations. Table 5-3 presents a selection of illustrative quotes drawn from expert interviews, highlighting stakeholder perspectives related to this theme.

Table 5-3: Quote table on tenant-driven factors

Respondent	Region	Quote
SL-10	Sri Lanka	"If possible, we should also gather feedback from the customer. Conducting a survey can help us gather relevant data."
SL-12	Sri Lanka	"Tenants become attached to a building when they are comfortable, even resisting rent increases to stay."
SL-04	Sri Lanka	"Frequent complaints from building tenants or departments signal a need for investigation."
HK-08	Hong Kong	"Tenants have certain demands. HVAC systems should be adjustable without disturbing them, possibly through BMS."
HK-05	Hong Kong	"Tech firms might require more power for servers. If existing facilities cannot meet future demands, upgrades are essential."
HK-10	Hong Kong	"Client demand for improved service levels, like advanced lighting, can drive SR, even if not necessary."

It can be observed that these trends align with the literature on tenant-centric retrofitting (Medrano-Gómez et al., 2025), where property value is increasingly tied to the occupant experience. Notably, global tenants wield greater bargaining power, influencing landlords to pursue SR as a means of reputation enhancement and market competitiveness.

5.3.2.5 Regional Drivers and Motivations for SR

Table 5-4 shows a heat map for SR drivers and motivators developed based on the frequency of references by the experts across Hong Kong and Sri Lanka.

Table 5-4: Comparative frequency of motivation themes between Hong Kong and Sri Lanka

Theme	Sub-Theme	Hong Kong	Sri Lanka
Financial Performance and Market Positioning	Business Value, Revenue and Branding	9	4
	Competitive Benchmarking and Market Positioning	11	3
	Energy Efficiency and Cost Savings	2	14
Operational Challenges and Technology Needs	Aging Systems and Maintenance Issues	8	9
	Security, Resilience and Risk Reduction	0	2
Sustainability and Policy Drivers	ESG, Net-Zero, and Sustainability Commitments	14	2
	Government Regulations and Incentives	9	0
Tenant-driven Factors	Tenant-Driven Factors	10	6

The contrasting motivations behind SR in Hong Kong and Sri Lanka are highly evident from this heat map. It is noteworthy that drivers are largely shaped by market positioning, ESG commitments, and tenant expectations in Hong Kong (Schneider Electric, 2025, Hong Kong Green Building Council Limited, 2025), evident in high frequencies for competitive benchmarking, ESG goals and tenant factors. These reflect a proactive, investor- and reputation-driven approach, where brand value is enhanced and global standards met through SR. Conversely, it can be observed that Sri Lanka's motivations are grounded in practical needs, particularly energy efficiency, aging infrastructure and cost reduction (Ramachandra and Weerasinghe, 2021). Regulatory and sustainability drivers were given less prominence possibly due to limited enforcement and incentives (Fasna and Gunatilake, 2020). While tenant influence is ackowledged by both regions, the nature of that influence differs, with Hong Kong's being more strategic and Sri Lanka's more reactive.

5.3.3 Challenges and Barriers

This theme refers to the multifaceted obstacles that hinder the planning and execution of SR projects. As illustrated in Figure 5-3, these barriers and challenges span across six overarching domains: (1) financial and investment, (2) institutional and organisational, (3) knowledge, culture and perception, (4) operational and site-specific disruptions, (5) policy, regulatory and procedural, and (6) technical and integration-related barriers. Multiple sub-themes are encapsulated under each of these categories. Thematic coding reveals how frequently these barriers are referenced, highlighting their prominence in influencing stakeholder decisions and retrofit implementation. Each barrier type is unveiled in detail in the following subsections, highlighting key insights and comparing how they manifest across the two regional contexts.

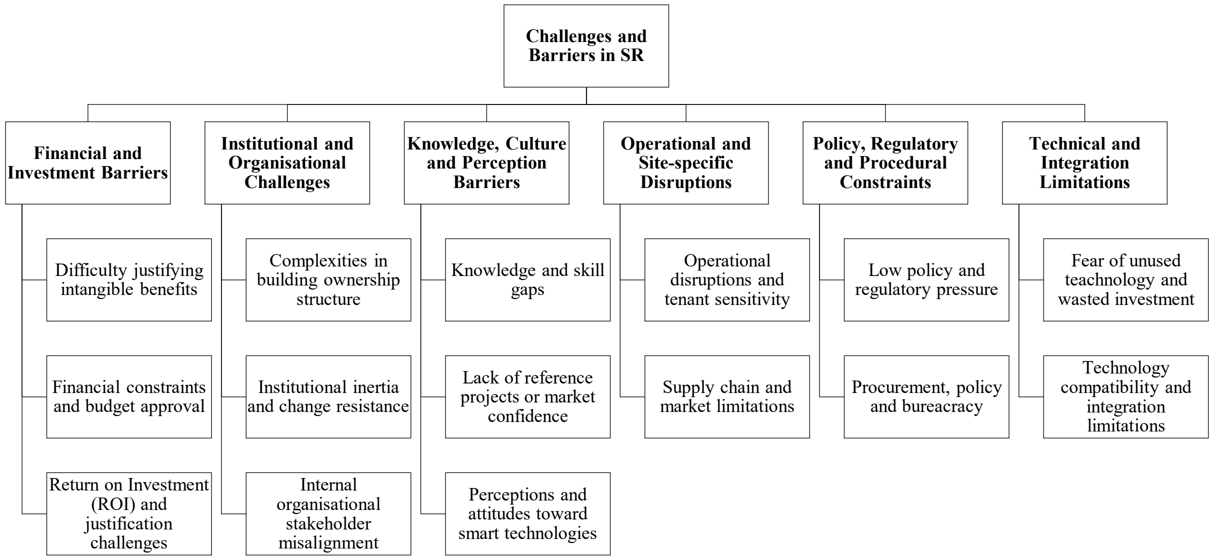

Figure 5-3: Overview of challenges and barriers in SR

5.3.3.1 Financial and Investment Barriers

Barriers in financial and investment aspects were a dominant theme across both Sri Lanka and Hong Kong. The challenges were manifested specifically in three dimensions: (1) the difficulty of justifying intangible benefits, (2) budgetary constraints, and (3) uncertainty surrounding Return on Investment (ROI).

The struggle to justify intangible outcomes (e.g., enhanced tenant satisfaction or predictive analytics) that are difficult to quantify was identified as a key barrier in both regions. As emphasized by SL-12 from Sri Lanka, "*Improved customer satisfaction, ultimately translates into higher property values*." However, this logic may not always satisfy the budget approvers. HK-06 from Hong Kong stated that landlords are reluctant to proceed without *"definite numbers"*, reinforcing the findings of Bolomope et al. (2021) that traditional financial metrics often dominate decision-making.

Regarding budget limitations, the Sri Lankan experts noted that the room for technological upgrades was limited by fixed budgets and the priority given to aesthetic elements (SL-10). According to the Hong Kong experts, the strict annual caps and the need for justifying investment through long-term financial planning were the main contributors to budget limitations (HK-08). HK-07 stated, *"Internally, budget is the biggest challenge,"* illustrating how SR implementation is obstructed by financial rigidity.

The issue of ROI justification was also closely tied to the above challenges. In both contexts, quantifiable returns are demanded by decision-makers, but the benefits of SR often span long timeframes, or a complete payback is difficult to calculate at the initial stage. SL-06 stated, *"We get stuck in meetings because some benefits are intangible"*.

While cost justification is a major hurdle in both regions, more structured corporate governance is seen in Hong Kong (Wen et al., 2025), whereas Sri Lanka manifests tighter resource constraints and spending priorities that are not focused on a common goal (Centre for Policy Alternatives, 2025).

5.3.3.2 Institutional and Organisational Challenges

Another significant barrier to SR implementation is the institutional and organizational challenges that exist in office buildings including ownership complexities, institutional inertia and stakeholder misalignment. Complexities surrounding fragmented ownership were particularly salient in strata-titled buildings or those with multiple owners where coordination becomes highly problematic. From a Sri Lankan perspective, SL-12 explained that having multiple owners could make unified decision-making difficult stating *"Each owner has their own strengths, weaknesses and objectives."* A similar situation prevails in Hong Kong and the presence of owners' corporations further complicated matters. HK-09 noted, *"Even if you go to a vote and you win, the losing owner might refuse to pay."* These structural barriers reinforce findings of Easthope et al. (2024) that collective investment in building upgrades are weakened by fragmented ownership.

Institutional inertia was another recurring barrier highlighting the resistance to change among key stakeholders. Reluctance from facility managers and government bodies were mentioned by the experts from both regions. SL-05 stated that, *"People are reluctant to change, the project eventually did not move forward."* The Hong Kong experts stated that similar issues could be attributed to the conservative nature of public agencies and Building Management Offices (BMO) (HK-06). This echoes the findings of Göhlich (2016) suggesting that organisational routines, once rooted, are difficult to disrupt.

Stakeholder misalignment within organisations was the third barrier that emerged in this theme. Isolated departments, conflicting priorities and *"Asian boss culture"* were highlighted by the experts as obstacles to SR decision-making (SL-10, SL-12, HK-11). According to SL-12 and HK-11 misinformation, lack of Chief Executive Officer (CEO) understanding or rivalry between sustainability and operations teams could derail technically justified projects.

While institutional and organisational barriers persist in both regions there is a diverging nature of complexity across regions. The obstacles in Sri Lanka mainly stem from conflicting objectives among different owners in strata-title buildings, isolated departments and misinformation (Gunarathna et al., 2018). Hong Kong, on the other hand, usually struggles with the presence of bureaucratic owners' corporations and a strict hierarchical culture where innovation may be restrained by 'boss-driven' decisions (Ma and Lam, 2019). Overall, deeply embedded organisational inertia reflects both cultures, despite differences in sophistication and scale. Aligning with the insights of Hincapie and Costa (2024), the findings on institutional and organisational challenges underscore the necessity of trust-building, cross-functional collaboration and leadership alignment to enable SR transformation.

5.3.3.3 Knowledge, Culture, and Perception Barriers

As explained by the experts, another set of barriers surround knowledge deficits, cultural attitudes and stakeholder perceptions. Prevalence of knowledge and skill gaps was a significant barrier across both regions, especially in Sri Lanka. SL-11 from Sri Lanka stated, *"With automation, you need to train the existing staff. You cannot just assume they will know how to handle it,"* and SL-02 noted, *"We need better training and exposure to smart building systems to fully utilize available technology,"* citing inadequate training, outdated practices and lack of familiarity with evolving technology as critical issues among many stakeholders, including owners, FM staff, consultants and contractors. The potential of SR implementation in Sri Lanka was further weakened by the absence of trained system integrators and the limited expertise of local suppliers. The problem was more subtle in Hong Kong, where it was centred around domain-specific Information Technology (IT) knowledge. As stated by HK-10, the implementation of data-intensive systems such as digital twins were sometimes constrained by *"a lack of understanding of new technologies by clients or FM teams"*. These are consistent with the findings of Zhou et al. (2021) on digital readiness divide.

The lack of precedent or reference project is the second challenge related to knowledge (SL-04, SL-10). The absence of demonstrable local success stories was noted by the Sri Lankan experts as one of the prime reasons for stakeholder scepticism. Without benchmarks, SR investments were perceived as risky and unproven by stakeholders.

Attitudinal issues were the third and perhaps the most deeply rooted barrier. In Sri Lanka, decision-making was often influenced by emotion, habit or informal knowledge networks rather than structured reasoning. SL-12 mentioned, *"Many high-level professionals rely on word-of-mouth as a primary and trusted source."* In Hong Kong, some landlords were more willing to prioritise short-term tenant stability over long-term efficiency gains, showing resistance to change (HK-06). Bridging this cognitive and cultural gap is essential for advancing retrofit agendas.

5.3.3.4 Operational and Site-Specific Disruptions

Operational complexity of executing upgrades in occupied buildings and the fragility of supply chains is another dominant theme of challenge confronting efforts for SR implementation in both Sri Lanka and Hong Kong. Although usually overlooked in planning, these barriers have significant implications for feasibility, stakeholder relations and scheduling.

The disruption caused to daily building operations, particularly to tenants and critical services, was a key concern. In office buildings particularly the ones housing sensitive operations such as financial institutions or data centres, even minor retrofitting tasks could impose significant logistical challenges. Demonstrating the necessity of contingency plans like night work or backup systems, SL-02 stated, *"HVAC systems cannot be switched off during working hours."* The same need exists in Hong Kong where HK-12 stated, *"SR disturbs their operation, the constraint refers to the tenant's side."* These insights therefore reinforce the findings of Hashemi and Dungrani (2025) which highlights the centrality of occupant considerations in retrofit decision-making.

The implementation barriers were further exacerbated by supply chain instability. According to the Sri Lankan experts, the industry suffers with severe procurement delays, fluctuating prices and difficulty in finding solutions compatible with aging systems. SL-02 reported, *"We had to cancel the order after six months because prices had increased by 50-60%."* Often, the unavailability of spare parts for older systems forced costly or impractical workarounds. Sri Lanka faced deeper challenges including economic instability and inflation. In Hong Kong, the more prominent constraints were the unavailability of vendors and labour shortages. The volatility of the market caused by the COVID-19 pandemic could have worsened the issue, as mentioned by the experts.

5.3.3.5 Policy, Regulatory and Procedural Barriers

Both regions face significant institutional barriers due to the lack of strong policy mandates and bureaucratic inefficiencies in procurement and regulatory approvals. Amongst these, a dominant theme was the lack of regulatory pressure or incentive schemes encouraging SR. The experts in Sri Lanka emphasized that *"there is no government mandate"* (SL-07) and *"no external funding sources"* (SL-06) to support SR initiatives. It was also stated that tenants and investors give minimal importance to green certifications such as LEED or Green Mark during decision-making (SL-12). HK-11 reported that *"unlike Singapore, there's no Government standard"*, noting that it is not yet mandatory in Hong Kong to conduct retro-commissioning or HVAC reviews. It is therefore clear that there is a strong lack of policy-driven initiatives for SR-related projects, which aligns with Braams et al. (2024)'s findings on the underutilization of government levers in driving sustainability transitions in the built environment.

Bureaucratic and procedural constraints are another emerging barrier under this theme. The experts from Sri Lanka revealed that procurement cycles are quite lengthy often spanning 8-10 months. Regulatory uncertainty caused by frequently changing policies, including inconsistent import restrictions, and their impact on procurement planning was also highlighted by SL-02 stating *"No one knows what will happen next."* The situation in Hong Kong was more complicated. The existence of restrictive building codes and overlapping jurisdictional constraints sometimes hinder SR implementation. For example, HK-09 stated that *"Many developers are interested in installing solar panels which however is restricted by Potential Datum (PD) limit. In most cases, the roof has already reached the highest height allowed and seeking government approval on relaxing the height limit usually takes several years."* Therefore, it is clear that there is divergence between environmental ambition and procedural reality in both regions that needs to be addressed.

5.3.3.6 Technical and Integration Limitations

The fear of underutilized systems and system compatibility issues was a dominant technical barrier in SR. This was demonstrated in the opinions of the experts from both Sri Lanka and Hong Kong. The apprehension that smart systems may not function as anticipated was a significant belief of the experts particularly if installation, testing and adoption are poorly executed. Attributing failure to inadequate post-installation testing, SL-11 from Sri Lanka mentioned, *"I have had experience with projects where the system stopped functioning soon after installation."* While innovative, others warned that sophisticated technologies like destination-controlled elevators may not suit all user groups. According to SL-12, *"Smart technology should only be introduced when it aligns with the needs of a diverse group, from CEOs to cleaners."* The findings of Ghaffarianhoseini et al. (2017) that overly complex or misaligned technology can hinder end-user engagement and long-term value realization are therefore reinforced by the above concerns.

The second recurring barrier identified under this theme is limitations in system integration. Early planning for system design and implementation, especially deciding between wired or wireless systems, was emphasized by the Sri Lankan experts. Late-stage installations caused by poor planning may escalate retrofit costs or cause structural damage (SL-10). A key constraint in Hong Kong was posed by proprietary BMS, often operated by third-party vendors. Referring to the cost of extracting data from closed systems, HK-12 explained, *"That extra batch of money is usually another constraint."* Vendors maintaining closed-loop architectures in BMSs charge expensive Application Programming Interface (API) access fees and restrict interoperability among systems (HK-11).

While system compatibility remains a major hurdle in both regions, its impact on Sri Lanka is higher as the industry struggles with technological readiness (Fasna and Gunatilake, 2020). On the other hand, the compatibility issues in Hong Kong stem from system fragmentation, vendor lock-in and complexities in IT governance (Zhou et al., 2021).

5.3.3.7 Analysis of Barriers across Regions

Table 5-5 is a heat map indicating the frequency of barrier-related references by the experts across Hong Kong and Sri Lanka.

Table 5-5: Frequency of barrier types in Hong Kong and Sri Lanka

Theme	Sub-Theme	Hong Kong	Sri Lanka
Financial and Investment Barriers	Difficulty justifying intangible benefits	3	3
	Financial constraints and budget approval	8	9
	ROI and justification challenges	1	4
Institutional and Organisational Challenges	Complexities in building ownership structure	2	4
	Institutional inertia and change resistance	2	4
	Internal organisational and stakeholder misalignment	5	11
Knowledge, Culture and Perception Barriers	Knowledge and skill gaps	2	16
	Lack of reference projects or market confidence	0	3
	Perceptions and attitudes toward smart technologies	6	10
Operational and Site-specific Disruptions	Operational disruptions and tenant sensitivity	10	4
	Supply chain and market limitations	4	12
Policy, Regulatory and Procedural Constraints	Low policy and regulatory pressure	3	4
	Procurement, policy, and bureaucracy	4	10

Technical and Integration Limitations	Fear of unused technology and wasted investment	0	3
	Technology compatibility and integration limitations	3	3

The results depict that financial constraints and budget approval is one of most frequently cited barriers in both Hong Kong and Sri Lanka. This furthers current understanding of the universal difficulty of implementing capital-intensive retrofits, regardless of the economic maturity (Fasna and Gunatilake, 2020, Bolomope et al., 2021). Resistance and scepticism towards SR (Ghaffarianhoseini et al., 2017) are also evident in both regions with ‘perceptions and attitudes toward smart technologies’ being frequently cited. ‘Difficulty justifying intangible benefits’ and ‘technology compatibility and integration limitations’ were cited equally across Sri Lanka and Hong Kong, indicating that such barriers could be universal and perpetual challenges present in SR that need to be urgently addressed (Zhou et al., 2021).

The results also suggest that capacity-building for SR and enhancing coordination, operations and decision cultures are key concerns for Sri Lanka given the higher citation frequency for ‘knowledge and skill gaps’ and ‘internal organisational and stakeholder misalignment’ (Fasna and Gunatilake, 2020). Sri Lanka could also be suffering from a structural disadvantage in accessing technology, vendors and stable procurement environments given the prominence given by the experts to ‘supply chain and market limitations’ and ‘procurement, policy and bureaucracy’.

‘Operational disruptions and tenant sensitivity’ appears to be more prominent in Hong Kong which could be mainly due to the high-tenant sensitivity in Hong Kong’s commercial real-estate demanding SR to align with lease terms while being strategically timed to avoid disruption (Jones Lang LaSalle Inc, 2024). The prominence given to ‘low policy and regulatory pressure’ by the Hong Kong experts could be due to the difficulty facility managers face in justifying SR projects without legislative backing (Hong Kong Green Building Council Limited, 2021).

Together, these insights reinforce the importance of designing the SRDSS to be stakeholder-sensitive, regionally adaptive, and capable of handling both hard constraints (funding, data, systems) and soft factors (attitudes, interdepartmental dynamics, trust gaps).

5.3.4 Stakeholder Roles and Influence

This theme encompasses the diverse actors involved in SR and their varying levels of impact across different project stages. Key stakeholders include consultants, contractors, facility managers, owners, cross-departmental teams and tenants. Their roles range from technical specification and project coordination to decision-making and end-user influence, often shaped by organizational culture and power dynamics.

5.3.4.1 Consultants and Auditors

Involving in SR projects from decision-making throughout the whole project are consultants, advisors or auditors. They were identified as key role-players in Hong Kong and Sri Lanka both shaping retrofit strategies and guiding decision-makers. Their contributions are particularly evident in conducting feasibility studies, drafting technical specification, offering procurement guidance and value engineering services. The Sri Lankan experts emphasized that the role of consultants as trusted technical expertise is quite significant especially when the internal capacity of the building owners is limited or when management prefers to obtain external expertise. SL-01 mentioned, *"We get the expertise of the consultants to prepare the specifications,"* highlighting role of consultants in creating clear and comprehensive scopes for the SR project. It is also expected that consultants are well-informed and updated about global trends and have the capacity to conduct in-depth cost-benefit analyses, be aware of reliable brands that are future proof and in-line with project goals.

While consultants in Hong Kong seemingly play a similar role, they are also required to comply with regulations and ESG commitments of the client. HK-12 mentioned that *"Usually, the landlord issues a tender and we look at performance gaps to suggest improvements."* Especially for larger ESG-focused projects, auditors and real estate advisors are in high demand to offer their services in due diligence and ROI evaluations. While consultants were respected as a trusted party in both regions, issues such as over-reliance on consultants by top management bypassing internal teams and the lack of retrofitting-specific insight of some consultants were highlighted during the interviews.

5.3.4.2 Contractors and Solution Providers

Contractors and solution providers were identified to be playing a key role in the design, selection and implementation SR technologies. In Sri Lanka, an advisory role beyond installation is often played by contractors. SL-05 noted that *"Usually, the exact technology will not be specified by clients; it's up to the contractor to select the appropriate, affordable solution"*. Clients often select contractors based on their track record, product reliability and responsiveness. However, escalating failure rates were common in the post-retrofit stage in Sri Lanka especially in environments where there is a lack of dedicated maintenance staff.

In addition to playing the typical role of contractors, in Hong Kong, they also act as technology scouts and educators. They are one of the key sources for clients to consult when it comes to identifying emerging smart technologies. Moreover, pilot demonstrations and ROI estimation are often conducted by contractors with the aim of building a trustworthy relationship with the client. Hong Kong's culture showcases a more personalised influence of contractor-client relationships, where developers may initiate discussions based on informal updates or demonstrations from trusted providers. HK-11 explained, *"If you have close contacts with the vendors you can ask "what are you doing lately?" and they might say "we are working on airside control hunting prediction algorithms", and you might say, "oh, interesting! Tell me more". So, it is very personal."*

However, the risk of sales-driven bias is emphasized in both regions, where benefits are oversold or proprietary systems are promoted by contractors. Therefore, practices such as Proof-of-Concept (POC) testing were mentioned as mechanisms used to maintain objectivity. SL-08 mentioned, *"Even if a product lacks advanced features, it's long-term durability is what truly matters."*

5.3.4.3 Cross-Department and Internal Dynamics

This theme was also mentioned frequently by the experts from both Hong Kong and Sri Lanka as sometimes an enabler or an obstacle in SR decision-making. While a lot of technicalities is embedded with SR projects, the success is hinged upon on collaboration among different organisational teams such as engineering, finance, legal and marketing. The Sri Lankan model showcased different priorities brought on to the table by each team where technical feasibility is looked at by the FM team, cost control is overseen by the finance department and senior management takes on overall value. SL-12 stated, *"A professional approach is important where both parties debate constructively, ultimately arriving at a shared solution,"* emphasizing on the ability to align these perspectives through mutual respect and open discussion for smooth project execution (SL-12).

While the internal dynamics took a similar approach in Hong Kong, enhanced specialization in departments and strategic alignment was also observed. Based on tenant demands or branding opportunities, decisions may be originated from the marketing or leasing team. Hence a more market-responsive model is reflected in Hong Kong with the perspective that SR is not only a technical upgrade but also a competitive tool. Still, the challenge of aligning departmental agendas, timelines and performance metrics were mentioned by the experts. This risk of isolated decision-making shared across both regions were said to often delay decisions or dilute the effectiveness of SR. Therefore, on top of technological soundness, navigating internal relationships and fostering strategic alignment is crucial for SR.

5.3.4.4 Facility Managers

As explained by the experts, facility managers play the central coordinating role of SR projects. In Sri Lanka, building issues are typically detected first by the facility managers through routine monitoring or tenant complaints. SL-11 stated, *"The FM team would report the issue to the management and propose solutions."* Key actions in the decision-making process, such as contractor recommendation, product evaluation and facilitating communication between stakeholders are conducted by the in-depth involvement of facility managers. The consultant assessments are often improved based on technical input by the facility manager ensuring that specifications are clear and comprehensive. A similarly pivotal role by a facility manager is played in Hong Kong with a more specialised and data-driven approach. FM teams with sustainability expertise may be employed by large developers in realising their ESG targets. Sometimes these services are outsourced to FM companies to obtain consultancy on market trends and smart technologies. As they are the party with on-ground insights and familiarity with the building and its operational history, the experts suggested that the involvement of facility managers in an SR project should be further enhanced. HK-06 explained, *"It's all about building reliability. For example, is the lift safe for people to use? Is the HVAC system providing a stable supply? These aspects fall under the responsibilities of facility and property management, rather than third-party providers."* Here, 'third-party providers' refers to outsourced service vendors or external consultants, not the facility and property management teams themselves, even if those roles are sometimes outsourced.

5.3.4.5 Management, Owners and Decision-Making Bodies

The influence of owners, top management and formal decision-making bodies were identified as one of the dominant, shaping SR initiatives in both Sri Lanka and Hong Kong. The high-level aspects of a project, such as setting SR priorities, determining project scope and approving funding, are under the authority of owners, top management and formal decision-making bodies, whose decisions are usually influenced by their perception of value, risk and alignment with business goals. Ownership structures in Sri Lanka seemed to varying across different buildings, but the authority to make the final decisions was seemingly with senior executives or the top-board. The experts noted that a clear articulation of the returns or benefits of the SR project was required to gain approval. The factors dominating board-level discussions were identified as budget justification, risk aversion and ROI. In strata-title properties, technically sound SR proposals maybe disapproved due to the lack of consensus between majority stakeholders. SL-12 explained, *"So, when you look at all four owners, their stakes are relatively small, and when it comes to decision-making, the majority shareholder often dominates the process. A strong managing agent represented by the FM team is crucial to navigating these differences and ensuring effective building management."* In Hong Kong, SR is treated as a strategic commercial decision rather than a compliance obligation. Retrofit priorities of owners, who are often developers or private landlords, are influenced by revenue goals, branding potential and competitive positioning. As explained by HK-07, *"Whether the organisation wants to achieve the green building certification or whether they just want to focus on the commercial aspects, that would be the owner's or the developers or the landlords' decisions."* Owners often tend to decide between pursuing ESG certifications or improving the potential for perceived tenant appeal and investor expectations by investing in SR initiatives.

5.3.4.6 Building Occupants or Tenants

While a significant driver in SR decision-making, the influence of tenants is often underestimated by decision-makers. The retrofit priorities of the client can be significantly shaped by the expectations, complaints and ESG commitments of the tenants. Their demands were identified as a key trigger for building owners and facility managers to initiate SR. Tenant influence was seen as reactive and operational in Sri Lanka. Tenants' complaints or comfort-related concerns are responded to by FM teams prompting assessments and potential system improvements. SL-04 highlighted, "*If we receive repeated concerns about specific issues, that signals a need for investigation.*" emphasizing satisfaction results in tenant retention, making them a pressure point for initiating investigation and discussions.

A more strategic influence is observed by tenants in Hong Kong, especially international firms and anchor tenants. To align with their brand image or sustainability commitments, additional performance such as ESG data, advanced smart features and customised solutions are continuously demanded. Even retrofit timelines, technology selection and space planning can be influenced by powerful tenants. HK-05 explained, *"The bargaining power of international groups is strong, landlords may relocate other tenants to accommodate their requests."* The growing tenant awareness of smart and sustainable technologies was an important insight from both regions. The need for Decision-Support Systems (DSSs) that consider tenants' needs (e.g., comfort, sustainability reporting) are therefore evident, to ensure both operational and occupier-driven priorities are met in SR decisions.

5.3.4.7 Comparison of the Stakeholder Influence Levels

Based on the opinions of the experts, a radar chart as shown in Figure 5-4 was developed to illustrate the varying level of influence of different stakeholders across the lifecycle stages of a SR project. Through thematic coding of interview transcripts in NVivo, where significant quotes related to stakeholder influence were extracted and coded, each quote was classified under one of the predefined SR lifecycle stages: problem identification, technical evaluation, specification and design, approval and funding, implementation oversight and strategic direction. The quotes were also grouped by stakeholder category, such as facility managers, consultants, contractors, owners/management, tenants and cross-departmental teams. For each stakeholder group, the number of references indicating involvement or influence in a particular lifecycle stage was counted. These frequency counts served as a proxy for the perceived level of influence and were subsequently used to generate the radar chart shown in Figure 5-4. While the method does not claim statistical precision, it offers a transparent and structured way of reflecting stakeholder prominence based on expert perceptions across different phases of SR decision-making.

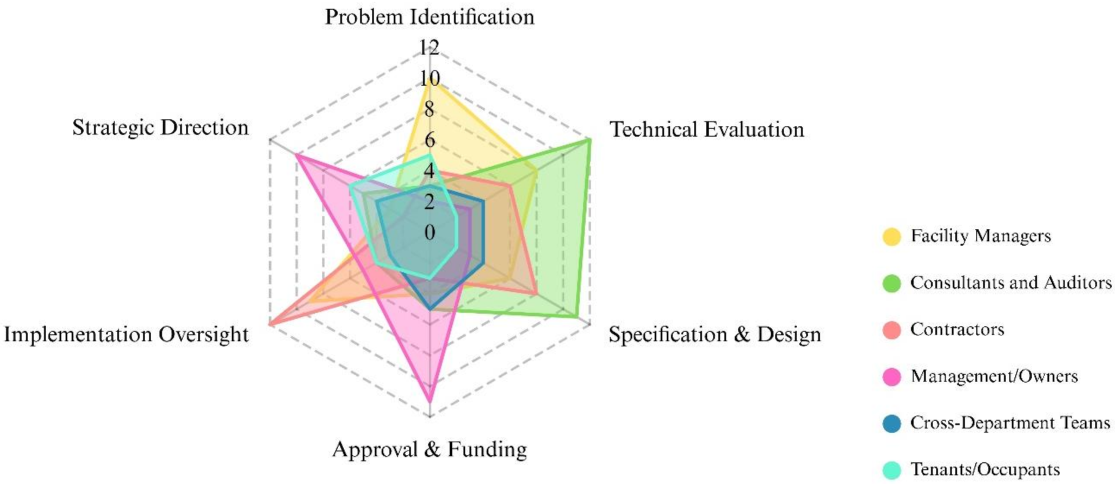

Figure 5-4: Stakeholder influence radar

Underscoring their hands-on insights into building systems and operations, facility managers were identified to play a consistently influential role across nearly all stages, especially in ‘problem identification’ and ‘implementation oversight’. The ‘technical evaluation’ and ‘specification and design’ stages were dominated by consultants and auditors. This reflects their contribution in shaping SR project designs and feasibility studies. This aligns with Jensen (2009), who emphasizes the operational expertise and first-hand knowledge that facility managers contribute to retrofit projects, which enables them to detect system inefficiencies early and support practical execution during implementation. Similarly, Fasna and Gunatilake (2020) identified FMs as central figures in Sri Lanka's retrofit context, often bridging the gap between technical feasibility and operational practicality.

It can be observed that the influence of consultants and auditors are prominent during technical evaluation and specification design. This is consistent with international best practices outlined in Royal Institution of Chartered Surveyors (2024), which defines the consultant's role in building performance assessment, retrofit option appraisal, and preparation of compliant design documentation. The findings, however, also indicate that their influence is situational and tends to decline during funding approval stages. This observation is in partial contradiction with the findings of Gann et al. (1998) where an end-to-end involvement of consultants is highlighted as a strategic partnership which also influences client decisions in building innovation projects. The diminished influence observed in this study may reflect either cultural decision-making patterns (e.g., deference to executive authority) or the transactional nature of consultancy in practice.

The influence of contractors and solution providers were more significant during implementation contributing towards system selection based on market trends and competition (Peiris et al., 2024). The influence of management and owners were concentrated around funding approvals and strategic planning. A top-down model can be seen with their influence, where they are the sole party making the decision whether a retrofit would go ahead or not (Lang et al., 2021). The moderate influence of cross-department teams across all stages justify the equal support and coordination between FM, finance, legal and marketing teams required throughout the entire lifecycle of a SR project (Moradi et al., 2024). While not always formally involved, SR decisions are influenced by tenants through expectations, complaints of sustainability-driven demands (Morgan et al., 2024). However, Peiris et al. (2024) highlight that tenant engagement is still insufficiently practised in SR projects, particularly in strata-titled or multi-owner properties, a situation that may apply more to the Sri Lankan context.

A visual representation of relative, not absolute, stakeholder influence is thus offered by Figure 5-4, helping to understand the power dynamics and coordination needs within SR decision-making ecosystems. While the ratings of the radar chart were grounded in coding frequency, the underlying degree of subjectivity is acknowledged. Therefore, efforts were made to mitigate this bias by cross-referencing the findings with related literature while maintaining thematic consistency and comparison across both case contexts.

5.3.5 Decision Criteria and Evaluation Factors

This theme relates to the tangible and intangible metrics used to assess and select SR solutions which showed a multi-faceted nature across both regions. Financial justification was identified as the foremost filter among other criteria. As SL-11 said, *"Finance is always the first consideration, then we evaluate the benefit."* This was attributed to the need of demonstrating clear economic returns from SR projects regardless of their environmental or operational benefits. 'Payback period' and 'ROI evaluation' were stated as key financial metrics in both Hong Kong and Sri Lanka. SL-02 highlighted, *"The key factor is often the payback period. If it is less than three or four years, most people proceed."* Due to the fast pace of technological obsolescence, projects having longer payback period (usually those exceeding five years) were often viewed as risky. However, it was noted that ROI played a more prominent role in Hong Kong, where it was incorporated within a broader framework. While ROI in Sri Lanka was focused on operational efficiency and energy savings, stressing on quantifiable improvements such as kW/TR reductions or reduced manpower through automation, financial decisions in Hong Kong were made by factoring in reputation, ESG alignment and rental uplift as well to the ROI calculation as well. This difference could be due to the high utility costs, financial conservatism and budget constraints in Sri Lanka (Caldera et al., 2023), where eliminating waste and improving efficiency are primary motivators. In Hong Kong, some interviewees noted that making financial justifications based on ROI alone is insufficient. They advocated for a broader view of value that includes performance, reputation and future adaptability, echoing the findings of Tan et al. (2018).

However, cost is rarely considered in isolation. Disruption to occupants, installation time, ease of control and supplier reliability are also often assessed by decision-makers forming a composite picture of feasibility and value. In Hong Kong, compliance with decarbonisation targets and integration with existing systems also emerged as priority concerns, reflecting the region's policy and investor-driven environment (Wen et al., 2025). Technical compatibility and risk minimisation were the other recurring factors identified from both regions. The main concerns regarding these two factors were the need for seamless integration with legacy systems, protection of tenant data and mitigation of noise and disruption during installation.

Given the long-term nature of SR investments, after-sales support and user-friendliness was commonly cited by the experts. SL-04 mentioned, *"If a supplier introduces a new concept or an alternative solution with long-term benefits, we may conduct a POC trial."* Hence demonstrated real-world testing is seen as a requirement of the Sri Lankan experts. This could be to ensure decisions are grounded in functionality rather than vendor promises reinforcing the need for evidence-based DSSs for SR.

The relevance and comprehensiveness of the criteria identified methodologically in Chapter 4 are further reinforced by these insights. The findings of the expert interviews reveal that though not always formalised, a wide array of technical, financial, operational, and strategic considerations are already engaged in real-world SR decision-making. The criteria identified in Chapter 4 under technical, financial and user-comfort categories are closely linked with the key dimensions of payback period, ROI, ease of integration, occupant impact and vendor reliability discussed above. The inclusion of environmental and regulatory criteria within the SRDSS is also supported by the emphasis on intangible values in Hong Kong, such as ESG alignment, brand reputation, and policy compliance. Although practitioners may apply these considerations in an ad hoc or experience-driven manner, the findings suggest that the industry inherently adopts a holistic perspective, reinforcing the value of developing a structured, transparent, and multi-criteria framework such as the one proposed in this study.

The thematic insights derived from expert interviews directly support and enrich the overarching research objective of developing a context-sensitive and stakeholder-informed SRDSS. By identifying the key drivers, barriers, stakeholder influences and evaluation criteria, this contextual analysis provides a grounded understanding of how SR decisions are made in real-world settings across Sri Lanka and Hong Kong. This stage of analysis also substantiates the practical relevance of the criteria shortlisted in Chapter 4, ensuring that the subsequent ANP-based prioritisation is not only methodologically rigorous but also reflective of industry practice and needs. Ultimately, the themes consolidate a multi-dimensional perspective that strengthens the SRDSS by aligning it with both contextual complexity and literature-grounded theory.

5.4 Establishing Criteria Weights using ANP

This phase focuses on determining the relative importance of SR decision-making criteria. Based on the pairwise comparisons provided by the experts, ANP was used to prioritize the criteria, while also considering the interdependencies among them. The following sections explain the fundamentals of the ANP method, data collection and analysis for ANP weight calculation and insights generated from the resulting importance weights.

5.4.1 ANP as a Multi Criteria Decision-Making Method

MCDM is a strong and extensively used methodology meant to help decision-makers in situations where numerous, often contradictory criteria impact the decision-making process (Gal et al., 2013). MCDM's central concept is to provide a systematic framework for evaluating and ranking different solutions based on a variety of criteria or objectives (Nielsen et al., 2016).

There are different MCDM methods that simplify decision-making using different pathways. Some of them include the 'weighted sum model', TOPSIS, 'preference ranking organization method for enrichment evaluation (Promethee)', AHP and ANP.

The 'weighted sum model' is a simple MCDM method that assigns weights to each criterion depending on its relative importance (Marler and Arora, 2010). For the purpose of determining the final weight, the scores for each alternative are multiplied by their respective weights. The 'TOPSIS' technique ranks alternatives based on their proximity to ideal and anti-ideal solutions (Zavadskas et al., 2016). The ideal solution has the best performance for each criterion, whereas the anti-ideal solution has the poorest performance. The 'Promethee' method evaluates and ranks alternatives based on partial pre-ordering (Majumdar and Choudhury, 2022). To generate a global ranking of alternatives, it employs preference functions and pairwise comparisons. ANP is a multi-criteria decision analysis method developed by Thomas L. Saaty (Saaty, 1996, Saaty, 2005). It is an extension of AHP (Saaty, 1980).

While the approaches described above constitute a subset of available MCDM strategies, their selection is frequently influenced by the nature of the decision problem, decision-makers' preferences, and data characteristics. Numerous studies have compared and evaluated the effectiveness of MCDM approaches in a variety of situations, advancing the understanding of their strengths and limits. Shown in Table 5-6 is a summary of previous studies that have used MCDM for retrofitting decision-making.

Table 5-6: Summary of previous studies on MCDM application in retrofit decision-making

No.	Source	Type of MCDM method used	Application of MCDM
1	Barnaś et al. (2023)	TOPSIS	To preliminarily select the most suitable building complexes to apply the thermal retrofitting solutions proposed in the study.

2	Xu et al. (2015)	ANP	To prioritise the critical success factors of sustainable building energy efficiency retrofit in hotels under the Energy Performance Contracting (EPC) mechanism
3	Si et al. (2016)	AHP	Comparative assessment of different technologies to be retrofitted to existing buildings to reduce carbon emissions and energy consumption
4	Balasbaneh et al. (2022)	AHP, TOPSIS	AHP was used to establish importance weights to criteria and TOPSIS was used to characterize the most appropriate material for retrofitting
5	Wong et al. (2008b)	AHP	To prioritize and assign the importance weightings for the perceived intelligent building selection criteria
6	Si and Marjanovic-Halburd (2018)	AHP	To calculate criteria weights for green technology selection in retrofits
7	Baseer et al. (2023)	pELECTRE Tri	To rank energy efficiency retrofit alternatives using traditional ELECTRE Tri, probability distribution and Monte Carlo simulation
8	Majumdar and Choudhury (2022)	AHP, PROMETHEE-II	AHP was used to rank different retrofit alternatives while PROMETHEE-II was used to confirm the reliability or consistency of the AHP findings.

AHP organizes a problem into numerous levels that form a hierarchy, with each decision element regarded to be independent (Darko et al., 2019, Sadeghi et al., 2022). Based on the hierarchical level, a complicated problem can be broken into numerous sub-problems, with each level denoting a set of criteria or attributes associated with each sub-problem (Wong and Li, 2008). The fundamental goal of the decision problem is to reach the highest level of the hierarchy. The lower levels represent the criteria of the corresponding upper levels. AHP allows criteria to be compared, with the importance of individual criteria based on their impact on the decision problem (Xu and Chan, 2013). Since its inception, AHP has been widely utilized in decision-making.

As an extension of AHP, ANP replaces AHP's hierarchy with a network; it means that "the relationships between levels are not easily classified simply as hierarchical versus non-hierarchical, or direct versus indirect" (Meade and Sarkis, 1999). This makes it possible for more complex relationships to exist between decision elements. ANP provides a more generic decision-making model that does not make assumptions about the independence of higher-level elements from lower-level elements or elements within their own level (Xu and Chan, 2013). The interdependencies in an ANP model can be graphically represented by a two-way arrow or arcs between different levels of criteria (Jharkharia and Shankar, 2007). If there are interdependencies at the same level of analysis, a looped arc can be utilized to express them. Figure 5-5 depicts the structural difference between an AHP hierarchy and an ANP network.

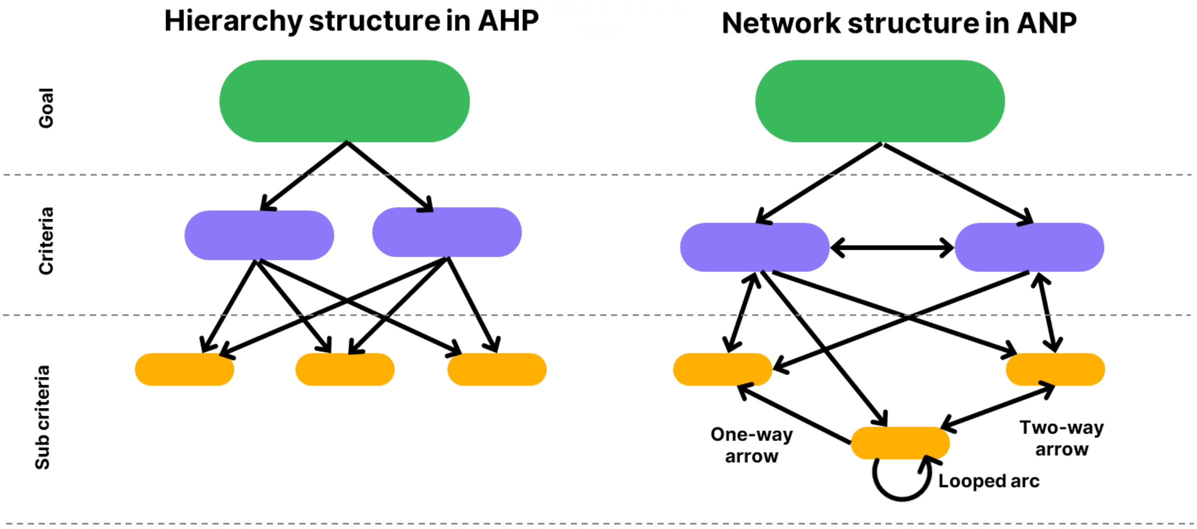

Figure 5-5: Structural differences between AHP and ANP

The structural developments in ANP (illustrated in Figure 5-5) are helpful to solve decision problems with complicated linkages, feedback loops and criteria interactions. ANP offers a unique capacity to handle complicated decision-making scenarios with interdependent criteria, as for the case of SR for office buildings. Therefore, ANP was selected as the MCDM method to establish the expert-based relative importance weights in this study.

5.4.2 Criteria Identification and Selection

As explained in Chapter 4, the criteria influencing SR decisions were initially identified through a comprehensive literature review, followed by a focus group discussion, which was used to validate the criteria identified from the literature. To shortlist the most significant criteria, a questionnaire survey was conducted with the participation of FM professionals. The survey responses led to the selection of 20 criteria, as shown in Table 5-7.

Table 5-7: Criteria influencing SR decisions

Criteria category	Criteria Label	Criteria
Financial	F1	Investment cost
	F2	Recurring operation, maintenance and repair costs
	F3	ROI (e.g., higher rental income)
	F4	Operational savings (e.g., labour, utility savings)
Technical	F5	Automated fault prediction capabilities
	F6	Reliability of retrofitted hardware
	F7	Reliability of retrofitted software
	F8	Compatibility with existing systems
	F9	Feasibility of installation
	F10	Availability of competent FM staff to operate and maintain the retrofitted system

	F11	Safety during retrofitting project (e.g., fire, human, structural)
	F12	Disturbance and inconvenience to current occupants during retrofitting project
User comfort and convenience	F13	Indoor environmental quality
	F14	User friendliness
Environmental	F15	Resiliency against physical climate risks (e.g., extreme weather, flooding)
	F16	Energy saving capabilities
Legal, safety and security	F17	Ability to comply with regulatory requirements
	F18	Improved data protection capabilities
	F19	Smarter access control and surveillance capabilities
	F20	Automated hazard prediction and response capabilities (e.g., automatically detecting water/gas leaks)

5.4.3 Application of ANP

The next stage was to determine the importance weights of the established criteria using the ANP method. To this end, the Super Decisions software, which is a specialist tool built for multi criteria decision analysis (Mu and Pereyra-Rojas, 2017), was used. The software automates the derivation of importance weights, making the process more efficient and offering a user-friendly interface for decision-makers by streamlining the complicated mathematical computations inherent in ANP.

The application of ANP for determining the importance weights involved six key steps: (1) defining the decision network; (2) pairwise comparison; (3) calculating local priority vectors; (4) constructing supermatrix and eigenvalue analysis; (5) consistency check; and (6) normalization. Priorities were used to determine the final importance weights, and the six steps are detailed below.

Defining decision network: ANP application began by modelling the decision problem as a network. The network is made up of criteria that have been organized into clusters and have interrelationships formed between them (Yitmen et al., 2022). The Super Decisions software was used to organize the 20 criteria (Table 5-7) into a network for this purpose. Based on the initial network developed, a total of 72 judgements were required to determine the importance of the 20 criteria. However, a pilot interview showed that making such a vast number of judgments takes excessive time and effort. Therefore, the representation of the criteria and their interrelationships were reviewed following the approach of Lai et al. (2022) with the modifications below made eventually (see Figure 5-6 for the final list of criteria C1 – C13):

- ‘Ability to comply with regulatory standards (F17)’ was omitted from the criteria list as the questionnaire survey responses showed that not complying with regulatory requirements is not an option for SR. As a result, it is more of a mandatory requirement than a criterion.
- ‘Reliability of retrofitted hardware (F6)’ and ‘reliability of retrofitted software (F7)’ were merged into one criterion titled ‘reliability of retrofit option (C5)’ as both criteria inherently address the overarching reliability of the retrofit option.
- ‘Automated fault prediction capabilities (F5)’, ‘resiliency against physical climate risks (F15)’ and ‘automated hazard prediction and response capabilities (F20)’ were merged into one criterion titled ‘automated risk prediction and response capabilities (C4)’, as they share the same focus - the retrofit option’s capacity to proactively predict and effectively respond to diverse risk scenarios and emergencies.
- ‘Safety during retrofitting project (F11)’, ‘feasibility of installation (F9)’ and ‘disturbance and inconvenience to current occupants (F12)’ were merged into one criterion titled ‘ease of implementing retrofitting project (C8)’, given their collective relevance to diverse criteria crucial for the seamless implementation of the retrofitting project.
- ‘Energy saving capabilities (F16)’ and ‘operational savings (F4)’ were merged into one criterion titled ‘energy saving capabilities (C11)’ because operational savings resulting from SR are predominantly assessed through the quantification of energy consumption reductions.
- Since ROI (F3) has the nature of a Key Performance Indicator (KPI) rather than a criterion, it was renamed as ‘ability to increase returns (C3)’.

Consequently, the number of criteria was reduced to 13 and the corresponding decision network developed on the Super Decisions software is shown in Figure 5-6. The network was organized into clusters. A cluster is a group of related elements within the decision network (Xu and Chan, 2013). In this study, the decision network was divided into five clusters: (1) financial, (2) technical, (3) user comfort and convenience, (4) environmental, and (5) legal, safety and security. Elements within each cluster (i.e. criteria) are referred to as ‘nodes’. Arrows connecting the nodes indicate the direction of influence or dependence. Influencing nodes point to influenced nodes. Dependencies and interdependencies in the ANP model are represented by one-way and two-way arrows, respectively. Looped arcs symbolize dependencies or interdependencies between nodes within the same cluster.

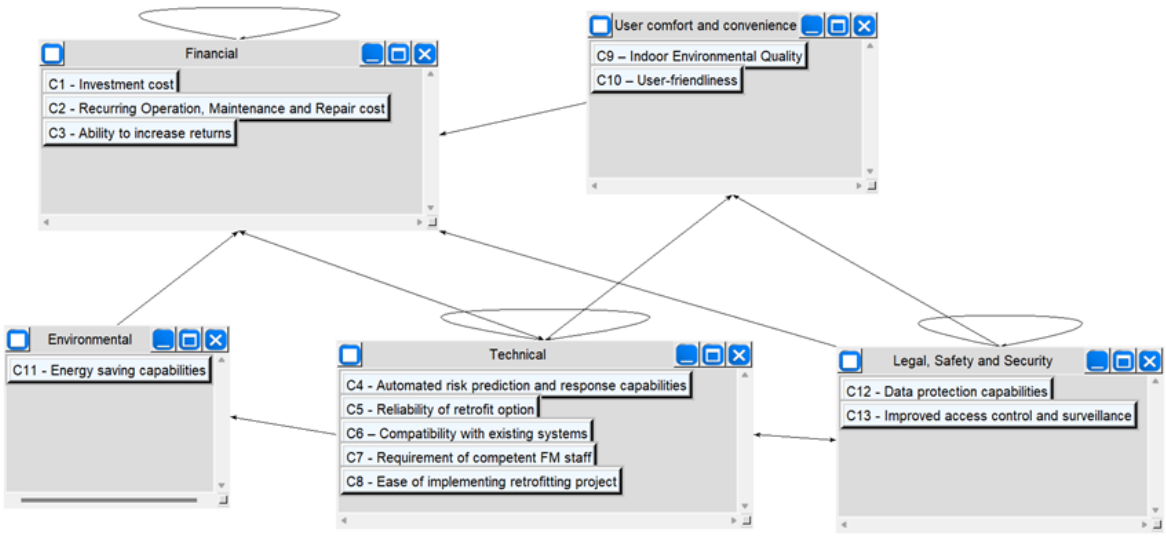

Figure 5-6: Relationship diagram of the 13 decision-making criteria

For illustration purposes, the dependencies between the node ‘investment cost’ in the ‘financial’ cluster and the nodes in the remaining clusters are explained below:

- Within the ‘financial’ cluster, the three nodes are interdependent because a higher investment cost could contribute to selecting SR options with relatively higher advanced features that result in reduced recurring operation, maintenance and repair costs, and higher ability to increase returns.
- ‘Investment cost’ is also influenced by ‘automated risk prediction and response capabilities’ in the technical cluster. For example, advanced HVAC systems with smart sensors offer varying levels of performance in predicting maintenance needs and optimizing energy usage. Basic systems provide predictive maintenance, while more advanced ones offer real-time monitoring and automated adjustments for better efficiency, often at a higher cost. Hence, when the level of automated risk prediction and response capabilities increases, it influences the investment cost.
- The influence of ‘reliability of retrofit option’ can also be explained using an example. For instance, before procuring a retrofit item, decision-makers often consider the materials used in its construction. Equipment made of more durable materials, such as metal instead of plastic, typically offer a longer lifespan and better reliability. However,

this enhanced reliability usually comes with a higher investment cost. Hence, it is evident that the reliability of a retrofit option also influences the investment cost.

- ‘Investment cost’ influences the ‘compatibility with existing systems’ because higher investment allows for better customization and integration. More funds enable tailored solutions and high-quality components, increasing the likelihood of achieving a retrofit that is highly compatible with existing systems.

Hence, a looped arc was drawn in the financial cluster indicating the interdependencies within the cluster and a two-way arrow was drawn between the financial and technical clusters indicating the interdependencies between the nodes in the two clusters.

Pairwise comparison: The final decision network comprised dependencies among the clusters and elements, which require 33 pairwise comparisons in total. The next stage in ANP involved conducting pairwise comparisons. Decision-makers provided these comparisons between nodes within each cluster and between different clusters. These comparisons were expressed using Saaty’s 1–9 scale (Saaty, 1980), which indicates the relative importance of one element over another. The relative importance was represented using a pairwise comparison matrix, as shown in Equation 5.1:

$$A = \begin{bmatrix} 1 & A_{12} & \cdots & A_{1n} \\ \frac{1}{A_{12}} & 1 & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{A_{1n}} & \frac{1}{A_{2n}} & \cdots & 1 \end{bmatrix} \qquad \text{Eq. (5.1)}$$

Where,

A is pairwise comparison matrix;

n is number of elements in the cluster;

$\mathbf{A_{1n}}$ is a component of the matrix given by the decision-maker's judgment on the importance of element 1 relative to element *n*

Opinions of the industry experts were sought for this part of the study through interviews. In-depth expert interviews were conducted with 12 professionals each from Sri Lanka and Hong Kong (representing developing and developed regions, respectively) as explained in section

5.2. The expert was shown and given an explanation of the decision network consisting of the criteria, along with an account of the influences and dependencies among the criteria. Each expert's responses to the comparisons were recorded and promptly entered into the Super Decisions software. The software enables decision-makers to easily input pairwise comparisons using an intuitive interface.

Calculating local priority vectors: The local priority vectors were determined next. The relative importance of nodes inside a cluster in the decision network is referred to as local priority. Local priorities were computed independently for each level using Equation 5.2.

$$W = \frac{eigenvector\ (A)}{\sum_{i=1}^{n} eigenvector\ (A)_i} \qquad \text{Eq. (5.2)}$$

Where,

W is local priority vector, which contains the relative importance weights of the elements within a cluster

eigenvector(A) is eigenvector of the pairwise comparison matrix A, which captures the importance relationships between elements in the cluster

n is number of elements in the cluster

i is index used to iterate through the elements of the eigenvector, ranging from 1 to n

The primary eigenvector shows the nodes' local priorities at that level. Local priorities aid in determining the significance of each node in its immediate setting. They were tailored to the relationships and comparisons at a particular level of the network.

Calculating global priority vectors: Following the establishment of the local priority vectors, the global priority vectors for the nodes were established. The overall importance of nodes throughout the complete decision network, considering the interdependencies between different levels, is referred to as global priority. Analysing the eigenvectors of the supermatrix yielded global priorities. ANP introduced the concept of a supermatrix, which accounts for node and cluster interdependence. The supermatrix was built using the Super Decisions software, which captured the interdependencies between criteria categories and criteria. ANP determines the principal eigenvector by examining the eigenvalues and eigenvectors of the supermatrix, which indicated the relative importance weights of each node in the network.

Equation 5.3 was used to construct the supermatrix C by taking the outer product of the local priority vectors:

$$C = W \otimes W \quad \text{Eq. (5.3)}$$

Where,

W is the set of local priority vectors for all clusters

$\otimes$ is outer product

C is square matrix representing the global relationships

Next, Equation 5.4 was used to obtain the global priority by calculating the principal eigenvector **V** of the supermatrix **C**:

$$V = \frac{eigenvector\ (C)}{\sum_{i=1}^{n} eigenvector\ (C)_i} \quad \text{Eq. (5.4)}$$

Where,

V is global priority vector, which represents the overall importance weights of all elements in the network

Eigenvector (C) is eigenvector corresponding to the principal eigenvalue of the supermatrix C

Eigenvector (C)$_i$ is i^{th} element of the eigenvector corresponding to the supermatrix *C*

n is total number of elements in the network

Again, the Super Decisions software was used to compute the eigenvalues and eigenvectors of the matrices involved. The principal eigenvector of the supermatrix represents the global priorities.

Consistency check: Consistency checking is a key step in ANP to verify that decision-makers' pairwise comparisons are reliable and consistent. Inconsistent judgments might lead to untrustworthy outcomes. According to Saaty (2005), the upper threshold Consistency Ratio (CR) values are 0.05 for a 3 × 3 matrix, 0.08 for a 4 × 4 matrix, and 0.10 for larger matrices. The Super Decisions software has a built-in consistency check function, and it calculated the Consistency Index (CI) and the CR to assess the reliability of the entered pairwise comparisons.

CI was obtained by:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{Eq. (5.5)}$$

Where,

λ_{max} is principal eigenvalue of A

n is number of elements in the cluster

The Random Index (RI) is a reference value derived from random consistency indices associated with matrices of different sizes. The CR was obtained by dividing CI by RI:

$$CR = \frac{CI}{RI} \quad \text{———— Eq. (5.6)}$$

The largest matrix among all pairwise comparisons was 10-by-10, for which the permitted CR is 0.1. When a calculated CR surpassed this allowed level, the expert was asked to evaluate his or her response and alter the associated comparison judgment. This procedure was repeated until the computed consistency was within the allowed limit. A total of 480 CR values were obtained from pairwise comparisons with all experts, with an average of 0.004. The minimum value was 0, while the maximum value was 0.0948.

Normalization: The final step was to synthesize the global priorities using normalized weights. The weights derived were normalized to guarantee that they add up to 1. Normalized weights were given by Equation 5.7.

$$V_{normalized} = \frac{V}{\sum_{i=1}^{n} V_i} \quad \text{———— Eq. (5.7)}$$

Where,

$\mathbf{V}_{normalised}$ is normalized global priority vector

V is global priority vector

$\mathbf{V}_i$ is i^{th} element of the global priority vector

The generated weights were automatically normalized by the Super Decisions software to produce a consistent list of priorities. This step provided the final importance weights for the criteria.

5.4.4 Data Analysis

The ANP importance weights derived from the responses of the experts were subject to statistical analyses. To this end, the SPSS was utilized. First, descriptive statistics (mean, median, maximum and minimum values) of the importance weights were computed based on all the responses from the industry experts. Second, two groups of descriptive statistics of the importance weights were calculated – one for Sri Lanka and the other for Hong Kong, in order to identify any difference in the importance weights between the two groups. Third, the Spearman rank correlation test was conducted on the important weight rankings between the Sri Lanka and Hong Kong groups so as to determine if there exists any regional variance. Spearman rank correlation coefficient, which may range from -1 (perfect negative association) to +1 (perfect positive association), was calculated by Equation 5.8.

$$r_s = 1 - \frac{6\Sigma D_i^2}{n(n^2-1)} \qquad \text{Eq. (5.8)}$$

Where,

r_s is Spearman rank correlation coefficient

n is number of observations

D_i is difference between ranks obtained from each pair of responses

5.4.5 Findings – ANP Weights from Sri Lanka and Hong Kong

Descriptive statistics of the importance weights were computed, as summarised in Table 5-8. The findings are interpreted and discussed in the following sections. Also covered are the various viewpoints of the experts from Hong Kong and Sri Lanka that represent the context of SR decisions in both developed and developing regions.

Table 5-8: Summary of criteria importance weights

Criterion		**Mean**			**Median**			**Maximum**			**Minimum**		
		Overall (combined)	**Hong Kong**	**Sri Lanka**	**Overall (combined)**	**Hong Kong**	**Sri Lanka**	**Overall (combined)**	**Hong Kong**	**Sri Lanka**	**Overall (combined)**	**Hong Kong**	**Sri Lanka**
C1	Investment cost	0.1870	0.2027	0.1712	0.1836	0.1992	0.1641	0.3664	0.3664	0.2587	0.0843	0.0843	0.1217
C2	Recurring operation, maintenance and repair	0.1935	0.1890	0.1981	0.2030	0.2011	0.2003	0.2852	0.2852	0.2354	0.0933	0.0933	0.1269
C3	Ability to increase returns	0.1646	0.1604	0.1688	0.1610	0.1514	0.1700	0.2892	0.2892	0.2608	0.0794	0.0794	0.1047
C4	Automated risk prediction and response	0.0322	0.0188	0.0455	0.0166	0.0133	0.0234	0.1094	0.0506	0.1049	0.0045	0.0045	0.0125
C5	Reliability of retrofit option	0.1746	0.1552	0.1939	0.1743	0.1338	0.1967	0.2485	0.2157	0.2485	0.0771	0.0771	0.1451
C6	Compatibility with existing systems	0.0332	0.0380	0.0284	0.0281	0.0256	0.0267	0.1388	0.1388	0.0501	0.0052	0.0052	0.0136
C7	Requirement of competent FM staff	0.0642	0.0778	0.0505	0.0376	0.0670	0.0387	0.2099	0.2099	0.1154	0.0148	0.0148	0.0234
C8	Ease of implementing retrofitting project	0.0147	0.0213	0.0081	0.0066	0.0082	0.0042	0.1249	0.1249	0.0248	0.0008	0.0008	0.0014
C9	Indoor environmental quality	0.0181	0.0095	0.0267	0.0110	0.0062	0.0239	0.0876	0.0287	0.0876	0.0023	0.0023	0.0076
C10	User-friendliness	0.0196	0.0125	0.0266	0.0152	0.0116	0.0226	0.0864	0.0286	0.0864	0.0025	0.0025	0.0080
C11	Improved energy efficiency	0.0266	0.0265	0.0267	0.0198	0.0168	0.0198	0.0627	0.0605	0.0627	0.0049	0.0049	0.0081
C12	Data protection capabilities	0.0351	0.0387	0.0314	0.0257	0.0218	0.0305	0.0925	0.0925	0.0656	0.0024	0.0024	0.0110
C13	Improved access control and surveillance	0.0368	0.0496	0.0240	0.0307	0.0340	0.0239	0.1177	0.0717	0.0633	0.0041	0.0111	0.0074

5.4.5.1 Importance weights of criteria - Hong Kong

Final importance weights of criteria for Hong Kong in Table 5-8 are graphically represented in Figure 5-7 along with the criteria weights of sub-groups of interviewees: contractor, consultant and client's representative.

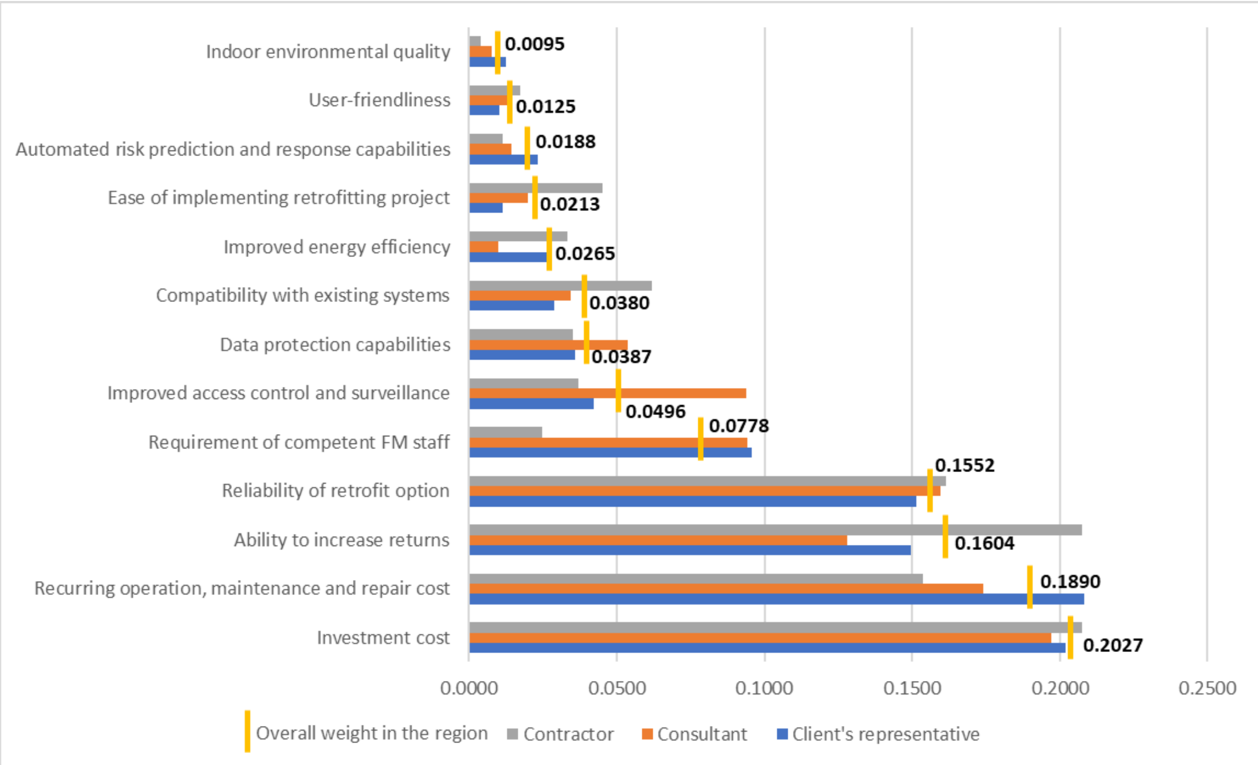

Figure 5-7: Importance weights of criteria - Hong Kong

'Investment cost' was assigned the highest weight, while the 'indoor environmental quality' was assigned the least. Notably, 'investment cost', 'recurring operation and maintenance cost', 'ability to increase returns' and 'reliability of retrofit option' earned higher importance weights. 'User-friendliness' and 'indoor environmental quality' had the lowest relative importance weights of all. In Hong Kong, criteria such as 'data protection capabilities' and 'compatibility with existing systems' had approximately the same importance weights.

In the sub-group analysis, the highest importance was found with 'ability to increase returns' and 'investment cost' by the 'contractor' group. The weights assigned to these criteria were almost identical. The importance level assigned to 'reliability of retrofit option' by the contractors was likewise quite high, but it is slightly lower than the highest level. 'Indoor environmental quality' received the lowest rating. The importance weights of the criteria ‘improved access control and surveillance,’ ‘data protection capabilities’ and ‘improved energy efficiency’ were nearly identical.

The consultants in Hong Kong rated ‘investment cost’ as the most important, while ‘indoor environmental quality’ was rated the least important. ‘Reliability of retrofit option’ and ‘recurring operation, maintenance and repair cost’ were thereafter prioritized over other criteria. It should also be noted that the consultants’ importance ratings for ‘user-friendliness,’ ‘increased energy efficiency’ and ‘automated risk prediction and response capabilities’ were nearly identical.

According to the responses of the interviewees of the client group, the criterion ‘recurring operation, maintenance and repair cost’ was the most important. ‘Investment cost’ was the criterion with the second highest importance, with a slightly lower rating. The criterion with the lowest importance is ‘user friendliness,’ while ‘indoor environmental quality’ and ‘ease of implementing retrofitting project’ had the second lowest ranking and approximately the same level of importance.

It is worth noting that ‘investment cost’ was rated highly by all interviewee groups. ‘Reliability of retrofit option’ was given equal importance by all the three groups, and they all rated ‘user-friendliness’ and ‘indoor environmental quality’ as relatively less important.

5.4.5.2 Importance weights of criteria – Sri Lanka

Similar to the analysis on the part for Hong Kong, the importance weights for Sri Lanka (Table 5-8) are graphically presented in Figure 5-8 along with the criteria weights corresponding to sub-groups of the interviewees.

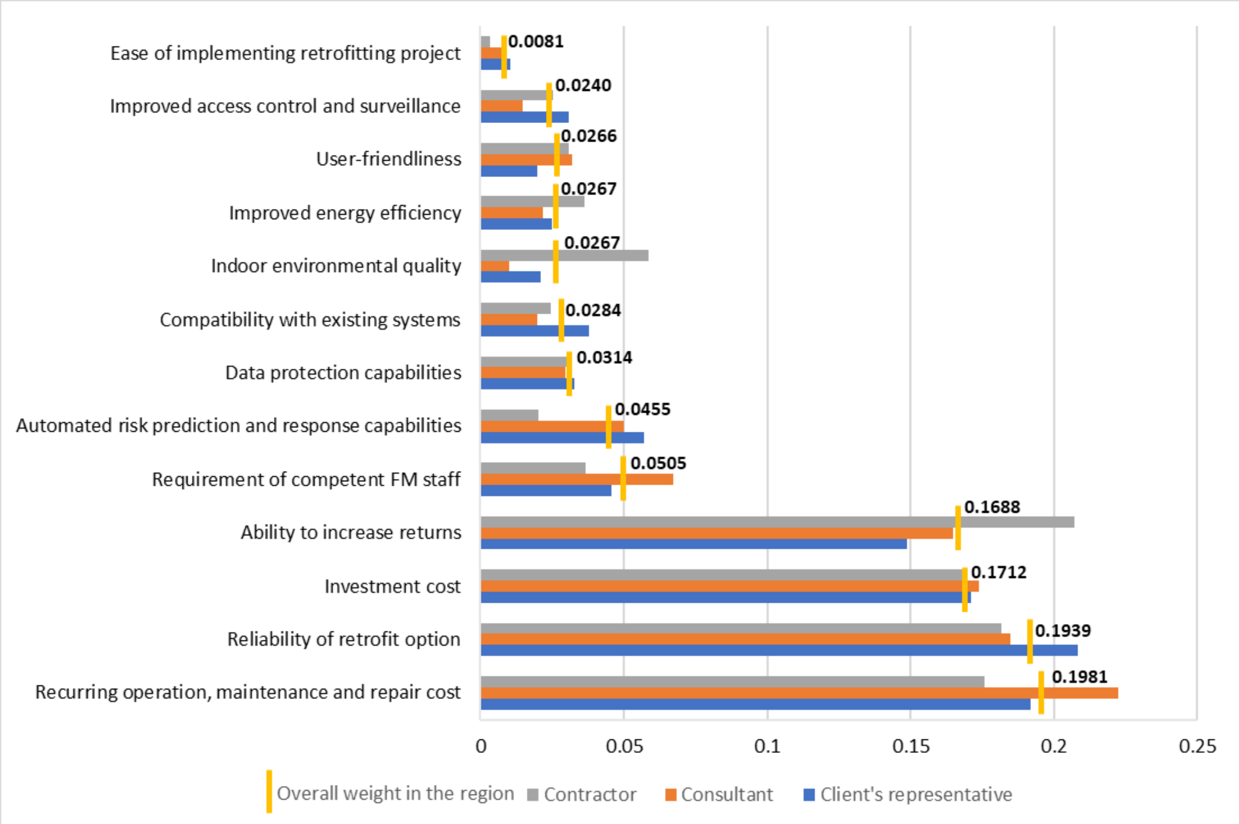

Figure 5-8: Final weights of criteria - Sri Lanka

Here, ‘recurring operation, maintenance and repair cost’ was rated with the highest importance. The second highest was ‘reliability of retrofit option’, which only has a 2% drop from the first. Despite being much lower than the first two, ‘ability to increase returns’ and ‘investment cost’ received significantly higher importance ratings than the other criteria. Their importance ratings were also nearly the same. The ‘ease of implementing retrofitting project’ received the lowest rating. Criteria such as ‘improved access control and surveillance,’ ‘increased energy efficiency,’ ‘user-friendliness’ and ‘indoor environmental quality’ were given nearly equal weighting.

The data were divided further based on the different groups of interviewees. According to the contractor group, the ‘ability to increase returns’ was the most important criterion. While not the most important, ‘reliability of retrofit option,’ ‘recurring operation, maintenance and repair cost,’ and ‘investment cost’ had much higher importance ratings than the rest. Contractors picked ‘ease of implementing retrofitting project’ as the factor with the lowest priority.

According to the consultants’ ratings, ‘recurring operation, maintenance and repair cost’ was particularly more important than the other criteria. ‘Reliability of retrofit option,’ ‘investment cost,’ and ‘ability to increase returns’ were ranked second, third and fourth. The consultants ranked ’indoor environmental quality’ and ‘ease of implementing retrofitting projects’ as the least important criteria, with their ratings being almost identical.

According to the client representatives, ‘reliability of retrofit option’ received the highest importance rating, followed by ‘ability to increase returns’, ‘recurring operation, maintenance and repair cost’, and ‘investment cost,’ which were much higher than the rest. The client’s representative assigned the lowest importance rating to ‘ease of implementing retrofitting project’.

It is worth noting that in Sri Lanka, the responses of all the three groups were quite consistent. ‘Reliability of retrofit option’, ‘ability to increase returns’, ‘recurring operation, maintenance and repair cost’, and ‘investment cost’ received the highest scores, while the score of ‘ease of implementing retrofitting project’ was the lowest.

5.4.5.3 Rank correlation of criteria weights between Hong Kong and Sri Lanka

To compare the criteria weights from the two regions, the Spearman Rank Correlation test was conducted. Table 5-9 shows the importance weights and the respective ranks of the criteria under the three categories of: Overall (combined), Hong Kong and Sri Lanka.

Table 5-9: Ranks of the criteria

	Criteria	**Overall (combined)**		**Hong Kong**		**Sri Lanka**	
		Importance weight	**Rank**	**Importance weight**	**Rank**	**Importance weight**	**Rank**
C1	Investment cost	0.1870	2	0.2027	1	0.1712	3
C2	Recurring operation, maintenance and repair	0.1935	1	0.1890	2	0.1981	1
C3	Ability to increase returns	0.1646	4	0.1604	3	0.1688	4
C4	Automated risk prediction and response	0.0322	9	0.0188	11	0.0455	6
C5	Reliability of retrofit option	0.1746	3	0.1552	4	0.1939	2
C6	Compatibility with existing systems	0.0332	8	0.0380	8	0.0284	8
C7	Requirement of competent FM staff	0.0642	5	0.0778	5	0.0505	5
C8	Ease of implementing retrofitting project	0.0147	13	0.0213	10	0.0081	12
C9	Indoor environmental quality	0.0181	12	0.0095	13	0.0267	9
C10	User-friendliness	0.0196	11	0.0125	12	0.0266	10
C11	Improved energy efficiency	0.0266	10	0.0265	9	0.0267	9
C12	Data protection capabilities	0.0351	7	0.0387	7	0.0314	7
C13	Improved access control and surveillance	0.0368	6	0.0496	6	0.0240	11

The calculated Spearman correlation coefficient is 0.743, indicating a strong positive correlation between the importance rankings of the criteria in Hong Kong and Sri Lanka. Furthermore, the p-value of 0.004, which is below the significance level (α) of 0.05, shows that the observed correlation is statistically significant. This significant positive correlation (r_s = 0.743, p = 0.004) implies that there is a certain level of agreement or similarity in the perceived importance of criteria between respondents from Hong Kong and Sri Lanka. However, it is worth noting that there are still certain differences in the perceived importance in the two regions, given that the value of r_s is not equal to 1.

The mean importance weights of the criteria rated by the experts in the two regions are shown graphically in Figure 5-9.

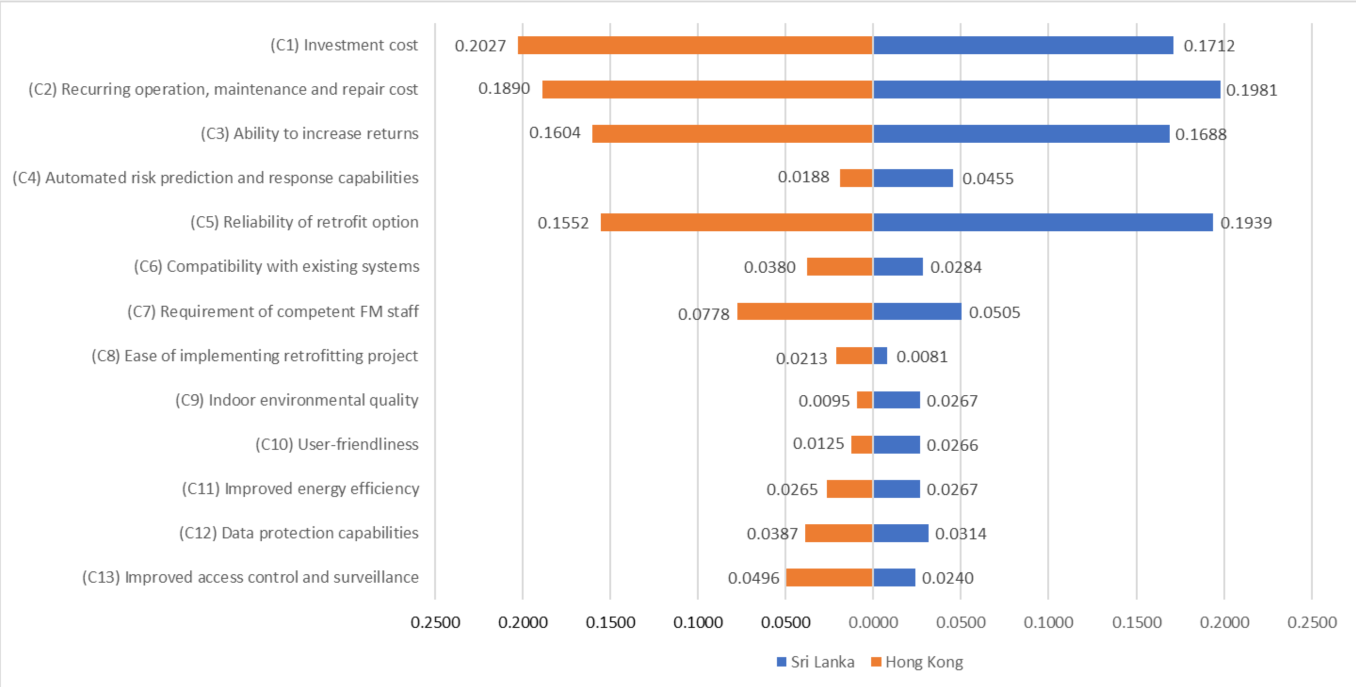

Figure 5-9: Comparison of criteria weights between Hong Kong and Sri Lanka

Figure 5-9 shows that criteria such as 'investment cost', 'recurring operation, maintenance and repair cost,' 'ability to increase returns,' and 'reliability of retrofit option' were substantially more important than the others in both regions. In comparison to the top five criteria, 'requirement of competent FM staff' was considered somewhat crucial; the values attributed to the remaining criteria were relatively less.

5.4.5.4 Priorities of SR Criteria from the Perspectives of Hong Kong and Sri Lanka

The detailed analysis of the importance weights of the identified SR decision-making criteria in both Hong Kong and Sri Lanka uncovers intriguing regional variations that significantly impact stakeholders' strategic concerns. The comprehensive insights gained from these specific regional circumstances, together with the comparative research, contribute to a more comprehensive knowledge of the elements impacting decision-making processes in the context of SR.

The priority given to 'investment cost' in Hong Kong's developed society emphasizes the economic focus that characterizes decision-making. The larger weight attributed to this criterion compared to 'recurring operation, maintenance and repair cost' in Sri Lanka, demonstrates a preference for upfront financial considerations. This corresponds to the economic robustness and financial capacities typical of developed regions, where decisions are made with immediate financial effects in mind (Alam et al., 2019). A well-planned and cost-effective investment in SR is expected to bring in long-term financial returns that align with economic sustainability goals (Construction Industry Council, 2018). It could also be motivated by the desire to invest in cutting-edge technologies that will result in long-term operational efficiency and economic rewards (Al Dakheel et al., 2020). Sri Lanka, on the other hand, prioritizes 'recurring operation, maintenance and repair costs', indicating a high emphasis on the long-term operational sustainability of SR projects in Sri Lanka. This is consistent with the common pragmatic approach to managing ongoing costs in developing regions (Sarkar and Singh, 2010). 'Reliability of retrofit option' securing the second-highest importance underscores the crucial function of technical dependability. In Sri Lanka, stakeholders prioritize solutions that assure the continuing and reliable operation of retrofitted systems.

The lower priority weights assigned to 'user-friendliness' and 'indoor environmental quality' show that in the Hong Kong context, user-centric and environmental issues may not be as prominent in decision-making. This could point to a stronger emphasis on technological and economic concerns. In Sri Lanka, the lower priority given to 'ease of implementing retrofitting project' might indicate that retrofitting projects are generally easy to conduct and thus taken for granted, leading to less emphasis on this criterion. Literature also highlights barriers such as 'lack of proper coordination' and 'lack of commitment and engagement to retrofitting projects' in Sri Lanka (Fasna and Gunatilake, 2020).

In Hong Kong, the match in importance weights for ‘data protection capabilities’ and ‘compatibility with existing systems’ indicates a balanced approach to technological integration. This balance is critical for ensuring that retrofitting solutions are compatible with existing systems while also satisfying the data security imperative (Sarkar and Singh, 2010). Criteria such as ‘improved access control and surveillance,’ ‘improved energy efficiency,’ ‘user-friendliness,’ and ‘indoor environmental quality’ having nearly identical priority ratings in Sri Lanka suggest a holistic approach to technological features (Fasna and Gunatilake, 2020). Stakeholders recognize the importance of these criteria in tandem, emphasizing a comprehensive view of SR.

Despite regional differences, both Hong Kong and Sri Lanka agree on the importance of ‘investment cost,’ ‘recurring operation, maintenance and repair cost,’ ‘ability to increase returns,’ and ‘reliability of retrofit option.’ This shared emphasis suggests universal recognition of key criteria shaping decision-making in SR, transcending regional boundaries. Stakeholders understand the importance of financial sustainability and returns on investment (Yang and Peng, 2001, Si et al., 2016, Periyannan et al., 2023). The comparative analysis reveals significant disparities in the prioritizing of individual criteria, highlighting the importance of tailored approaches (Sarkar and Singh, 2010). Criteria such as ‘automated risk prediction and response capabilities,’ ‘improved access control and surveillance,’ ‘ease of implementing retrofitting project’ and ‘indoor environmental quality’ exhibit varying degrees of importance in the two regions, necessitating nuanced decision-making strategies. The findings highlight the significance of user-centric considerations in Hong Kong, where ‘ease of conducting retrofitting project’ is ranked as a top-10 priority. The emphasis on ‘indoor environmental quality’ as a key factor in Sri Lanka corresponds with a focus on user experience. These variances highlight the importance of developing region-specific technology adoption strategies that balance economic concerns with user-centric priorities (Owusu-Manu et al., 2022, Si et al., 2016, Napoli et al., 2020).

5.4.5.5 Insights from Stakeholder Perspectives

Despite their different positions, all the three interviewee groups in Hong Kong, contractors, consultants, and client representatives, underline the importance of ‘investment cost.’ This agreement emphasizes the widespread acceptance of economic considerations in decision-making. The fact that all the groups place equal emphasis on ‘reliability of retrofit option’ implies a shared understanding of the crucial role that technical dependability plays in the success of retrofitting programs. ‘User-friendliness’ and ‘indoor environmental quality’ were rated substantially lower by all three groups suggests a potential gap in prioritizing issues that directly affect end-users and indoor comfort. These findings show a convergence on economic considerations and technical reliability, while also exposing differences in the priority attributed to user-centric and environmental issues among different stakeholder groups in Hong Kong’s SR decision-making landscape. This echoes the findings of Gallo et al. (2022) that importance assigned to certain criteria in a decision-making context can vary based on the perspective or background of the decision-makers. It also suggests that engineers, who typically handle the design of retrofitting interventions, may assign more weight to certain criteria, while other professionals, such as project managers or contractors, may prioritize other aspects. Addressing these differences may improve alignment of priorities and expectations among stakeholders, resulting in more complete and user-friendly retrofitting solutions.

Responses from the three interviewee groups in Sri Lanka reflect a consistent pattern. The alignment of priorities, particularly the acknowledgement of ‘investment cost, ‘reliability of retrofit option,’ ‘ability to increase returns’ and ‘recurring operation, maintenance and repair cost,’ demonstrates a shared understanding among different stakeholders. The findings highlight the need for collaborative decision-making, particularly in places where stakeholder groups concur in their prioritizing. This provides an opportunity for stakeholders to align tactics, pool resources and address the specified goals for successful SR projects as a group. The uniform ranking of ‘ease of implementing retrofitting project’ as the least important by all stakeholder groups reflects a widespread perception that ease of implementation is a low priority when compared to other criteria. While ‘ease of implementing retrofitting project’ is consistently of lower importance, stakeholders should still address challenges related to project implementation to ensure the seamless execution of retrofitting initiatives.

5.4.5.6 Implications of Findings

SR project stakeholders must realize the differences in priorities between developed and developing regions. A one-size-fits-all approach is unlikely to produce the best results. Instead, strategic considerations should be tailored to each region’s economic capacities, technological environments and user expectations (Sarkar and Singh, 2010). SR project stakeholders in Hong Kong should focus on cost-effectiveness, long-term sustainability and technological reliability. Awareness of the lower importance assigned to user-centric and environmental criteria should guide strategies for engaging end-users and addressing environmental concerns. The priorities highlighted in Sri Lanka point to a SR approach with a significant emphasis on operational sustainability, technological reliability and a comprehensive understanding of economic and technological issues. Addressing implementation problems and implementing a comprehensive technological integration strategy will help SR initiatives succeed in Sri Lanka. It is critical for effective decision-making in both developed and developing regions to balance the emphasis on economic aspects (e.g., 'investment cost') with operational sustainability (e.g., 'recurring operation, maintenance and repair cost'). While acknowledging regional differences, stakeholders should keep abreast with the global trends and developing technology. The field's ongoing progress needs a combination of specialized regional strategies and a larger understanding of advancements that could help both developed and developing contexts. The findings provide a glimpse of present priorities, but the field's dynamic nature demands continual re-evaluation to match strategies with evolving trends, technology and stakeholder expectations.

5.5 Chapter Summary

This chapter presented the results of stakeholder interviews conducted across Hong Kong and Sri Lanka, which provided both qualitative contextual insights and quantitative inputs for the criteria weighting process. The thematic analysis of the open-ended interview responses revealed that real-world SR decisions are shaped by a complex interplay of financial reasoning, stakeholder influence, technological compatibility, policy pressures and operational realities. Despite differences in regional contexts, the findings indicated that industry professionals across both regions inherently consider a broad set of criteria, reinforcing the need for a holistic and structured DSS.

The qualitative insights were then compared against the criteria established through earlier literature and industry consultation. The strong alignment between practice-driven considerations and the study's criteria framework confirms the contextual relevance of the SRDSS. The second half of the chapter detailed how the ANP method was employed to establish the relative importance of the finalized criteria using pairwise comparisons provided by the same experts. The results revealed differences in priority weightings between Hong Kong and Sri Lanka, underscoring the value of region-specific application of the SRDSS. Collectively, this chapter lays the groundwork for the application of the SRDSS in real-world case studies, which is discussed in the next chapter.

CHAPTER SIX

6 REAL-WORLD APPLICATION OF THE SRDSS[6]

6.1 Introduction to the Chapter

This chapter presents the application of the Smart Retrofitting Decision-Support System (SRDSS) through four real-world case studies drawn from Hong Kong and Sri Lanka. Building on the earlier development stages of the SRDSS, this chapter operationalizes the system by applying the developed decision-making criteria and weighting mechanisms to evaluate and rank SR alternatives in selected office buildings. It begins with a pilot study to validate and finalize scoring methods for each criterion, followed by the implementation of the full SRDSS framework, including Entropy weight calculations, ANP weight integration and TOPSIS-based ranking, for each case. The aim of this chapter is to demonstrate the SRDSS's practical utility, highlight its adaptability across diverse contexts, and extract insights regarding regional variations in SR decision-making priorities.

6.2 Methods

In line with the five-phase research design (Figure 3-1), a pilot study and case studies were conducted to apply the developed framework to real-world scenarios. The pilot study served as a bridge between the preceding and subsequent stages of the study by establishing a method for scoring retrofit alternatives under each criterion at the individual building level. Firstly, the methods for scoring each criterion were devised. Then, these methods were presented to two experts, one from Hong Kong and one from Sri Lanka, to obtain feedback on the practicality of the scoring methods. The two experts were experienced facility managers with over 10 years of experience in office building management. The finalized scoring methods are shown in Table 6-1.

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[6]The core research and findings in this chapter have been peer-reviewed before publication in:

Peiris, S., Lai, J., & Kumaraswamy, M.M. (2025). *Developing a Smart Retrofitting Decision-Making Model for Office Buildings: A Case Study* [Paper presentation]. CIB World Building Congress 2025, Purdue, United States of America.

Table 6-1: Key features of the criteria scoring methods

Category	Criterion	Description	Measuring Unit	Min	Max
Finance	C1 - Investment cost	This criterion assesses the total upfront cost of the retrofit alternative including equipment, installation and associated expenses	Any currency	AV	AV
	C2 - Operational cost	This criterion assesses the annual costs related to the operation, maintenance and repair of the retrofit alternative	Any currency	AV	AV
	C3 - Financial return	This criterion assesses the payback period of the retrofit alternative	Years	AV	AV
Technical	C4 - Automated risk prediction and response capabilities	This criterion assesses the level of accuracy of the retrofit alternative in (1) predicting system faults and hazards, (2) predicting physical climate risks and (3) related response capabilities	Scale	1	5
	C5 - Reliability of retrofit option	This criterion assesses the level to which the retrofit alternative is reliable to function with no errors	Scale	1	5
	C6 - Compatibility with existing systems	This criterion assesses the level to which the retrofit alternative is compatible with the existing building components	Scale	1	5
	C7 - Requirement of competent FM staff	This criterion assesses the level of competency required of the FM staff to manage the retrofit alternative	Scale	1	5
	C8 - Ease of implementing retrofitting project	This criterion assesses the ease of implementing the retrofit alternative in terms of (1) requirement for safety during retrofitting project and (2) disturbance and inconvenience to current occupants	Scale	1	5
User comfort and convenience	C9 - Indoor environmental quality	This criterion assesses the level to which the retrofit alternative contributes to indoor environmental quality improvement in terms of thermal comfort, acoustic comfort, indoor air quality and visual comfort	Scale	1	5
	C10 - User friendliness	This criterion assesses the level to which the users would find the retrofitted alternative user friendly and convenient to use	Scale	1	5
Environmental	C11 - Energy saving capabilities	This criterion assesses the annual saving in energy	kWh	AV	AV

		consumption of the building, as a result of the retrofit alternative			
Legal, safety and security	C12 - Data protection capabilities	This criterion assesses the level to which the alternative is capable of protecting sensitive data	Scale	1	5
	C13 - Access control and surveillance capabilities	This criterion assesses the level to which the retrofit alternative is effective in achieving access control	Scale	1	5

Note: AV denotes actual value of the respective criterion being measured.

Alternative scoring should be conducted by the facility manager responsible for retrofit decision-making at the building where the SRDSS is implemented. Scoring methods included both direct value inputs and subjective scoring on a Likert scale (1–5), depending on the nature of each criterion. Direct value inputs were used for quantitative criteria such as investment cost, operational cost, financial return and energy saving capabilities. They were input directly using the quantitative values submitted by the suppliers or calculated by the facility manager's team. Likert scale scoring was used for qualitative criteria which include automated risk prediction and response capabilities, reliability of retrofit option, compatibility with existing systems, requirement of competent FM staff, ease of implementing retrofitting project, indoor environmental quality, user friendliness, data protection capabilities and access control and surveillance capabilities. These qualitative criteria required assigning a subjective score based on the facility manager's perception of each retrofit alternative.

Following the pilot study, case studies were conducted to develop the rest of the SRDSS and test its applicability. Four office buildings were selected, comprising two from Hong Kong and two from Sri Lanka. This ensured a diverse representation of SR contexts in both developed and developing regions. The case studies involved discussions with the facility manager overseeing the SR project. General project data and detailed data on various retrofit alternatives from different suppliers were collected. Referring to a bespoke questionnaire, each retrofit alternative was scored by the facility manager. The decision matrix shown in Table 6-2 was constructed using these inputs, with columns representing criteria (as listed in Table 6-1) and rows representing retrofit alternatives. The retrofit alternatives are detailed in Tables 6-3 to 6-7.

Table 6-2: Decision matrix template

	C_1	C_2	C_3	C_4	C_5	------	C_j	------	C_m
V_1	$X_{1,1}$	$X_{1,2}$	$X_{1,3}$	$X_{1,4}$	$X_{1,5}$	------	$X_{1,j}$	------	$X_{1,m}$
V_2	$X_{2,1}$	$X_{2,2}$	$X_{2,3}$	$X_{2,4}$	$X_{2,5}$	------	$X_{2,j}$	------	$X_{2,m}$
⋮	⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋱	⋮
V_i	$X_{i,1}$	$X_{i,2}$	$X_{i,3}$	$X_{i,4}$	$X_{i,5}$	------	$X_{i,j}$	------	$X_{i,m}$
⋮	⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋱	⋮
V_n	$X_{n,1}$	$X_{n,2}$	$X_{n,3}$	$X_{n,4}$	$X_{n,5}$	------	$X_{n,j}$	------	$X_{n,m}$

Notes: V_i - i^th alternative considered in the decision (i = 1, 2, …, n); C_j - j^th criterion considered in the decision-making process (j = 1, 2, …, m); $X_{i,j}$ - Score of the i^th alternative under the j^th criterion; m - Total number of criteria; n - Total number of alternatives.

Once the decision-matrix was completed with the alternative scores, it serves as the foundation for the Entropy weighting process to ensure objective and context-sensitive weighting adjustments. The Entropy calculation involves three stages: normalizing the decision matrix to standardize criterion values using Eq. (6.1) and Eq. (6.2), calculating the Entropy value for each criterion using Eq. (6.3) and Eq. (6.4), and computing the Entropy weight factor using Eq. (6.5) and Eq. (6.6).

$$\sum_{i=1}^{n} x_{ij} \qquad \text{Eq. (6.1)}$$

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \qquad \text{Eq. (6.2)}$$

$$h = \frac{1}{\ln(n)} \qquad \text{Eq. (6.3)}$$

$$e_j = -h \sum_{i=1}^{n} r_{ij} \ln r_{ij} \qquad \text{Eq. (6.4)}$$

$$d_j = 1 - e_j \qquad \text{Eq. (6.5)}$$

$$We_j = \frac{1 - e_j}{\sum_{j=1}^{m} (1 - e_j)} \qquad \text{Eq. (6.6)}$$

Where,

$\boldsymbol{d_j}$ is The degree of divergence for the j^{th} criterion

$\boldsymbol{e_j}$ is The entropy value for the j^{th} criterion

$\boldsymbol{h}$ is The normalization factor for entropy calculation

$\boldsymbol{n}$ is number of alternatives

$\boldsymbol{r_{ij}}$ is The normalized value of x_{ij} after applying normalization

$\boldsymbol{We_j}$ is The entropy-based weight for the j^{th} criterion

$\boldsymbol{x_{ij}}$ is score of the i^{th} alternative for the j^{th} criterion in the decision matrix

Once the Entropy weights were calculated, the weights derived from the ANP method were merged with Entropy weights to incorporate both expert opinions and data-driven adjustments, ensuring a balanced weighting approach that includes both subjective and objective insights. As not all criteria are applicable to every retrofit project, based on the nature of the project, some criteria had to be excluded from the evaluation. Hence, before combining the ANP and Entropy weights, the ANP weights of the applicable criteria were normalised using Eq. (6.7). The combined weights were then obtained using Eq. (6.8).

$$w'_{pj} = \frac{w_{pj}}{\sum_{j=1}^{m'} w_{pj}} \qquad \text{Eq. (6.7)}$$

$$W_{bj} = \alpha W_{pj} + (1 - \alpha) W_{ej} \qquad \text{Eq. (6.8)}$$

Where,

$\boldsymbol{\alpha}$ is A parameter that determines the relative importance of the ANP weight in the combined weight calculation

$\boldsymbol{m'}$ is Total number of remaining criteria after excluding irrelevant criteria

$\boldsymbol{W_{bj}}$ is Combined weight for the j^{th} criterion, calculated as a weighted combination of ANP and entropy weights

$\boldsymbol{w_{pj}}$ is The weight of the j^{th} criterion obtained from the ANP method

$\boldsymbol{w'_{pj}}$ is Re-normalized weight of the j^{th} criterion

Afterwards, the TOPSIS method was used to rank retrofit alternatives. The process included: creating a weighted normalized decision matrix using combined ANP and Entropy weights to reflect each criterion's importance using Eq. (6.9), identifying the positive and negative ideal solutions for each criterion, representing the best and worst possible values using Eq. (6.10) and Eq. (6.11), calculating the Euclidean distances from each alternative to the ideal solutions using Eq. (6.12) and Eq. (6.13), and ranking the alternatives by determining the relative closeness to the positive ideal solution (PIS) based on their proximity to the negative ideal solution (NIS) using Eq. (6.14). The retrofit alternative with the highest τ_i value was ranked as the most suitable solution.

$$R_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} . W_{bj} \qquad \text{Eq. (6.9)}$$

$$L^{+} = \left((maxR_{ij} \mid j \in B), (minR_{ij} \mid j \in C)\right) = (R_j{}^{+} \mid j = 1, 2, \ldots, m) \qquad \text{Eq. (6.10)}$$

$$L^{-} = \left((minR_{ij} \mid j \in B), (maxR_{ij} \mid j \in C)\right) = (R_j{}^{-} \mid j = 1, 2, \ldots, m) \qquad \text{Eq. (6.11)}$$

$$d^{+} = \sqrt{\sum_{j=1}^{m} \left(R_{ij} - R_{ij}{}^{+}\right)^2} \qquad \text{Eq. (6.12)}$$

$$d^{-} = \sqrt{\sum_{j=1}^{m} \left(R_{ij} - R_{ij}{}^{-}\right)^2} \qquad \text{Eq. (6.13)}$$

$$\tau_i = \frac{d^{-}}{d^{+} + d^{-}} \qquad \text{Eq. (6.14)}$$

Where,

$\boldsymbol{B}$ is Set of benefit criteria

$\boldsymbol{C}$ is Set of cost criteria

$\boldsymbol{d^{+}}$ is The Euclidean distance of an alternative from the positive ideal solution

$\boldsymbol{d^{-}}$ is The Euclidean distance of an alternative from the negative ideal solution

$\boldsymbol{L^{+}}$ is The PIS representing the best values for benefit and cost criteria

$\boldsymbol{L^{-}}$ is The NIS representing the worst values for benefit and cost criteria

$\boldsymbol{R_{ij}}$ is The combined weighted normalized decision matrix

R_j^+ is The positive ideal value for criterion

R_j^- is The negative ideal value for criterion

τ_i is The final performance score of alternative i, calculated as the relative closeness to the ideal solution

Figure 6-1 summarises the process flowchart of the SRDSS. The process begins with inputting retrofit data from buildings, which is basically the alternative scores. Next, the process involves Entropy weight calculation for criteria, combined with ANP weights of criteria, followed by combined weight calculation for criteria and TOPSIS calculation for retrofit alternative prioritization. Finally, the output is the identification of the best SR alternative, leading to the completion of the selection process. While the criteria, criteria scoring methods and the ANP weights remain the same in every application as preset items in the SRDSS, the alternative scores, Entropy weights, combined weights and the TOPSIS results are unique to each project.

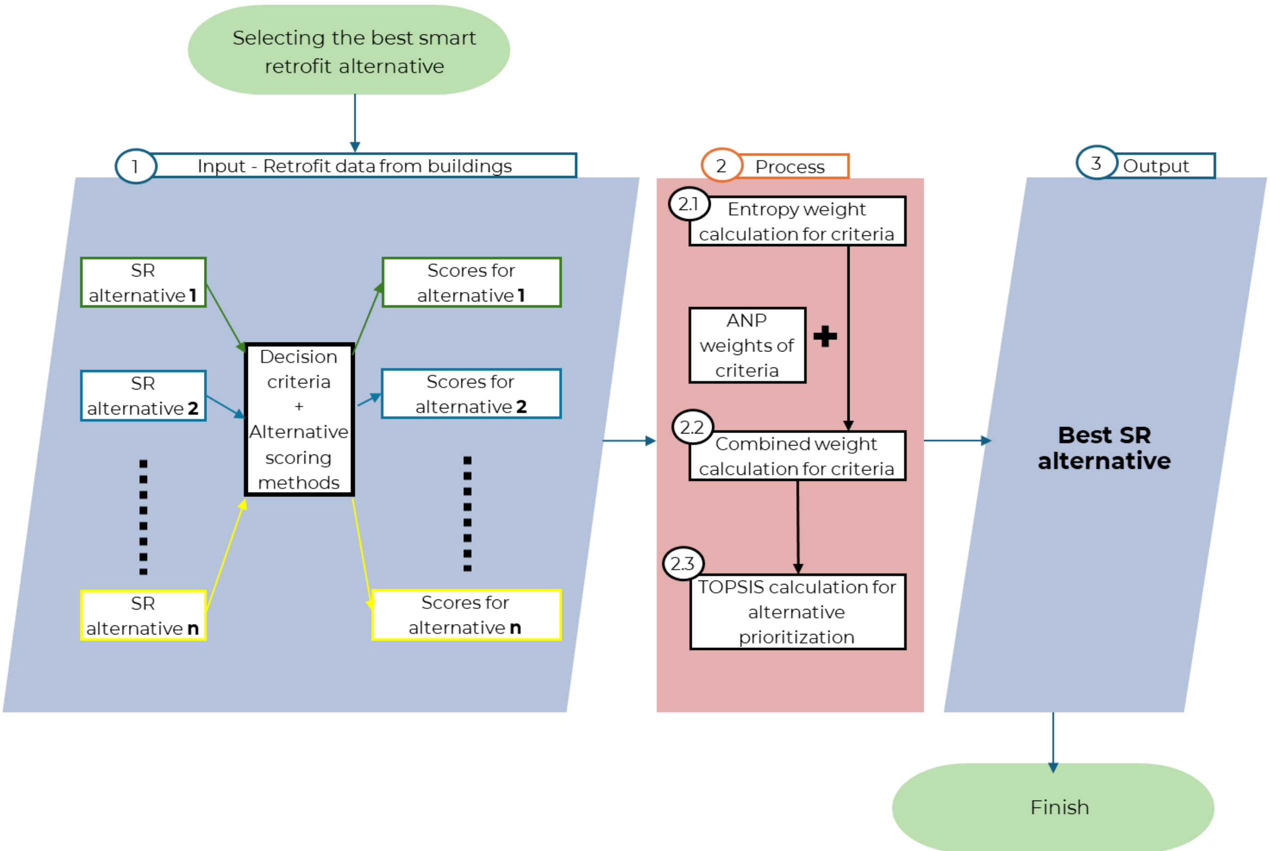


Figure 6-1: Process flowchart of the SRDSS

6.3 Findings and Discussion

The selection of case study buildings was based on building type and recency of the SR project completion. Two office buildings from Sri Lanka and Hong Kong each were selected where a

SR project was conducted in the last five years. Table 6-3 presents an overview of the case study buildings and the respective SR projects considered in each case.

Table 6-3: Information about the case study buildings

Case study no.	**Region**	**Age of building (years)**	**No. of storeys**	**Total gross floor area (m^2)**	**Average number of building users per day**	**SR project considered**	**Retrofit project start and end dates**
1	Hong Kong	32	40	56,894	1,042	IoT-based lighting system in car park	December 2023 – April 2024
2	Hong Kong	24	12	7,942	700	Chiller plant control automation	March – May 2023
3	Sri Lanka	27	39	117,100	6,000	Smart car park management system	June – Dec 2021
4	Sri Lanka	39	30	600,000	1,800	Smart pressure/temperature independent control valve with actuator	October 2020 - September 2022

The selected SR projects from each case study building differed in nature, the mandated specifications and the number of tenderers who submitted the bids. The retrofit alternatives for implementing the IoT-based LED car park lighting system in the first case were proposed by three tenderers, each meeting a set of technical and functional specifications required by the building's representative. The specifications mandated that the lighting retrofit system include IoT-enabled LED lights integrated with a smart platform for centralized control. The platform needed to be connected to the cloud while offering real-time monitoring of energy data, system operating parameters and recommendations for performance optimization. Additionally, the system was to deliver fault and alert notifications, offer predictive maintenance capabilities, and incorporate a user-friendly dashboard for comprehensive system oversight. Table 6-4 summarises the key differences and similarities between the alternatives in case study 1.

Table 6-4: Key technical features and value propositions of the alternatives – case study 1

Case study 1 - IoT-based lighting system in car park			
Feature	Alternative 1	Alternative 2	Alternative 3
Lighting and dimming control	T5/T8 LED, time-based and occupancy-based scheduling with adjustable dimming levels	T5/T8 LED, time-based scheduling with adjustable dimming levels	T5/T8 LED, real-time dimming adjustments based on vehicle movement and occupancy levels, zone customization

Sensors	Passive Infrared (PIR) motion sensors with and daylight sensors	PIR motion sensors	Light Detection and Ranging (LiDAR) based occupancy sensors and daylight sensors
Communication protocol	Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 operating on 2.4 GHz Industrial, Scientific and Medical radio (ISM) band	IEEE 802.15.4 operating on 2.4 GHz ISM Band	IEEE 802.15.4 operating on 2.4 GHz ISM Band
Security features	Advanced Encryption Standard (AES) 128-bit data encryption with private-server/cloud setup	Transport Layer Security (TLS) 1.3 data encryption and biometric authentication for platform access	AES 256-bit data encryption with multi-layered firewall protection for cloud server access
Monitoring features	Lighting status (on/off/dim), emergency lighting status, failure alert, energy consumption, abnormal power consumption alert	Lighting status (on/off/dim), failure alert, energy consumption	Lighting status (on/off/dim), usage trends, failure alert, energy consumption

Tenderers bidding for the chiller plant control automation project in the second case was required to propose a system with advanced monitoring, control automation and a smart platform. Altogether two tenderers submitted bids, and the specifications mandated their proposals to have ultrasonic flow meters, sensors, real-time monitoring with a software system to facilitate third-party data collection and analysis. The smart platform had to provide insights into energy usage, system performance and fault management with mobile app notifications. Additionally, all data points from the existing BMS were needed to be connected to the cloud. Table 6-5 summarises the key differences and similarities between the alternatives in case study 2.

Table 6-5: Key technical features and value propositions of the alternatives – case study 2

Case study 2 - Chiller plant control automation		
	Alternative 1	Alternative 2
Core technology	Powered by Metasys, with advanced algorithms and programs	AI-based system using artificial neural networks and a proprietary data-driven AI algorithm
Predicted energy savings	5-15% energy savings excluding benefits from mechanical upgrades	3-5% energy savings compared to traditional rule-based controllers
Key features	**Efficiency-based sequencing:** Determines the most efficient combination of chillers based on Coefficient of Performance (COP) **Adaptive tuning loops:** Uses proportional/integral/derivative algorithms for optimal performance	**AI-driven optimization:** uses historical data to predict cooling demand based on real-time building electrical load, operating data, and forecasted weather conditions **Real-time control:** continuously adjusts chiller plant operations for optimal performance

	Pump and tower control: Utilizes algorithms such as Braun-Diderrich for optimizing chiller and tower fan energy consumption **Patented Pattern Recognition Adaptive Control (PRAC+) adaptive tuning:** Reduces energy use and improves comfort by stabilizing control loops	**Adopts an Analytics-as-a-Service (AaaS)** model, where AI resources are supplied by a centralized Regional Digital Control Centre (RDCC). This reduces implementation time and costs while allowing flexible scaling of computing resources
Design flexibility	Supports various system configurations (e.g., variable primary flow, primary/secondary systems)	Adaptable to various chiller plant configurations

The smart car park management project in the third case was for a 9-storey car park. The system needed to include a barrier gate and a revenue collection system, utilizing vehicle number plate recognition integrated with a slot management system. It required different features such as real-time monitoring, customer management, various payment methods, anti-pass-back activation and special scenario activations. The barrier gates were to open and close in less than a second, using number plate recognition technology. Bids for this project was submitted by three suppliers. Table 6-6 summarises the key differences and similarities between the alternatives in case study 3.

Table 6-6: Key technical features and value propositions of the alternatives – case study 3

Case study 3 - Smart car park management system			
	Alternative 1	Alternative 2	Alternative 3
Barrier gate (country of manufacture)	Chinese-manufactured	Chinese-manufactured	Australian-manufactured
Software	Smart parking automation and access control	AI-driven surveillance and vehicle recognition	Smart parking automation specialised for commercial properties
Camera	Surveillance and Automatic Number Plate Recognition (ANPR)	Surveillance and ANPR	Surveillance and ANPR
Payment Kiosk	Self-service automated payment kiosk	Self-service automated payment kiosk	Manned or semi-automated station with staff assistance
Slot management	Ultrasonic or infrared sensors with indicator lights	AI-enabled camera-based slot monitoring	Ultrasonic or infrared sensors with indicator lights
Warranty	2 years	2 years	2 years

The smart valve retrofit project in the fourth case involved the replacement of modulating and flow control valves, actuators, controllers, thermostats, and control power transformers in the Air Handling Units (AHUs) of the building’s HVAC system. The existing components were replaced with new, intelligent pressure/temperature-independent control valves and actuators. Bids for this project were also submitted by three suppliers. The proposed alternatives for the retrofit projects in each case differed in technical configurations and offered distinct value propositions. Table 6-7 summarises the key differences and similarities between the alternatives in case study 4.

Table 6-7: Key technical features and value propositions of the alternatives – case study 4

Case study 4 - Smart pressure/temperature independent control valve with actuator			
	Alternative 1	Alternative 2	Alternative 3
Pressure/temperature independent control	Ensures accurate flow control under varying system conditions	Ensures accurate flow control despite pressure fluctuations	Ensures accurate flow control under varying pressure and temperature
Energy measurement	Measures flow and energy consumption using ultrasonic sensors	Measures and optimizes energy usage with integrated flow and temperature sensors	Equipped with ultrasonic flow sensors and temperature sensors to measure coil energy
Communication protocol	Supports Building Automation and Control network (BACnet) MS/TP and BACnet Internet Protocol (IP)	Compatible with BACnet MS/TP and BACnet IP	Supports BACnet MS/TP and BACnet IP
Actuator	Rotary electric actuator with IP54 protection, 24V AC/DC operation, and 0-10V DC/4-20mA feedback	Rotary electric actuator with IP54 protection, 24V AC/DC operation, and 0-10V DC/4-20mA feedback	Rotary electric actuator with IP54 protection, 24V AC/DC operation, and 0-10V DC/4-20mA feedback
Data storage	Stores cumulative flow and energy data for up to 6 months	Stores cumulative flow and energy data for up to 6 months	Stores cumulative flow and energy data for up to 6 months
Web interface	Allows easy configuration and monitoring via a web-based interface	Allows easy setup and monitoring via integrated web server	Allows web-based configuration tools for easy parameterization

The SRDSS applied to the case studies was in the form of a MS Excel file. It was structured as a step-by-step calculation process with clearly labelled sections for each stage. The first section serves as the foundation of the SRDSS, where users provide all necessary data for the evaluation process. It comprises a table with each column indicating the 13 SR decision-making criteria and the rows representing the alternatives and their scores under each criterion. This table was used by the facility manager at the case building to input relevant data about their retrofit project into the SRDSS. Table 6-8 shows the case-specific alternative scores entered by the facility managers.

Table 6-8: Case-specific alternative scores

	Case 1			Case 2		Case 3			Case 4		
	A1	A2	A3	A1	A2	A1	A2	A3	A1	A2	A3
C1 - Investment cost (in million HK$/LKR)	0.607	0.669	0.692	0.420	0.421	12	13	49	30.2	41.4	62.9
C2 - Operational cost (in million HK$/LKR)	0.453	0.533	0.453	0.060	0.25	0.1	0.15	0.135	1.3	0.3	2
C3 - Financial return (Years)	4.43	5.18	5.05	1.84	3.84	-	-	-	5	7	9
C4 - Automated risk prediction and response	4	3	3	4	3	4	4	4	4	4	4
C5 - Reliability of retrofit option	4	3	3	4	3	5	5	4	4	4	4
C6 - Compatibility with existing systems	3	3	3	3	3	4	5	5	3	3	3
C7 - Requirement of competent FM staff	4	4	4	4	4	3	4	4	3	3	3
C8 - Ease of implementing retrofitting project	3	3	3	4	3	5	4	3	2	2	2
C9 - Indoor environmental quality	3	3	3	4	4	4	4	4	4	4	4
C10 - User-friendliness	4	3	3	4	3	5	5	4	5	5	5
C11 - Energy saving capabilities (in million kWh/year)	0.079	0.074	0.079	0.24	0.3	-	-	-	0.273	0.218	0.27
C12 - Data protection capabilities	3	3	3	-	-	5	5	5	4	4	4
C13 - Access control and surveillance capabilities	-	-	-	-	-	5	5	5	-	-	-

Note: All monetary values are presented in millions. Values for Case 1 and Case 2 are in Hong Kong Dollars (HK$), while values for Case 3 and Case 4 are in Sri Lankan Rupees (LKR); "-"denotes that the respective criterion was not applicable for that specific alternative in the corresponding case

By entering project data into the SRDSS, the facility manager compared the alternatives based on a mix of direct value criteria, such as investment and operational costs, and Likert-scale criteria, such as ease of implementation and user-friendliness. To assess the cost-effectiveness of each alternative, annual energy savings were converted to a monetary value by multiplying the energy savings by the electricity cost per unit. This figure was then used to calculate the payback period by dividing the investment cost by the annual energy savings, as shown under the 'financial return' criterion. Because this evaluation was conducted after the retrofit implementation, these values were readily available at the time of the case study. While the SRDSS uses 13 criteria for evaluation, not all 13 criteria are applicable to all SR measures. The criterion 'access control and surveillance capabilities' was not applicable for cases 1, 2 and 4. 'Data protection capabilities' was not applicable for case 2. As a smart car park management system does not result in any energy savings in the building, the criteria 'energy saving capabilities' and 'financial return' were not applicable for case 3. Therefore, cases 1, 2, 3 and 4 considered only 12, 11, 11 and 12 criteria respectively.

Subsequent steps in the MS Excel-based SRDSS used Eq. (6.1) to (6.14) to progressively transform the initial data. The ANP weights brought into the calculation in Eq. (6.7) depends on the region of the case study building considered. Table 6-9 shows the region-specific ANP weights assigned to each criterion based on the expert interview exercise explained in Chapter 5.

Table 6-9: Region-specific ANP weights

Criteria	Hong Kong		Sri Lanka	
	Importance weight	Rank	Importance weight	Rank
C1 - Investment cost	0.2027	1	0.1712	3
C2 - Operational cost	0.1890	2	0.1981	1
C3 - Financial return	0.1604	3	0.1688	4
C4 - Automated risk prediction and response	0.0188	11	0.0455	6
C5 - Reliability of retrofit option	0.1552	4	0.1939	2
C6 - Compatibility with existing systems	0.0380	8	0.0284	8
C7 - Requirement of competent FM staff	0.0778	5	0.0505	5
C8 - Ease of implementing retrofitting project	0.0213	10	0.0081	12
C9 - Indoor environmental quality	0.0095	13	0.0267	9
C10 - User-friendliness	0.0125	12	0.0266	10
C11 - Energy saving capabilities	0.0265	9	0.0267	9
C12 - Data protection capabilities	0.0387	7	0.0314	7
C13 - Access control and surveillance capabilities	0.0496	6	0.0240	11

Since the Entropy weight is case-specific, the combined weight is also case-specific. The Entropy weights and the combined weights for each case study is shown in Table 6-10.

Table 6-10: Case-specific Entropy weights and combined weight

Criteria	Entropy weight (We_j)				Combined weight (Wb_j)			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
C1 - Investment cost	0	0.08496	0.80703	0.16396	0.10663	0.15363	0.50386	0.19313
C2 - Operational cost	0.08683	0.12729	0.04927	0.71670	0.14283	0.16727	0.11906	0.46198
C3 - Financial return	0.06535	0.09823	-	0.10030	0.11707	0.13709	0.08146	0.13812

C4 - Automated risk prediction and response	0.27884	0.08710	0	0	0.14932	0.05387	0.00941	0.01032
C5 - Reliability of retrofit option	0.27884	0.08710	0.01878	0	0.22108	0.12868	0.08698	0.08513
C6 - Compatibility with existing systems	0	0.08496	0	0	0.01999	0.06332	0.01900	0.02084
C7 - Requirement of competent FM staff	0	0.08496	0.03066	0	0.04091	0.08512	0.05417	0.04264
C8 - Ease of implementing retrofitting project	0	0.08710	0.07548	0	0.01122	0.05524	0.01562	0.01169
C9 - Indoor environmental quality	0	0.08496	0	0	0.00502	0.04771	0.00477	0.00524
C10 - User-friendliness	0.27884	0.08710	0.01878	0	0.14600	0.05041	0.01562	0.00686
C11 - Energy saving capabilities	0.01132	0.08625	-	0.01904	0.01959	0.05765	0.01324	0.02404
C12 - Data protection capabilities	0	-	0	-	0.02034	-	0.01933	-
C13 - Access control and surveillance capabilities	-	-	0	-	-	-	0.02478	-

Note: "-" denotes that the respective criterion was not applicable for that specific alternative in the corresponding case

The Entropy weights for certain criteria in cases 1, 3 and 4 are 0. This occurs when all alternatives within a given case receive the same score for a specific criterion. Since entropy measures the degree of dispersion or uncertainty in the data (Jahan et al., 2016), a criterion where all alternatives have the same score provides no discriminatory power in the decision-making process. Hence, that criterion does not contribute to differentiating the alternatives thereby having no Entropy weight in that scenario.

In the final step of the MS Excel-based SRDSS, distance calculations determined how close each alternative is to the ideal and how far from the worst-case scenario, allowing the calculation of the relative closeness of each alternative to the PIS, leading to the final ranking. Screen captures of the final stage of the SRDSS showing the final rankings from each case are shown in Figure 6-2.

Alternatives	d^+	d^-	$d^+ + d^-$	τ_i	Rank
V1	0.00000	0.03200	0.03200	1.00000	1
V2	0.03200	0.00000	0.03200	0.00000	3
V3	0.03081	0.00800	0.03881	0.20611	2

Figure 6-2(a): Final ranking of case 1

Alternatives	d^+	d^-	$d^+ + d^-$	τ_i	Rank
V1	0.00641	0.11560	0.12200	0.94750	1
V2	0.11560	0.00641	0.12200	0.05250	2

Figure 6-2(b): Final ranking of case 2

Alternatives	d^+	d^-	T_i	Rank
V1	0.00000	0.26502	1.00000	1
V2	0.02089	0.25709	0.92485	2
V3	0.26470	0.00549	0.02031	3

Figure 6-2(c): Final ranking of case 3

Alternatives	d^+	d^-	$d^+ + d^-$	T_i	Rank
V1	0.12833	0.10473	0.23306	0.44938	2
V2	0.02085	0.22072	0.24157	0.91370	1
V3	0.22470	0.00172	0.22642	0.00758	3

Figure 6-2(d): Final ranking of case 4

Figure 6-2: Final rankings of the retrofit alternatives from each case

The application of the SRDSS across four case studies provided key insights into its effectiveness in guiding SR decisions. The ranks of alternatives varied across the cases, underscoring the fact that optimal SR solutions are highly context dependent. The case studies demonstrated that different SR measures and project types require different decision-making priorities, reinforcing the necessity of a structured MCDM approach to balance competing factors.

The results confirmed that cost-related factors (investment and operational costs) remain dominant concerns in decision-making. In Hong Kong, within both case 1 and case 2, the alternatives with the lowest investment and operational costs were strongly preferred. This suggests that in developed regions, cost-effectiveness is a crucial factor, possibly due to higher labour and operational costs (Alam et al., 2019). In the Sri Lankan context, the lowest-cost option in terms of investment and operational cost was preferred in case 3. In case 4, a higher initial cost option was chosen due to its superior benefits such as relatively very low operational cost and shorter payback period. This indicates that in developing regions, there might be more flexibility to prioritize long-term benefits over initial costs (Sarkar and Singh, 2010, Peiris et al., 2024). In technologically advanced settings such as Hong Kong, where technical performance drive decision-making, automation capabilities and reliability played a dominant role. In Sri Lanka, however, practicality of the system was critical, as large-scale automation adoption is still limited in Sri Lanka compared to Hong Kong. This might reflect the need for solutions that are advanced yet adaptable to the existing infrastructure in developing regions. This aligns with previous studies such as Si and Marjanovic-Halburd (2018) and Mangan (2023) that emphasize how regional economic and technological differences shape SR priorities.

In terms of operational considerations, the low requirement for skilled FM staff was a significant factor in both Sri Lankan cases. In contrast, in Hong Kong, this was not a major deciding factor, as all alternatives in both Hong Kong cases necessitated a higher level of FM staff expertise. Since Hong Kong has a well-developed FM industry with formal training and certifications (Gilleard, 2024), the need for highly skilled staff is generally factored into retrofit decisions. In contrast, Sri Lanka's FM sector relies more on manual interventions, with limited availability of skilled professionals (Perera et al., 2016), making retrofit solutions requiring minimal expertise more attractive. These differences highlight the importance of tailoring SR approaches to the specific context of each region, considering not just the technological aspects but also the economic, infrastructural, and operational realities of developed and developing regions.

6.4 Chapter Summary

This chapter demonstrated the end-to-end application of the SRDSS on four office building case studies, two from Hong Kong and two from Sri Lanka, featuring different types of SR projects. A pilot study was conducted to validate the system's scoring methodology and the SRDSS was applied across the cases, generating case-specific decision matrices, Entropy weights, and integrated ANP-Entropy weights. The final rankings produced by the TOPSIS method revealed that SR decision-making is highly context-dependent, with cost considerations being dominant in both regions, but with emphasis on technical sophistication and staff competency differing across regions. The chapter underscored the flexibility and relevance of the SRDSS in accommodating region-specific constraints and preferences, thus reinforcing its potential as a decision-making aid for facility managers in both developed and developing regions.

CHAPTER SEVEN

7 VALIDATION OF THE SRDSS

7.1 Introduction to the Chapter

This chapter presents the validation and refinement of the Smart Retrofitting Decision-Support System (SRDSS) developed in this study. Following the application of the system across multiple case scenarios, an expert validation exercise was conducted to assess the system's credibility, practical relevance and adaptability in real-world contexts. The validation process involved presenting the system to experienced practitioners in the FM and built environment sectors, gathering their feedback and identifying potential enhancements. In addition to reporting the validation of the system's logic, structure and usability, this chapter also outlines the improvements made to the SRDSS, particularly its interface and calculation flow, based on the insights obtained from the practitioners. The effectiveness of these enhancements is also demonstrated in this chapter, through the application of the improved SRDSS to real-world cases that were evaluated using the originally developed SRDSS as explained in the preceding Chapter 6.

7.2 Data Collection

To ensure the reliability, accuracy and practical applicability of the developed SRDSS, a structured validation exercise was conducted. This validation process was conducted through interviews with industry experts in Australia. The purpose of the validation exercise was to ensure that the SRDSS is credible and adaptable beyond Hong Kong and Sri Lanka. Insights from the experts from a country such as Australia, which has a strong emphasis on sustainability, rigorous energy efficiency standards and widespread SB adoption (Bell, 2005), help assess whether the SRDSS aligns with international best practices across different economic, regulatory and technological landscapes, making it more universally applicable. The adoption of expert interviews as a validation approach is consistent with previous studies, where similar methods were used to evaluate DSSs and frameworks in the built environment (Vergara et al., 2025, Madureira et al., 2021, Sadeghi and Goerlandt, 2023). The interviews were conducted with ten experts selected based on their experience in handling retrofit projects in office buildings (Table 7-1).

Table 7-1: Characteristics of the validation experts

Interviewee	Position (organisation type)	Work experience (years)
Expert A	Engineering and facilities lead (FM services provider)	40+
Expert B	Head of facilities management (Client's representative – lease hold office building)	21
Expert C	Head of technical services (Client's representative – lease hold office building)	19
Expert D	Regional services manager (FM services provider)	12
Expert E	Account manager (FM services provider)	18
Expert F	Workplace coordinator (FM services provider)	5
Expert G	Technical facilities manager (Client's representative – lease hold office building)	7
Expert H	Facilities manager (Client's representative – lease hold office building)	7
Expert I	Facilities services manager (Client's representative – lease hold office building)	15
Expert J	Workplace manager (FM services provider)	12

During the interviews, the experts were provided with a demonstration of the SRDSS, which included a walkthrough of the working process of the SRDSS, a sample case study application and a review of calculated results and rankings generated for that case. Thereafter, expert feedback on the SRDSS was obtained using a bespoke interview guideline. The interview guide is provided in Appendix A7.1 (page 239). Structured to gather comprehensive feedback from the experts, the guideline is divided into five sections: methodology, criteria, reasonableness of results, applicability, and recommendations. Each section features a mix of rating scales and open-ended questions to assess specific aspects of the SRDSS. The experts were asked to rate the clarity of the methodology, the coverage of relevant criteria, appropriateness of the weighting method, reasonableness of the results and the practicality of the SRDSS in real-world scenarios. A five-point scale ('Very High (5)', 'High (4)', 'Average (3)', 'Low (2)', and 'Very Low (1)') was used for this purpose. Open-ended questions invited suggestions for improvement and additional comments. The expert feedback was addressed by conducting iterative refinements on the SRDSS, which increased its practicality, decision confidence, and ease of use for facility managers.

7.3 Feedback from Validation Exercise

The validation exercise revealed that the clarity of the methodology was generally well-received, with three experts rating it as very high (score = 5) and seven as high (score = 4).

Positive feedback highlighted the detailed information provided in the selection process, making it effective and understandable. Experts appreciated the clear guidance on factors to consider in competitive bidding and the well-explained distribution of weights among factors. The ability to compare multiple alternatives under diverse criteria was considered beneficial, especially for large-scale retrofit projects where multiple technical and financial trade-offs exist. Experts commended the SRDSS's structured and transparent ranking process, which provided clarity when justifying retrofit decisions to stakeholders. The general coverage of the criteria was rated highly, with four experts rating it as very high (score = 5) and six as high (score = 4). The comprehensive and detailed set of criteria incorporated in the SRDSS was appreciated for providing greater clarity and applicability across different organizations and projects. The ability to customize criteria to suit specific needs was seen as enhancing the SRDSS's flexibility. The approach for weighting the criteria received positive feedback, with six experts rating it as very high (score = 5) and four as high (score = 4). The integration of ANP and Entropy was well-received, as it systematically accounted for both subjective and objective weights, reducing biases in decision-making. The thoroughness and comprehensiveness of the information used for weighting the criteria were noted as key strengths.

The reasonableness of the results obtained from the SRDSS was rated highly, with four experts rating it as very high (score = 5), five as high (score = 4), and one as average (score = 3). The SRDSS was commended for its practical effectiveness and comprehensive evaluation of criteria beyond cost. The use of TOPSIS was recognized as accurate, and the reliability of results was noted to depend on correct data input. The practicality and applicability of the SRDSS in real-world scenarios were rated highly, with four experts rating it as very high (score = 5) and six as high (score = 4). The SRDSS aligns with the industry's push towards digital solutions and has significant potential for high industry adoption. Its practicality and efficiency make it highly applicable for managing and selecting options in various real-world projects. The inclusion of both developing and developed regional contexts was recognized as a key strength, making the SRDSS adaptable to different economic and regulatory environments. The likelihood of recommending the SRDSS to others in the industry was rated positively, with five experts rating it as very high (score = 5), three as high (score = 4), and two as average (score = 3). The experts found the SRDSS to be a significant improvement over current unstructured methodologies and appreciated its straightforward, scientific, and adaptable approach. A summary of the expert ratings is shown in Table 7-2.

Table 7-2: Summary of expert ratings

	Evaluation criteria	No. of responses				
		Very high 5	**High 4**	**Average 3**	**Low 2**	**Very low 1**
1	Clarity of methodology	3	7			
2	General coverage of criteria	4	6			
3	Criteria weighting approach	6	4			
4	Reasonableness of the results	4	5	1		
5	Practicality and applicability of the model	4	6			
6	Recommending the model to others in the industry	5	3	2		

However, some experts indicated that the likelihood of recommending the SRDSS to others would be higher if the SRDSS included clear reasoning for the selections and more interaction with the SRDSS to identify potential issues or areas for improvement. A summary of the challenges highlighted and the respective improvements suggested for the SRDSS is given in Table 7-3.

Table 7-3: Summary of challenges and suggested improvements

	Challenge	Suggested improvement
1	While the SRDSS effectively ranked alternatives, it did not explicitly highlight why certain options performed better, making it difficult for decision-makers to interpret the results at a deeper level.	Adding features to visualize trade-offs, such as comparative cost-benefit graphs, to help facility managers make more informed decisions.
2	The user interface in Excel required manual data input and lacked interactivity.	Implementing a user-friendly platform, such as an app, to improve the SRDSS's usability and simplify decision-making.
3	In some cases, the TOPSIS performance scores of multiple alternatives were close (e.g., 0.99159 vs. 0.93143), making it difficult to confidently determine a superior option.	Incorporating a threshold percentage to indicate when rankings are too close to differentiate meaningfully and adding confidence levels to the numbers for better decision-making.

Overall, the validation exercise demonstrated that the SRDSS system is a robust and effective tool for SR of office buildings. The feedback from the building experts highlighted its strengths and provided valuable insights for further refinement and improvement.

7.4 SRDSS Refinement

Based on the expert feedback, refinements were implemented to enhance usability and interactivity of the SRDSS. The single worksheet file was separated to a file with four separate sheets: (1) input sheet, (2) retrofit details storage sheet, (3) a calculations sheet, and (4) dashboard. This improved version was built by integrating VBA macros into the MS Excel-based file to improve efficiency by automating calculations. The improved version updates rankings dynamically when users modify inputs, improving real-time decision-making. In the input sheet, dropdown menus and automated form inputs were added to simplify data entry and reduce the risk of input errors (Figure 7-1).

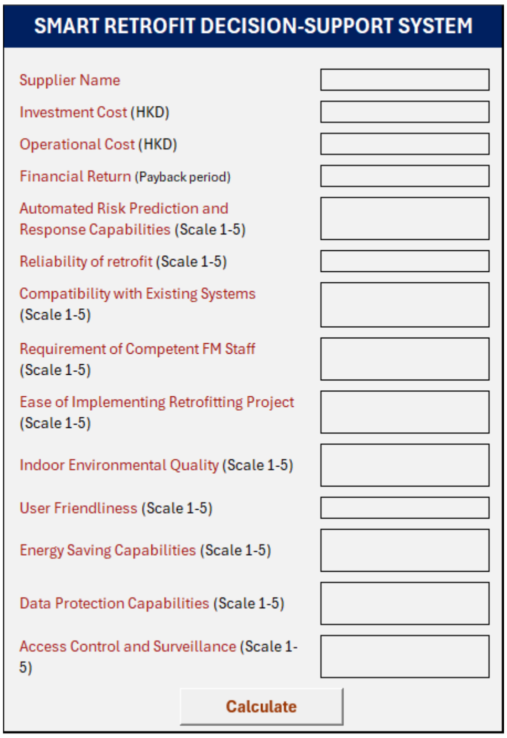


Figure 7-1: Input interface of the improved SRDSS

Each input field is clearly labelled with a criterion, such as 'Investment Cost', 'Energy Saving Capabilities'. The unit or rating scale of each criterion is explicitly stated, improving clarity. As Figure 7-1 is extracted from the refined SRDSS model applied to case 1, the currency is presented in Hong Kong Dollars (HKD). The interface accommodates both numerical input and subjective ratings on a scale. The 'Calculate' button at the bottom of the interface triggers a VBA macro within MS Excel. This macro reads the data entered into the input fields, stores them in the retrofit details storage sheet, performs the calculations of the SRDSS (normalization, weighting, distance calculations, etc.) in the calculations sheet and displays the results (ranking of alternatives) on the 'dashboard'.

To make results more interpretable, a comparative performance dashboard was added to visually represent the strengths and weaknesses of each alternative. The dashboard provides a summary of the rankings and percentages of proximity to PIS, while a cost-benefit criteria chart offers the underlying details that support this summary. It allows decision-makers to see why an alternative is ranked higher or lower by showing its performance on each individual criterion. Figure 7-2 shows a screen capture from the improved SRDSS, featuring the summary table extracted from the dashboard, for the four real-world cases that were previously evaluated using the original SRDSS in Chapter 6.

Supplier Name	Rank	Percentage of Proximity to PIS
Alternative 1	1	100%
Alternative 2	3	0%
Alternative 3	2	20.61%

Figure 7-2 (a): Case 1

Supplier Name	Rank	Percentage of Proximity to PIS
Alternative 1	1	94.75%
Alternative 2	2	5.25%

Figure 7-2 (b) Case 2

Supplier Name	Rank	Percentage of Proximity to PIS
Alternative 1	1	100%
Alternative 2	2	92.48%
Alternative 3	3	2.03%

Figure 7-2 (c): Case 3

Supplier Name	Rank	Percentage of Proximity to PIS
Alternative 1	2	44.94%
Alternative 2	1	91.37%
Alternative 3	3	0.76%

Figure 7-2 (d): Case 4

Figure 7-2: Summary of retrofit option evaluations

The summary table shows the ranking of each supplier's retrofit alternative, from 1 (best) to highest number (worst). The ranking is determined by the ANP-Entropy-TOPSIS based calculations performed by the VBA macro, based on the data entered in the input sheet. 'Percentage of Proximity to PIS' quantifies how close an alternative is to the PIS. A higher percentage means the alternative is closer to the ideal solution.

Figure 7-2 shows that the top-ranked solution differs across the four cases, emphasizing that the optimal retrofit choice is highly dependent on the specific project type (lighting, chiller, etc.) and the unique characteristics of the building and its location. In the IoT based lighting project in case 1, alternative 1 achieved a perfect alignment with the PIS (100%), while, alternative 1 in case 2's chiller plant control project achieved a very high proximity to the PIS (94.75%). In the smart car park management project of case 3, alternative 1 achieved a perfect alignment to the PIS (100%). In case 4's smart control valve project, alternative 2 is the preferred choice with 91.37% proximity to PIS.

By examining the spread or range of proximity scores within each individual case, the SRDSS's ability to distinguish among the alternatives in that specific context becomes clear. Case 1 shows a clear winner. Alternative 1 perfectly aligns with the PIS, while alternative 2 is completely misaligned. In case 2, there is a strong differentiation with alternative 1 being far superior. This indicates a relatively clear best choice for optimizing the chiller plant. In case 3, alternative 1 is the best, but alternative 2 also boasts a great proximity to PIS (92.48%). The SRDSS suggests a clear preference for alternative 1, but it also indicates that alternative 2 would be a reasonable choice if needed. Hence, the SRDSS is more conclusive on this case compared to the prior two cases. In case 4, alternative 2 is the clear winner, followed by alternative 1, and then alternative 3. Figure 7-3 shows the screen captures of the cost-benefit criteria chart from each case.

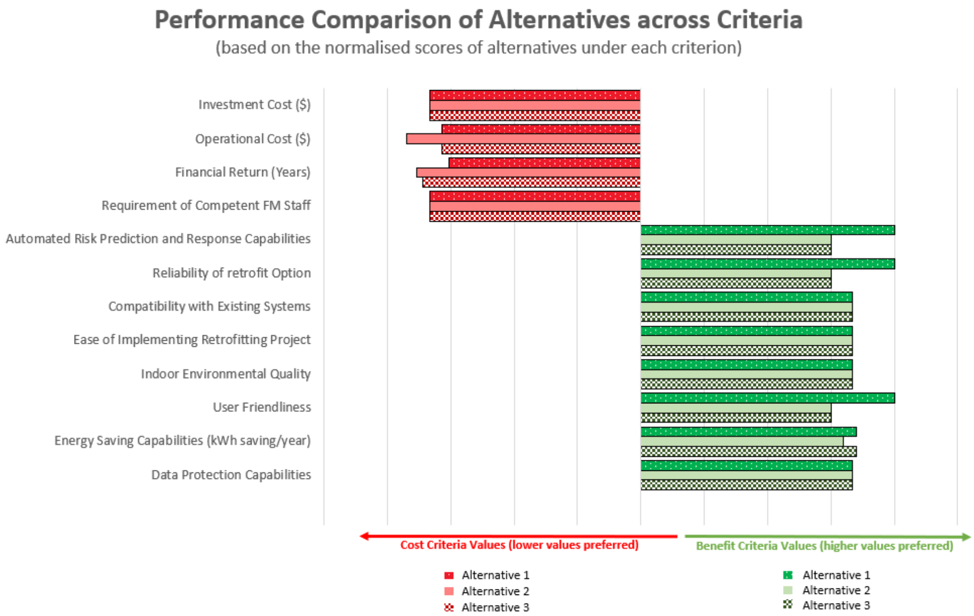


Figure 7-3(a): Cost-benefit criteria chart from case 1

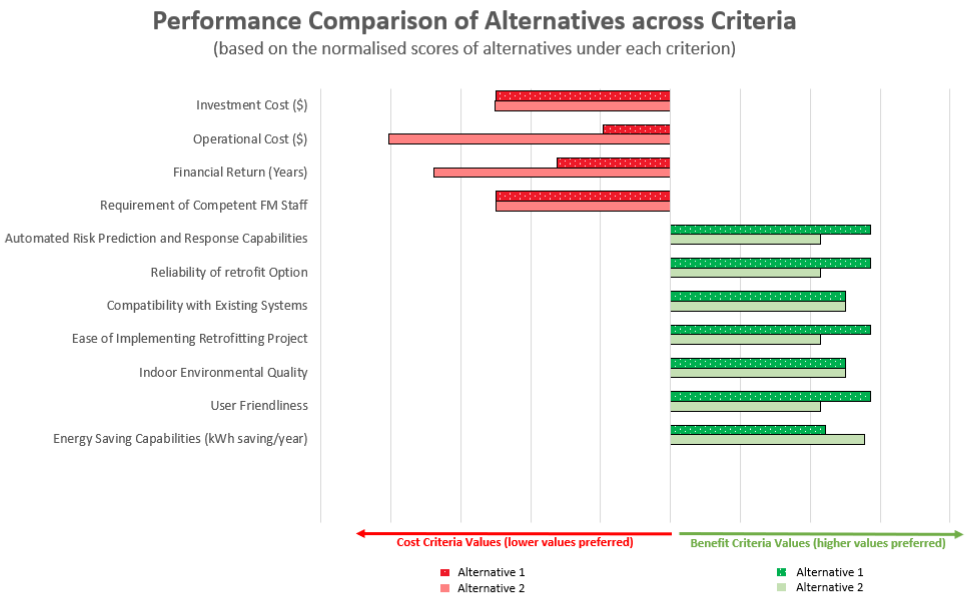


Figure 7-3(b): Cost-benefit criteria chart from case 2

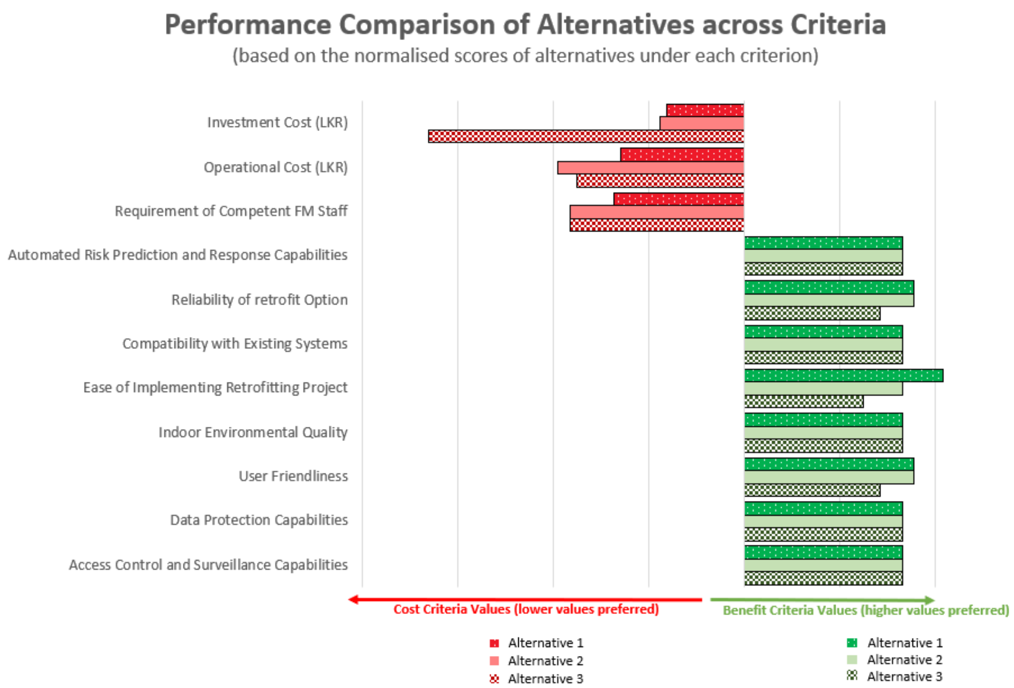


Figure 7-3(c): Cost-benefit criteria chart from case 3

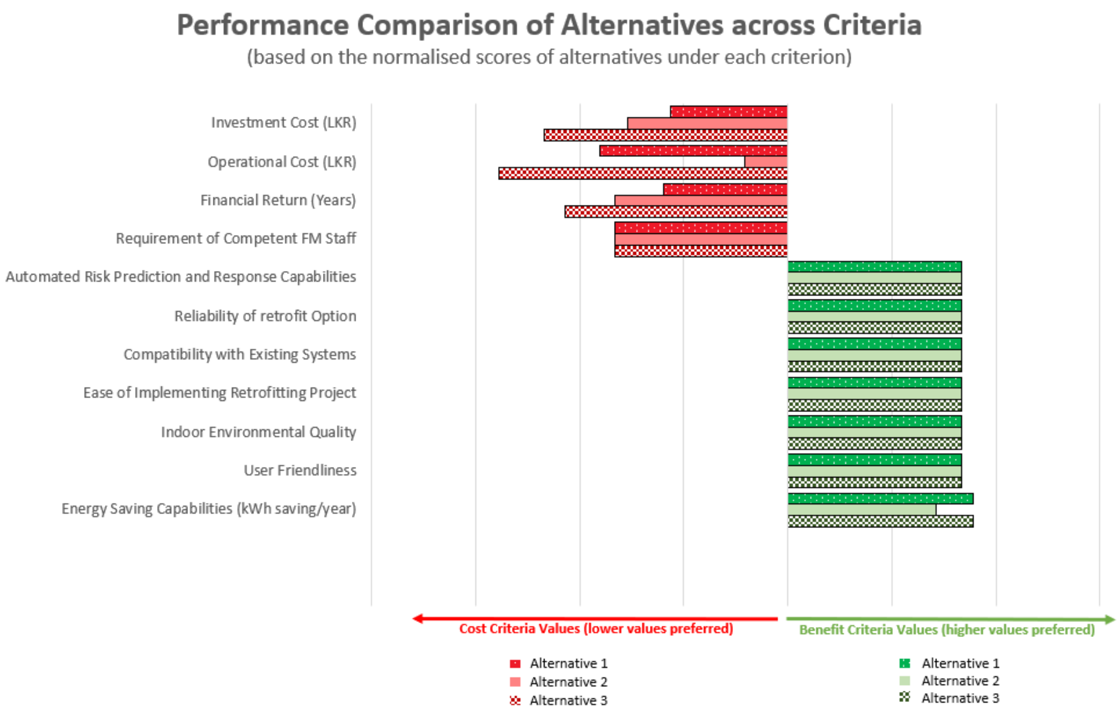


Figure 7-3(d): Cost-benefit criteria chart from case 4

Figure 7-3: Cost-benefit criteria charts extracted from dashboard

The criteria used in the SRDSS (investment cost, operational cost, financial return, energy saving capabilities, etc.) are listed along the vertical axis of the cost-benefit criteria chart. Each alternative is represented by a coloured and patterned bar for each criterion. The length and direction of the bar indicate the alternative's performance against that criterion. This chart is derived based on the normalized scores of alternatives under each criterion allowing for a fair comparison across criteria measured in different units or scales. Red bars represent “Cost Criteria” (where lower values are preferred). The further the bar extends to the left, the higher the cost and the worse the alternative performs on that cost criterion. Green bars represent “Benefit Criteria” (where higher values are preferred). The further the bar extends to the right, the higher the benefit and the better the alternative performs on that benefit criterion.

The cross-benefit criteria chart for case 1 shows that alternative 1 consistently outperforms the other alternatives across all criteria. It offers a superior balance of low costs and high benefits. In case 2, alternative 1 significantly outperforms alternative 2 by minimizing costs and being more proactive, reliable, easy to implement, and user friendly. While alternative 2 outperforms alternative 1 in terms of energy saving capabilities, it does not outweigh its extra costs. In case 3, alternative 1 outperforms the other two alternatives in all criteria except for when its performance is equal to that of the other alternatives. Alternative 3 must have lost its competitiveness due to its very high investment cost compared to the others. In case 4, it appears that alternative 2’s relatively lower costs makes it the superior choice amongst others despite its lower energy saving capabilities. To illustrate the main calculation procedure, the Entropy calculation segment of the VBA code is provided below, while the complete code is shown in Appendix A7.2 (page 241).

```
wsCalc.Cells(entropyRow, 1).Value = "Pos. Entropy Factor"
    wsCalc.Cells(negativeEntropyRow, 1).Value = "Neg. Entropy Factor"

    If alternativesCount > 1 Then
        entropyValue = 1 / Application.WorksheetFunction.Ln(alternativesCount)
    Else
        entropyValue = 0
    End If

    wsCalc.Cells(entropyRow, 2).Value = entropyValue
    wsCalc.Cells(negativeEntropyRow, 2).Value = -entropyValue

    ' Additional entropy calculation
    wsCalc.Cells(additionalCalculationStartRow, 1).Value = "Positive Entropy"
    wsCalc.Rows(additionalCalculationStartRow + 1).Value = wsData.Rows(1).Value

    For col = 2 To lastCol
        Dim additionalSumValue As Double
        additionalSumValue = 0

        ' If the total sum of the column is zero, set entropy to zero
        If wsCalc.Cells(totalsRow, col).Value = 0 Then
            wsCalc.Cells(additionalCalculationStartRow + 2, col).Value = 0
        Else
            ' Compute entropy
            For row = 2 To LastRow
                proportion = wsData.Cells(row, col).Value / wsCalc.Cells(totalsRow,
col).Value
                If proportion > 0 Then
                    logProportion = Application.WorksheetFunction.Ln(proportion)
```

```
                    additionalSumValue = additionalSumValue + (proportion *
logProportion)
                End If
            Next row

            If alternativesCount > 1 Then
                wsCalc.Cells(additionalCalculationStartRow + 2, col).Value = -(1 /
Application.WorksheetFunction.Ln(alternativesCount)) * additionalSumValue
            Else
                wsCalc.Cells(additionalCalculationStartRow + 2, col).Value = 0
            End If
        End If
    Next col

    ' New entropy-based calculation
    wsCalc.Rows(newCalculationStartRow).Value = wsData.Rows(1).Value
    sumOfNewCalcValues = 0

    For col = 2 To lastCol
        Dim newCalcValue As Double
        newCalcValue = 0

        ' If the total sum of the column is zero, set the calculation to zero
        If wsCalc.Cells(totalsRow, col).Value = 0 Then
            wsCalc.Cells(newCalculationStartRow + 1, col).Value = 0
        Else
            ' Compute new entropy-related values
            For row = 2 To LastRow
                proportion = wsData.Cells(row, col).Value / wsCalc.Cells(totalsRow,
col).Value
                If proportion > 0 Then
                    logProportion = Application.WorksheetFunction.Ln(proportion)
                    newCalcValue = newCalcValue + (proportion * logProportion)
                End If
            Next row

            If alternativesCount > 1 Then
                wsCalc.Cells(newCalculationStartRow + 1, col).Value = 1 - (-(1 /
Application.WorksheetFunction.Ln(alternativesCount)) * newCalcValue)
            Else
                wsCalc.Cells(newCalculationStartRow + 1, col).Value = 0
            End If
        End If
        sumOfNewCalcValues = sumOfNewCalcValues +
wsCalc.Cells(newCalculationStartRow + 1, col).Value
    Next col

    ' Calculate Entropy Weights
    wsCalc.Cells(entropyWeightsStartRow, 1).Value = "Entropy Weights"
    wsCalc.Rows(entropyWeightsStartRow + 1).Value = wsData.Rows(1).Value
    For col = 2 To lastCol
        If sumOfNewCalcValues <> 0 Then
            wsCalc.Cells(entropyWeightsStartRow + 1, col).Value =
wsCalc.Cells(newCalculationStartRow + 1, col).Value / sumOfNewCalcValues
        Else
            wsCalc.Cells(entropyWeightsStartRow + 1, col).Value = 0
        End If
    Next col
```

The refinements significantly improve the SRDSS's practicality, making it more accessible to a wider range of users while maintaining its methodological rigor. It transforms the MS Excel sheet from a manual calculation tool into an automated and user-friendly DSS.

7.5 Insights from the Validation and Refinement of the SRDSS

The consistency across the application cases builds confidence in the SRDSS's reliability and validity. The SRDSS produced consistent and logical results across different case studies. The alignment between the 'Proximity to PIS' scores and the cost-benefit criteria chart visualizations validate the SRDSS's internal consistency. The consistent application across different projects and regions also suggests potential for standardization in SR decision-making.

The SRDSS successfully evaluated diverse retrofit measures: lighting systems, chiller plant control, car park management and control valves. This demonstrates the SRDSS's adaptability to various SB technologies and contexts. The integration of diverse criteria, from financial and energy savings to data protection and ease of implementation, ensured a holistic evaluation. It demonstrated the ability to weigh trade-offs, as seen in case 4 where higher costs were justified by superior benefits. The SRDSS effectively incorporated qualitative criteria such as user-friendliness and compatibility with existing systems into a quantitative decision framework. This ability to quantify qualitative aspects enhances the SRDSS's usefulness in real-world scenarios where such factors are crucial but often difficult to measure.

Furthermore, the VBA-driven automation enhances user-friendliness and convenience, overcoming manual computational limitations seen in traditional Excel-based Decision-Support Systems (DSSs). The validation across four real-world case studies in developed and developing regions demonstrates practical applicability, whereas many prior studies rely on theoretical frameworks or single-region applications.

The refinement of rankings through ANP and Entropy-based weighting allowed the SRDSS to effectively balance subjective expert knowledge with objective data-driven insights. The integration of ANP, Entropy and TOPSIS offers several distinct advantages. Unlike other MCDM methods such as AHP, simple multi-attribute rating technique, weighted sum model and weighted product model, which assume independence among criteria, ANP accounts for complex interdependencies between criteria, making it more suitable for real-world problems. The Entropy method ensures objective weighting of criteria by minimizing personal biases. Meanwhile, TOPSIS provides a straightforward and intuitive ranking of alternatives by evaluating their proximity to the PIS. While combinations of two MCDM methods are common (Zhao et al., 2019, Pinzon Amorocho and Hartmann, 2022, Wang et al., 2023, Daniel and Ghiaus, 2023), the integration of three methods is rare, and no previous retrofit studies have employed ANP-Entropy-TOPSIS in combination. This innovative approach combines the strengths of all three methods, providing a robust, transparent and comprehensive framework for decision-making. These features of the SRDSS overcome the limitations of existing decision-making approaches presented in Chapter 2, thereby highlighting its novel contribution in bridging methodological gaps and offering a rigorous yet adaptable support system for SR decision-making.

While the SRDSS demonstrates strong decision-support capabilities, several limitations must be acknowledged. First, data quality and accessibility remain as key challenges, as the SRDSS relies on accurate and comprehensive data on retrofit alternatives. Incomplete or inaccurate data can lead to suboptimal decisions. Even though the SRDSS has been successfully validated as applicable to office buildings in both developed and developing regions, its effectiveness across different building types requires further validation. While the refined SRDSS incorporates the 'percentage proximity to PIS' factor, which provides insight into how closely alternatives align with the PIS, it does not fully address the expert-recommended threshold for differentiating closely ranked alternatives. However, the SRDSS assumes that even a marginally superior option remains as the best choice, since decision-making in competitive bidding often requires selecting the most favourable alternative, regardless of the magnitude of difference. Furthermore, the study did not incorporate a full-scale sensitivity analysis to assess the impact of variations in input data on final rankings. Given the complexity of the calculations, adjusting multiple variables simultaneously (e.g., criteria weights, alternative scores) would require an extensive analysis, which may not yield straightforward insights. However, the model's built-in ANP-Entropy weighting mechanism inherently balances subjective and objective factors, reducing the likelihood of extreme sensitivity to minor data variations. Additionally, the percentage proximity to PIS metric already provides insight into the relative differences between alternatives, offering decision-makers an intuitive way to interpret ranking stability.

Further work in this direction could focus on technological improvements such as an app or web-based platforms with user-friendly interfaces and a dynamic threshold mechanism that ensure consistent data inputs, enhance accessibility and improve results interpretation. It could also explore scenario-based sensitivity analysis, where selected variables, such as criteria weights and cost factors, are adjusted systematically to test the robustness of rankings. Additionally, Monte Carlo simulations or One-at-a-time (OAT) sensitivity testing could be implemented through automated tools (e.g., Excel VBA or Python) to assess decision stability under varying conditions. The validation of the SRDSS could be extended by applying it to a broader range of building types, such as residential complexes, healthcare facilities and industrial buildings, assessing how the SRDSS adapts to varying operational requirements and stakeholder considerations. By addressing these limitations and focusing on these areas for improvement, the SRDSS can become an even more powerful tool for supporting sustainability in buildings.

7.6 Chapter Summary

This chapter has demonstrated the validation and iterative enhancement of the SRDSS framework through expert feedback and application of the improved SRDSS to real-world cases. The validation process confirmed the model's effectiveness in supporting complex decision-making by clearly distinguishing between retrofit alternatives using a structured, criteria-based approach. Expert insights led to several refinements in the system's interface, explanation flow and adaptability, which were incorporated into an improved version of the SRDSS. The reapplication of the enhanced system to the same four cases previously analysed using the original SRDSS in Chapter 6 demonstrated several improvements, most notably, enhanced clarity and usability, while maintaining analytical rigour. These efforts collectively strengthened the model's practical value, bridging the gap between academic research and industry adoption of SRDSS.

CHAPTER EIGHT

8 CONCLUSIONS

8.1 Introduction to the Chapter

This final chapter consolidates and reflects on the key outcomes of the research by revisiting the study's original objectives and demonstrating how each was achieved through the methodological processes and findings presented in earlier chapters. It presents a synthesis of the study's contributions to both theory and practice in the domain of SR decision-making. Recognising the inherent boundaries of any research endeavour, the chapter also acknowledges the study's limitations, offering transparency regarding its scope and areas for potential enhancement in future research. Building upon these reflections, the chapter concludes with a comprehensive outline of future research directions aimed at extending the applicability, robustness and impact of the Smart Retrofitting Decision-Support System (SRDSS). Together, these elements provide a holistic overview of the research journey, its theoretical and practical significance, and its potential to inform ongoing and future developments in SR.

8.2 Review of Research Objectives and Summary of Research Findings

Having identified multiple challenges and complexities in SR decision making, the aim of this research was to develop an SRDSS for holistic, optimal selection of SR alternatives for office buildings. By undertaking a mixed-method MCDM approach a system for SR decision-making was developed based on the ANP-Entropy-TOPSIS methods. The scope of this research is confined to leasehold office buildings, where ownership is retained by a landlord, and most of the space is occupied by tenants. To demonstrate the applicability of the envisaged SRDSS across different economies, the Hong Kong and Sri Lankan scenarios were selected as being representative of developed and developing regions, respectively.

The following five research objectives were formulated and then achieved as described in foregoing chapters, in achieving the research aim of the study.

1. Identify, refine and structure a comprehensive set of criteria for evaluating SR alternatives in office buildings
2. Establish the relative importance of the identified criteria by capturing their interdependence
3. Develop an SRDSS through the integration of MCDM methods

4. Apply the SRDSS to real-world case studies from both developed and developing regions and compare the findings between the regions
5. Validate the usability, reliability and practicality of the SRDSS and refine the system based on validation outcomes

The following sections summarise the processes undertaken to achieve these objectives by reviewing the achievement of each objective.

Objective 1 - Identify, refine and structure a comprehensive set of criteria for evaluating SR alternatives in office buildings

To address the first objective, a rigorous four-stage research process was implemented. This phase, forming the foundation of the study's research framework and detailed in Chapter 4, comprised a comprehensive literature review, a focus group discussion, an extended literature review and a questionnaire survey. Initially, manual content analysis was conducted on 14 papers identified through a systematic literature search, resulting in the development of a two-tier decision-making criteria hierarchy. This framework comprised 14 preliminary criteria themes grouped under five overarching categories: financial, technical, human, environmental and legal.

These preliminary criteria were then presented to a panel of nine experts during a focus group discussion, where the experts were invited to assess the relevance of the criteria, recommend modifications and propose additional criteria. In response to the insights gained, a second, extended literature review was conducted using a refined set of keywords derived from the focus group feedback. A total of 121 papers were analysed through manual content analysis, ultimately producing 32 SR decision-making criteria, categorised into 14 updated sub-themes within the same five overarching groups.

Subsequently, these 32 criteria were subjected to validation through a questionnaire survey administered to FM professionals in Hong Kong. Based on 160 valid responses, a statistical analysis using mean score ranking was employed to shortlist the most important criteria. This process yielded a final list of 20 decision-making criteria. Additionally, group comparisons were conducted using the Mann-Whitney U test and the Kruskal-Wallis H test to identify potential variations in perception across respondent groups.

The outcomes of this stage contribute significantly to the knowledge base by offering a validated and structured framework for SR decision-making. The finalised criteria effectively capture the multifaceted nature of retrofit decision-making by covering: i) financial, ii) technical, iii) user comfort and convenience, iv) environmental, and v) legal, safety and security aspects. Notably, the findings highlight the often-overlooked importance of user comfort and convenience which is an insight that adds value to both academic understanding and practical application. In the context of a limited body of literature on SR-specific decision-making criteria, this framework fills a crucial gap and serves as a foundational tool to guide facility managers in adopting a systematic approach to SR decisions. The validated criteria framework developed in this phase also provided the basis for subsequent stages of model development in the study.

Objective 2 - Establish the relative importance of the identified criteria by capturing their interdependence

Once the core set of decision-making criteria had been identified, the second objective was to establish the relative importance of these criteria using the ANP method. The ANP method was selected due to its ability to account for interdependencies among criteria, offering a more accurate determination of priority weights. To achieve this objective, a two-part qualitative-quantitative research design was employed, as detailed in Chapter 5, involving 24 semi-structured expert interviews, 12 conducted in Hong Kong and 12 in Sri Lanka. The interviewees were experienced professionals with direct involvement in SR projects, including FM representatives of office building owners, contractors and consultants.

The first part of the interview focused on gathering contextual insights through open-ended questions exploring SR drivers and motivators, challenges and barriers, key stakeholders and influencers, and current decision-making practices. This contextual exploration served to ground the subsequent ANP exercise in the specific realities of each region, ensuring that expert judgments in the second part were informed by a deep understanding of local operational constraints, decision-making cultures and strategic priorities. Thematic coding and qualitative analysis were carried out using NVivo 15 to derive key insights from these discussions.

In the second part of the interview, the experts participated in pairwise comparisons of criteria as required by the ANP method. To enhance practicality of the ANP exercise, the original 20 criteria were consolidated into 13. The resulting pairwise comparison ratings were analysed using the Super Decisions software, generating the final set of ANP weights for each region.

The contextual findings underscored key regional differences. In Sri Lanka, SR was primarily motivated by the need for energy efficiency, cost reduction and catching up with technological standards. In contrast, motivations in Hong Kong were more aligned with ESG commitments, tenant demands and market competitiveness. Common barriers across both regions included financial limitations, institutional inertia and difficulties with technical integration. However, capacity constraints and procurement challenges were more pronounced in Sri Lanka, whereas vendor lock-in emerged as a significant concern in Hong Kong. Stakeholder influence also varied, with different actors playing critical roles at various stages of the SR process in each region.

In terms of prioritised criteria, both regions valued factors such as ROI, payback period, disruption minimisation, user-friendliness and ESG alignment. Yet, preferences diverged: Sri Lanka emphasised tangible financial returns and technical validation, while Hong Kong placed greater weight on broader business performance metrics and regulatory compliance.

The ANP results reflect these regional distinctions, reinforcing the inadequacy of a one-size-fits-all approach to SR decision-making. The established region-specific weights provide a context-sensitive evaluation framework that allows stakeholders to prioritise criteria according to local needs and strategic goals. This not only enhances the precision of retrofit decisions but also enables more effective allocation of resources, ensuring that SR initiatives are both practical and impactful. By incorporating these regional nuances into the weighting system, the study contributes to the development of adaptable policies and decision tools that are better suited to the diverse urban environments of both developed and developing economies.

Objective 3 - Develop an SRDSS through the integration of MCDM methods

While ANP accounts for interdependencies among decision-making criteria, it relies on expert judgement, which may introduce subjectivity. To mitigate potential biases and enhance the specificity of the importance weights for each retrofit project, this study integrated the Entropy method alongside ANP. The Entropy method objectively determines criteria weights based on the degree of variation in retrofit alternative scores, allowing the model to capture context-specific information grounded in actual retrofit data.

To apply the Entropy method, scoring methods were developed to evaluate retrofit alternatives against each decision criterion. These methods were tailored to suit the unique nature of each criterion, whether tangible or intangible, and were pilot tested for practicality. The pilot test involved two FM professionals, one from Hong Kong and one from Sri Lanka, whose feedback was used to refine and finalise the scoring approaches.

Subsequently, a MS Excel-based platform was developed as the core interface for the SRDSS. The platform includes designated sheets for inputting alternative scores, executing calculations and presenting outputs. Equations were embedded to carry out the computation of Entropy weights, combined ANP-Entropy weights, and the final ranking of alternatives using the TOPSIS method. The TOPSIS approach was selected for its clarity and effectiveness in ranking alternatives based on their relative closeness to the ideal solution. The MS-Excel tool was designed to be user-friendly, with intuitive layouts, clear labels and simplified input/output structures to facilitate adoption by practitioners. The third objective, which included the development of the SRDSS, was therefore achieved through the steps explained above and detailed in Chapter 6. This represents a pivotal contribution by synthesising the key MCDM techniques into a functional Decision-Support Systems (DSS) customised for SR.

Objective 4 - Apply the SRDSS to real-world case studies from both developed and developing regions and compare the findings between the regions

Following the development of the SRDSS under the third objective, the next phase of the research was undertaken to evaluate the system's applicability and practical relevance. Therefore, the fourth objective, as reported in Chapter 6, was achieved through empirical testing of the SRDSS across four case studies, two from Hong Kong and two from Sri Lanka, demonstrating the system's adaptability across varying economic, technological and regulatory contexts. The case study office buildings were selected based on their implementation of SR projects and the availability of comprehensive data. Each case involved real-world projects where multiple SR alternatives had been considered during the decision-making process.

Interviews were conducted with the facility manager of each selected project to collect the necessary data. Quantitative data for tangible criteria (e.g., investment cost, payback period, energy savings) were extracted from supplier documents and technical specifications. For intangible criteria (e.g., user-friendliness, compatibility with existing systems), the facility managers provided Likert scale-based ratings grounded in their experience and knowledge. These scores were input into the MS Excel-based SRDSS, which first calculated objective criteria weights using the Entropy method. These Entropy-derived weights were then integrated with the expert-driven ANP weights to derive the combined weights. Using the weighted retrofit scores, the TOPSIS method was applied to rank the SR alternatives based on their relative closeness to the ideal solution.

The case study results yielded several insightful findings. Firstly, the rankings of SR alternatives varied significantly across the four cases, underlining that optimal SR decisions are highly context-specific. This variation provided empirical evidence that structured DSSs, capable of balancing competing priorities tailored to project type, stakeholder needs and regional constraints, are essential. Across all the cases, cost-related factors (investment cost and operational cost) emerged as dominant considerations, affirming the centrality of financial viability in SR decision-making. However, notable regional contrasts emerged in technological priorities: in Hong Kong, alternatives with advanced features such as automation and reliability were strongly preferred, reflecting the region's mature digital infrastructure and high-performance expectations. In contrast, Sri Lankan facility managers placed greater emphasis on practicality and adaptability, a trend shaped by infrastructure limitations and the relatively nascent stage of smart technology adoption.

Furthermore, operational factors such as the requirement for highly skilled FM staff held different levels of importance across regions. In Sri Lanka, ease of implementation and reduced dependence on specialised staff were crucial due to the scarcity of trained professionals. Conversely, in Hong Kong, such concerns were less prominent, given the availability of certified FM personnel and a more established support ecosystem.

Overall, the SRDSS facilitated a multi-criteria evaluation of SR alternatives, enabling facility managers to make balanced and informed decisions that extend beyond energy savings alone. By incorporating diverse decision dimensions, including user comfort, system compatibility, financial feasibility and environmental impact, the system fostered a holistic view of sustainability. Its use of ANP, Entropy and TOPSIS provided a robust and structured methodology, affirming the SRDSS as a practical, transparent and adaptable tool applicable across diverse regional contexts.

Objective 5 - Validate the usability, reliability and practicality of the SRDSS and refine the system based on validation outcomes

The fifth and final objective focused on validating the SRDSS in terms of usability, reliability and practicality, and refining the system based on the validation outcomes. This objective, as reported in Chapter 7, was crucial in ensuring that the SRDSS was not only theoretically sound but also practically applicable and capable of addressing the real-world needs of facility managers and decision-makers involved in SR projects.

The validation exercise, in the form of expert interviews, was conducted with ten experienced FM professionals based in Australia, all of whom had prior involvement in SR projects. Each interview began with a walkthrough of the SRDSS's working mechanism, followed by a demonstration using a sample case study implemented through the MS Excel-based platform. A bespoke questionnaire was then administered, inviting experts to evaluate the SRDSS based on five key aspects: methodological soundness, appropriateness of criteria, reasonableness of results, applicability to practice and suggestions for enhancement.

Feedback from the experts was systematically analysed, revealing overall strong endorsement of the SRDSS. The system was praised for its transparent and logic-driven structure, its capacity to incorporate both tangible and intangible evaluation criteria, and the balanced integration of subjective (ANP) and objective (Entropy) weighting mechanisms. The experts also valued how the MCDM framework clarified trade-offs among alternatives, facilitating more evidence-based and accountable decision-making.

Importantly, the validation process also yielded constructive recommendations for enhancement. The experts suggested the inclusion of visual features, such as comparative cost-benefit graphs, to better illustrate trade-offs and assist facility managers in interpreting results. Other suggestions included developing a more user-friendly digital interface (e.g., a standalone app or web-based version) to improve accessibility and incorporating a threshold mechanism to indicate when alternative rankings are too close to differentiate meaningfully.

In response to this feedback, the SRDSS was refined and implemented as a VBA-macro-enabled MS Excel tool. This enhancement introduced automated data entry, real-time calculations and graphical outputs, thereby improving user experience and minimizing manual effort. The final version of the SRDSS thus offers facility managers a structured, intuitive and practical system, enhancing transparency, reducing subjectivity, and supporting consistent, well-informed SR decision-making across varying project contexts.

8.3 Contributions of the Research

The main contribution of this thesis is a practical DSS that helps facility managers choose the best SR alternatives for office buildings. By balancing financial, technical, environmental, legal and user-related factors, the model makes complex retrofit decisions clearer, fairer and more adaptable across different countries and building types.

8.3.1 Contributions to Theory

8.3.1.1 Adding depth to the role of SR in sustainability transitions

This study makes several novel contributions to the theoretical understanding of SR in the built environment. First, it advances the conceptualisation of SR beyond its conventional role as a means to reduce energy consumption and greenhouse gas emissions. The research establishes SR as a multifaceted strategy that not only supports global sustainability goals but also enhances building comfort, liveability and user well-being. The study highlights that while financial payback remains a critical factor, user-centric and operational concerns are equally essential for driving retrofit adoption. This expanded perspective adds depth to the theoretical framing of SR as a socially, economically and environmentally integrated solution.

8.3.1.2 Establishing a validated criteria framework for SR decision-making

The research offers a validated framework for SR decision criteria, developed through a combination of literature review, a focus group discussion and a questionnaire survey. This contributes a much-needed structure for future academic work aiming to model SR decisions across diverse contexts. By highlighting underexplored areas such as occupant well-being, user-friendliness and ease of implementation, the study encourages scholars to expand the conceptual boundaries of SR evaluation.

8.3.1.3 Advancing scholarly understanding through systematic literature review

The systematic literature review conducted as part of this study, as reported in Chapter 2, also contributes to knowledge through the first bibliometric analysis dedicated specifically to SR research, offering valuable insights for academics exploring this evolving field. It identifies leading authors, institutions and countries, thereby mapping the intellectual landscape and informing future scholarship. The accompanying qualitative review synthesizes thematic gaps and emerging directions in SR research, emphasising the need for more pragmatic, user-focused and performance-based solutions. The findings point to key research gaps in criteria development, stakeholder behaviour and post-retrofit performance evaluation, thereby laying the groundwork for future research in SR evaluation tools and behaviourally informed frameworks.

8.3.1.4 Introducing a novel hybrid MCDM framework for SR

Another significant theoretical contribution lies in the development of the SRDSS, which is the first DSS in SR literature to adopt a holistic, hybrid MCDM framework that captures both subjective and objective aspects of decision-making. The SRDSS integrates a comprehensive set of criteria, including ‘financial’, ‘technical’, ‘user comfort and convenience’, ‘environmental’, and ‘legal, safety, and security’ dimensions, within a unified structure. By combining the ANP method, which models interdependencies among criteria, and the Entropy method, which captures context-specific variability objectively, the study enhances the methodological rigour and depth of MCDM applications in SR research. The final decision output is generated through TOPSIS, enabling proximity-based ranking aligned with practical needs. The integration of these three methods in a single framework is rare in the existing body of retrofit decision-support literature, positioning this study as a contributor to a novel methodological approach in the field.

8.3.2 Contributions to Practice

8.3.2.1 A deployable and user-friendly SRDSS for real-world application

The study yields substantial practical contributions, most notably through the delivery of a fully functional, user-friendly and ready-to-use MS Excel-based SRDSS. Designed for direct application by facility managers, consultants and policymakers, the tool offers a transparent, structured and justifiable approach to evaluating multiple retrofit alternatives. The integration of VBA-driven automation ensures ease of use, reducing manual effort in data entry and calculations, and making the tool accessible even to users with limited technical expertise. Its application across four real-world office building case studies, two in Hong Kong and two in Sri Lanka, demonstrates the model’s reliability, adaptability and consistency across diverse economic and operational settings. The case studies further validate the model’s practicality, showing how it can be applied to diverse technologies, including lighting systems, car park management, chiller control, and valves, demonstrating flexibility and cross-solution applicability.

The SRDSS also empowers decision-makers to evaluate trade-offs across competing objectives, cost, performance, energy efficiency, user comfort and implementation feasibility, within a single platform. Through the features of SRDSS’s dashboard, facility managers gain a robust overview to justify recommendations to top management, which is particularly valuable in large-scale projects with multiple stakeholders.

In addition, the SRDSS stands out when compared with existing commercial decision-support tools in the market. A comparative review of prominent platforms such as Decision Lab 2000, D-Sight, MCDM Solver and TOPSIS Calculator reveals that while each offers valuable functionality, none provides the holistic integration and contextual flexibility achieved by the SRDSS developed from this study. For example, Decision Lab (DecisionLab, 2000) and D-Sight (D-Sight, 2025) rely on preference-based methods like PROMETHEE, which require pre-defined preference functions and lack the ability to model interdependencies among criteria. Others, such as MCDM Solver (Zolfani and Hasheminasab, 2020) mostly assume independence among criteria. While MCDM Solver offer multiple methods, it largely treats them as standalone modules, providing limited hybridisation in the sense of combining subjective and objective weighting schemes or integrating weighting and ranking techniques into a cohesive decision-making process. Most commercially available tools also lack transparency in terms of how trade-offs between alternatives are handled and how final rankings are derived, limiting users ability to trace the rationale behind the decisions. In contrast, the SRDSS is offered as an MS Excel-based solution, automating complex calculations through VBA, while integrating ANP for interdependencies, Entropy for objective weighting, and TOPSIS for ranking, a combination rarely seen even in advanced tools. This unique integration ensures that the SRDSS produces balanced, data-driven and context-sensitive decisions, all within an interface that is accessible to facility managers without the need for specialised software training. Moreover, none of the reviewed tools include a built-in set of decision criteria specifically tailored for SR. SRDSS incorporates a validated, comprehensive set of SR-specific criteria enabling users to conduct evaluations without needing to independently define criteria or scoring methods. This significantly reduces the time, effort and uncertainty involved in initiating assessments.

8.3.2.2 Adapting to contextual realities in developed and developing regions

In addition, the findings from the contextual and stakeholder analyses offer actionable insights for SR implementation across developed and developing regions. In Hong Kong, priority is usually given to cost-effectiveness, long-term performance and technological reliability, while also addressing the relatively lower emphasis on user-centric and environmental criteria. In Sri Lanka, a greater focus is required on ease of implementation, skill requirements and operational sustainability, with findings encouraging the adaptation of advanced technologies to existing infrastructure constraints. This distinction promotes tailored retrofit strategies that avoid one-size-fits-all solutions and accommodate economic and infrastructural realities.

8.3.2.3 Guiding policy, resource allocation and localised strategies

The importance weights assigned to criteria in this study provide practical guidance for prioritising resources in retrofit planning. These weights reflect the real-world concerns of stakeholders and can help streamline decision-making, particularly when resources are constrained. In parallel, the contextual analysis of SR practices in both developed and developing regions reveals significant insights for tailoring policies to local needs. For instance, the study highlights the lack of regulatory enforcement in both contexts and showcases how inter-departmental coordination, stakeholder readiness and knowledge gaps shape retrofit success. These findings equip policymakers and consultants with a clearer understanding of where systemic support and education are needed. By accounting for regional specificities, the SRDSS supports more context-aware policies and strategies, allowing government bodies and consultants to design solutions that address unique local challenges. The model also holds potential to inform benchmarking practices, policy formulation and incentive schemes by offering a replicable, evidence-based evaluation process.

8.3.2.4 Enabling progress towards global sustainability goals

In a broader context, the SRDSS supports the global sustainability agenda by enabling more efficient and effective retrofit interventions. By promoting resource-efficient practices and helping stakeholders select options that maximise sustainability returns, the model contributes to the achievement of UN Sustainable Development Goals, particularly Goal 7 (Affordable and Clean Energy), Goal 9 (Industry, Innovation and Infrastructure) and Goal 11 (Sustainable Cities and Communities). Its scalability allows for potential replication in other high-density urban environments such as Singapore, Tokyo and New York, making it a valuable asset for advancing sustainable urban development worldwide.

8.3.2.5 Contribution to ESG priorities

In addition to its alignment with the UN Sustainable Development Goals, the SRDSS offers direct contributions to the ESG agenda increasingly adopted by corporations and investors as a benchmark for sustainable performance. From an environmental perspective, the model facilitates more resource-efficient retrofit decisions that can reduce carbon emissions, energy consumption and operational waste. From a social perspective, it supports improved occupant well-being, comfort and productivity by embedding user-oriented criteria such as indoor environmental quality, convenience and health considerations into decision-making. From a governance perspective, the structured, transparent and evidence-based methodology strengthens accountability and justifiability of retrofit investments, enabling facility managers and corporate leaders to demonstrate compliance with reporting standards and stakeholder expectations. By bridging these three dimensions, the SRDSS provides a practical tool for organisations to improve their ESG performance while simultaneously advancing long-term asset value and resilience.

8.4 Limitations of the Research

8.4.1 Limitations in the Systematic Literature Review

While the systematic literature review stage provided foundational insights, several limitations must be acknowledged. First, the bibliometric search relied on carefully selected keywords derived from previous studies. However, relevant publications lacking these keywords may have been missed. Second, the review excluded grey literature and reports from non-academic sources such as the US Department of Energy and the European Commission, which could have offered valuable insights into real-world SR practices. Third, citation-based productivity metrics may be skewed by the recency of publications. Additionally, the bibliometric analysis was conducted using relatively straightforward techniques. More advanced methods, such as network centrality measures, hierarchical clustering or bibliometric mapping with Bibliometrix R, could offer deeper analytical perspectives. Lastly, the review was restricted to publications indexed in Scopus and Web of Science, potentially excluding relevant studies from other databases, if any.

8.4.2 Limitations of the SR Criteria Identification Phase

The focus group discussion and questionnaire survey were subject to sample-related constraints. The focus group discussion was limited in participant size, which may affect the generalisability of the criteria identified. While the study achieved its intended goal of criteria identification, broader industry input, particularly through large-scale surveys, would help strengthen the findings. Additionally, the focus group and survey data were collected only from participants based in Hong Kong, which limits the geographical generalisability of results.

8.4.3 Contextual Boundaries and Regional Generalisability

This study focused on two regional contexts, Hong Kong and Sri Lanka, chosen to represent developed and developing economies respectively. While this dual-context approach enabled rich comparative insights, it also limits the generalisability of findings to other geographical settings with different regulatory, technological or cultural conditions. The stakeholder priorities, constraints and retrofit drivers in other regions may vary. Furthermore, while the SRDSS was validated in Australia through expert interviews, it was not actually tested on Australian buildings.

However, the SRDSS was designed with adaptability in mind. While the present application was demonstrated in the contexts of Hong Kong and Sri Lanka, the underlying method, logic and procedural sequence remain generalisable. If applied to other regions or different building types, decision-makers may adjust the relative weightings of criteria to reflect the unique characteristics, priorities and contextual circumstances of their facilities, while still retaining the robustness of the overall framework.

8.4.4 Scope Limitations of the SRDSS

The SRDSS was developed and validated specifically for use in office buildings. While it has shown strong applicability in both developed and developing urban contexts, its extension to other building types (e.g., residential, industrial, institutional) has yet to be tested. Each building typology may involve different operational dynamics, user behaviours and retrofit objectives, warranting further adaptation of the tool. Moreover, while the SRDSS provides a structured and robust framework for evaluating retrofit alternatives, it assumes that available data are accurate and complete. In practice, data quality remains a challenge, any inaccuracies in input (e.g., scoring of alternatives, cost estimates) could lead to misleading recommendations.

8.4.5 Quantification of Intangible Criteria

One of the most significant challenges encountered during this research was the quantification of intangible criteria, such as user satisfaction, convenience and data privacy, in the evaluation of retrofit alternatives. While tangible criteria (e.g., energy consumption, payback period) allowed for direct numerical value extraction, the intangible criteria required subjective assessment. In this study, these were operationalised using Likert scales and assessed through facility manager perceptions. Although this approach provided a workable solution, it introduces a degree of subjectivity that may limit comparability across different projects.

8.4.6 Ranking Sensitivity and Differentiation between Close Alternatives

Another limitation concerns the ranking mechanism, particularly in situations where alternatives received very similar overall scores. Although the model incorporates the 'percentage proximity to the positive ideal solution (PIS)' with the ranking, it does not fully implement the expert-recommended dynamic threshold for distinguishing between alternatives with marginal score differences. In its current form, the model treats even small differences in proximity as meaningful, which reflects the reality of many procurement processes where one alternative must be selected. However, for decision scenarios where greater interpretative sensitivity is needed, future improvements could include dynamic thresholding or confidence band analysis to enhance clarity in borderline cases.

8.4.7 Need for Comprehensive Sensitivity Analysis

Although the SRDSS integrates ANP and Entropy methods to balance subjective and objective weighting, the study did not incorporate a full-scale sensitivity analysis. A comprehensive examination of how small variations in input values, such as criteria weights or performance scores, affect final rankings could provide deeper insight into the model's robustness. Given the complexity of the SRDSS and the interplay between multiple MCDM techniques, performing such an analysis would be methodologically demanding and may not yield straightforward conclusions. Nonetheless, the use of percentage proximity to PIS already offers users a built-in mechanism to assess the confidence level in final rankings. Future research could develop add-on modules or simulation routines to facilitate more systematic sensitivity testing.

8.5 Future Research Directions

8.5.1 Bridging Current Gaps in SR Research

A key outcome of this study is the framework developed through the systematic literature review reported in Chapter 2, which highlights several research gaps and offers a roadmap for future exploration. Notable directions include improving methodologies for smartness evaluation, advancing RES integration from both technical and managerial perspectives, strengthening cybersecurity in SR applications, and addressing legal and policy requirements. Additionally, the human dimension of SR warrants further attention, particularly in enhancing stakeholder engagement, decision transparency and user acceptance. The synthesis of these future pathways, as illustrated in the conceptual research nexus developed in this study, provides a foundation for catalysing collaborative SR-related research efforts across disciplines.

8.5.2 Investigating Evolving Stakeholder Priorities and Behaviour

Future studies should explore how economic, technological and regulatory shifts influence stakeholder priorities in the SR domain. Specific attention could be given to user-centric aspects, such as comfort, satisfaction and behavioural preferences, which have been underrepresented in current SR decision-making frameworks. Surveys and interviews could be employed to capture the evolving expectations of building occupants, facility managers and owners. Additionally, regulatory frameworks play a critical role in shaping adoption behaviour and technology uptake. Investigating how different policies impact decision-making across various governance models, for example, through subsidies or incentives that encourage prioritisation of criteria such as energy savings, would offer valuable insights for tailoring national or regional retrofit strategies.

8.5.3 Expanding Contextual and Typological Application of the SRDSS

While the SRDSS was validated using office buildings in two regions, its applicability across different building typologies (e.g., residential, healthcare, industrial) remains a fertile area for further research. Testing the model in other urban contexts, such as densely populated cities in Europe, the Americas or Africa, could validate its adaptability and generalisability. Regional economic, regulatory and technological differences may significantly influence SR decision priorities. Future research could also examine the role of Public Private Partnerships (PPPs) in facilitating retrofitting in developing countries (Jayasena et al., 2025), along with the contributions of government agencies, private enterprises, and community involvement in broader retrofit adoption.

8.5.4 Improving Intangible Criteria Measurement

Future studies may overcome this limitation by employing more advanced techniques for quantifying intangible factors. Potential avenues include the use of occupant surveys and post-occupancy evaluation frameworks to capture broader user perspectives, the development of industry benchmarks for commonly assessed qualitative attributes or the application of emerging methods such as fuzzy logic, Bayesian networks or artificial intelligence to translate subjective perceptions into more robust numerical values. Integrating real-time building performance data with user feedback (e.g., via IoT-enabled sensors combined with mobile-based user surveys) could also provide a more evidence-driven basis for evaluating intangible criteria. These directions would enhance the objectivity and reproducibility of SR decision-making in future applications of the SRDSS.

8.5.5 Enhancing Model Features Through Technological Improvements

Technological advancements can significantly improve the usability and performance of the SRDSS. A future research stream could focus on developing a web-based or app-based version of the tool with a user-friendly interface and embedded calculation protocols. Enhancements may also include a dynamic threshold mechanism for differentiating closely ranked alternatives, improving interpretability for end-users. Moreover, incorporating scenario-based sensitivity analysis, Monte Carlo simulations or OAT sensitivity testing could help assess how changes in input variables affect final rankings (Shen, 2024, Hosamo et al., 2024). These features could be implemented via open-source platforms like Python for improved automation and robustness.

8.5.6 Advancing Criteria Weighting Methods and Post-Retrofit Feedback

Although Entropy was selected in this study for its simplicity and widespread use, future research could explore the impact of other objective weighting methods, such as CRITIC. Unlike Entropy, CRITIC accounts for both data dispersion and inter-criteria correlation, potentially offering more refined weight allocations by reducing redundancy. Another important direction is the inclusion of post-retrofit feedback mechanisms. The current SRDSS is a pre-decision tool and does not incorporate performance monitoring after implementation. Building a feedback loop would enable dynamic learning and continuous refinement of decision models based on real-world performance data.

8.5.7 Real-Time and Data-Driven Decision Support

The current SRDSS operates as a static tool based on predefined inputs. Future developments could focus on integrating real-time data streams from BMS and IoT sensors. This would enable performance-based, dynamic decision-making, supporting more responsive and continuous retrofitting evaluations. The integration of environmental and operational data could also help automate alternative scoring and trigger recalculations as new data becomes available, further enhancing the decision-support capability of the model (Piira et al., 2022, Taboada-Orozco et al., 2024, Baset and Jradi, 2025).

8.5.8 Integrating Smart Contracts for Performance Assurance

Future research could explore the integration of smart contracts into the SRDSS framework to enhance transparency, accountability and more efficient and reliable operations and contract administration, especially in multi-stakeholder settings or PPP-led projects (Sinaga et al., 2023, Nour El-Din et al., 2024). Smart contracts could formalise and enforce performance-based agreements, with automatic execution triggered by predefined retrofit outcomes such as energy savings or user comfort thresholds. The SRDSS's outputs, including alternative rankings, weighted criteria and expected benefits, could serve as input conditions for these contracts. Such a system could also support token-based incentives or compliance verification, creating a more secure and trust-driven environment for SR implementation.

8.5.9 Leveraging AI for Predictive and Adaptive Decision-Making

AI offers another promising avenue for enhancing the SRDSS. Machine learning algorithms could be trained on datasets from completed SR projects to predict the most effective retrofit strategies for different building profiles and stakeholder preferences (Bocaneala et al., 2025). Natural Language Processing (NLP) could be used to extract criteria and insights from unstructured documents like technical reports and policy guidelines (Mahadevkar et al., 2024). Furthermore, AI could enable automated scenario simulation and adaptive decision-making as stakeholder behaviours, regulations or technology options evolve (Liu et al., 2024). These enhancements would transform the SRDSS into a more intelligent, context-aware and learning-oriented DSS.

8.6 Chapter Summary

This chapter brought together the key outcomes of the study through a structured review of the research objectives and how they were achieved, an articulation of the study's theoretical and practical contributions, a critical discussion of its limitations, and a forward-looking outline of future research directions. Each research objective was revisited to demonstrate how it was systematically addressed through the adopted methodology and case study application. The study's contributions were categorised to highlight its value in advancing SR theory, supporting decision-making practice, and informing policy and resource allocation. While the study achieved its intended aim and objectives, specific limitations were acknowledged in relation to methodological scope, data generalisability and tool functionality. These insights informed a comprehensive set of future research directions, including technological enhancements to the SRDSS, broader contextual validation, and the integration of emerging technologies. Altogether, this chapter underscores the study's overall impact while setting a foundation for further exploration and refinement of the SRDSS.

APPENDICES

Appendices for Chapter 4

A4.1: Online Questionnaire

Decision-making Criteria for Smart Retrofitting for Commercial Buildings

Dear Sir/Madam,

The aim of this survey is to identify and shortlist the critical criteria to be considered during smart retrofitting decision-making for commercial buildings.

This survey (typically can be completed in a few minutes) is set out in five (5) sections:

1. Consent statement
2. Personal particulars
3. Smart retrofitting decision making criteria hierarchy
4. Rating the importance of smart retrofitting decision making criteria
5. Indicating any additional decision-making criteria

If you have any questions, please contact the student investigator of this project, Miss Sanduni Peiris of PolyU at sanduni.peiris@.

SECTION 1: CONSENT STATEMENT

Please note that your participation in this survey is voluntary.

Before proceeding to the questions, kindly make sure that you understand the content in the 'Information Sheet': https://drive.google.com/file/d/1ft3hDtWW_zFtuGVkWfTMmb-eru-Vk2Jv/view?usp=sharing

The information obtained from this survey may be used in future research and published.

Your opinion and personal information will be used solely for the purposes of this project under strict confidentiality.

Please select your choice below. You may print a copy of this section for your records. Clicking on the "Agree" button indicates that: (1) you have read and fully understood the above information; and (2) you voluntarily agree to participate in the survey. *

○ Agree

○ Disagree

SECTION 2: PERSONAL PARTICULARS

Please state the FM sector(s) you are/have ever been involved in (select all those that apply) *

- ☐ Commercial buildings
- ☐ Residential buildings
- ☐ Hotels
- ☐ Hospitals
- ☐ Shopping Complexes
- ☐ Construction Projects
- ☐ Educational Institutes
- ☐ Academia
- ☐ Other: ____________

Job level: *

- ◯ Senior (e.g. General Manager, Vice President, Chief Engineer)
- ◯ Middle (e.g. Manager, Engineer)
- ◯ Junior (e.g. Management Officer, Assistant Engineer)

Experience (years): *

- ◯ Less than 10
- ◯ 10 - 19
- ◯ 20 - 29
- ◯ 30 or above
- ◯ Other: ____________

Professional qualification/membership (select all those that apply): *

- ☐ IFMA
- ☐ HKIFM
- ☐ BSOMES
- ☐ RICS
- ☐ Other: ____________

Academic qualification (select all those that apply): *

- ☐ Doctorate
- ☐ Master
- ☐ Bachelor
- ☐ Other: ____________

Gender: *

◯ Male

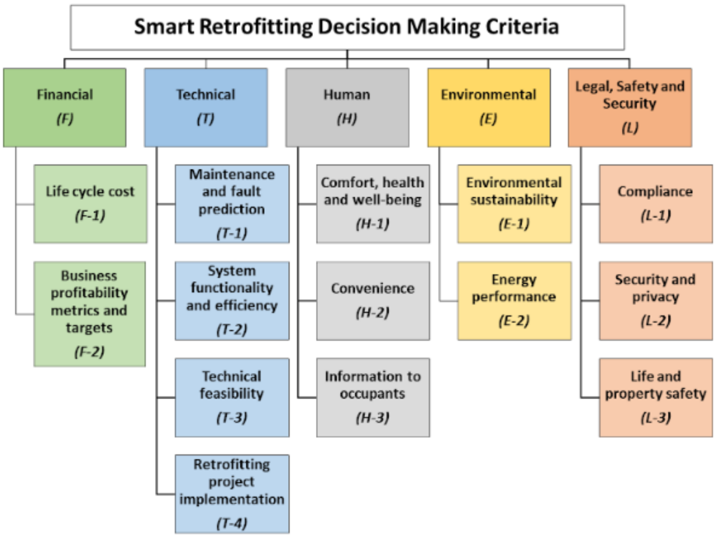
◯ Female

◯ Prefer not to say

SECTION 3: SMART RETROFITTING DECISION MAKING CRITERIA HIERARCHY

'Smart retrofitting' refers to the process of upgrading an 'existing, non-smart building' to become smarter by retrofitting new smart systems and technologies.

The figure below gives an overview of criteria that can be used to compare different smart retrofitting solutions (e.g. smart A/C system, smart carpark system) and decide the most suitable option for a particular building.



SECTION 4: RATING THE IMPORTANCE OF SMART RETROFITTING DECISION MAKING CRITERIA

Please rate the importance of the following criteria in selecting the most suitable option among different smart retrofitting solutions.

Life cycle cost (F-1) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Investment cost	○	○	○	○	○
Recurring operation, maintenance and repair costs	○	○	○	○	○
Disposal cost at the end of life cycle	○	○	○	○	○

Business profitability metrics and targets (F-2) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Return on investment (e.g. higher rental income)	○	○	○	○	○
Operational savings (e.g. labour, utility savings)	○	○	○	○	○
Competitive positioning on the market (e.g. attract new tenants, tenant retention)	○	○	○	○	○

Maintenance and fault prediction (T-1) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Automated fault prediction capabilities	○	○	○	○	○
Inefficient operation detection and diagnosis	○	○	○	○	○

System functionality and efficiency (T-2) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Reliability of retrofitted hardware	○	○	○	○	○
Reliability of retrofitted software	○	○	○	○	○

Technical feasibility (T-3) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Compatibility with existing systems	○	○	○	○	○
Feasibility of installation	○	○	○	○	○
Scalability of the retrofitted system for future business growth	○	○	○	○	○
Availability of competent FM staff to operate and maintain the retrofitted system	○	○	○	○	○

Retrofitting project implementation (T-4) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Duration of retrofitting work	○	○	○	○	○
Availability of expertise to oversee the retrofitting project	○	○	○	○	○
Retrofitting work scheduling (e.g. night time work)	○	○	○	○	○
Safety during retrofitting project (e.g. fire, human, structural)	○	○	○	○	○
Disturbance and inconvenience to current occupants during retrofitting project	○	○	○	○	○

Comfort, health and well-being (H-1) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Ability to improve indoor environmental quality (e.g. air quality, thermal, visual, acoustic comfort)	○	○	○	○	○
Ability to support human health and wellness certification (e.g. WELL)	○	○	○	○	○

Convenience (H-2) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
User friendliness of the retrofitted system	○	○	○	○	○
Ability to minimize human intervention in building operation (e.g. less manual control needed for A/C)	○	○	○	○	○

Information to occupants (H-3) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Ability to increase occupant awareness of building operation (e.g. sensors in meeting rooms indicating no-shows and long meetings)	○	○	○	○	○

Environmental sustainability (E-1) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Resilience against physical climate risks (e.g. extreme weather, flooding)	○	○	○	○	○
Ability to support environmental sustainability certification (e.g. BREEAM, LEED)	○	○	○	○	○

Energy performance (E-2) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Energy saving capabilities	○	○	○	○	○
Ability to facilitate onsite renewable energy generation	○	○	○	○	○

Compliance (L-1) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Ability to comply with regulatory requirements	○	○	○	○	○

Security and privacy (L-2) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Improved data protection capabilities	○	○	○	○	○
Smarter access control and smarter surveillance capabilities	○	○	○	○	○

Life and property safety (L-3) *

	Very High Importance	High Importance	Moderate Importance	Low Importance	Very Low Importance
Automated hazard prediction and response capabilities (e.g. automatically detecting water/gas leaks)	○	○	○	○	○

SECTION 5: INDICATING ANY ADDITIONAL CRITERIA

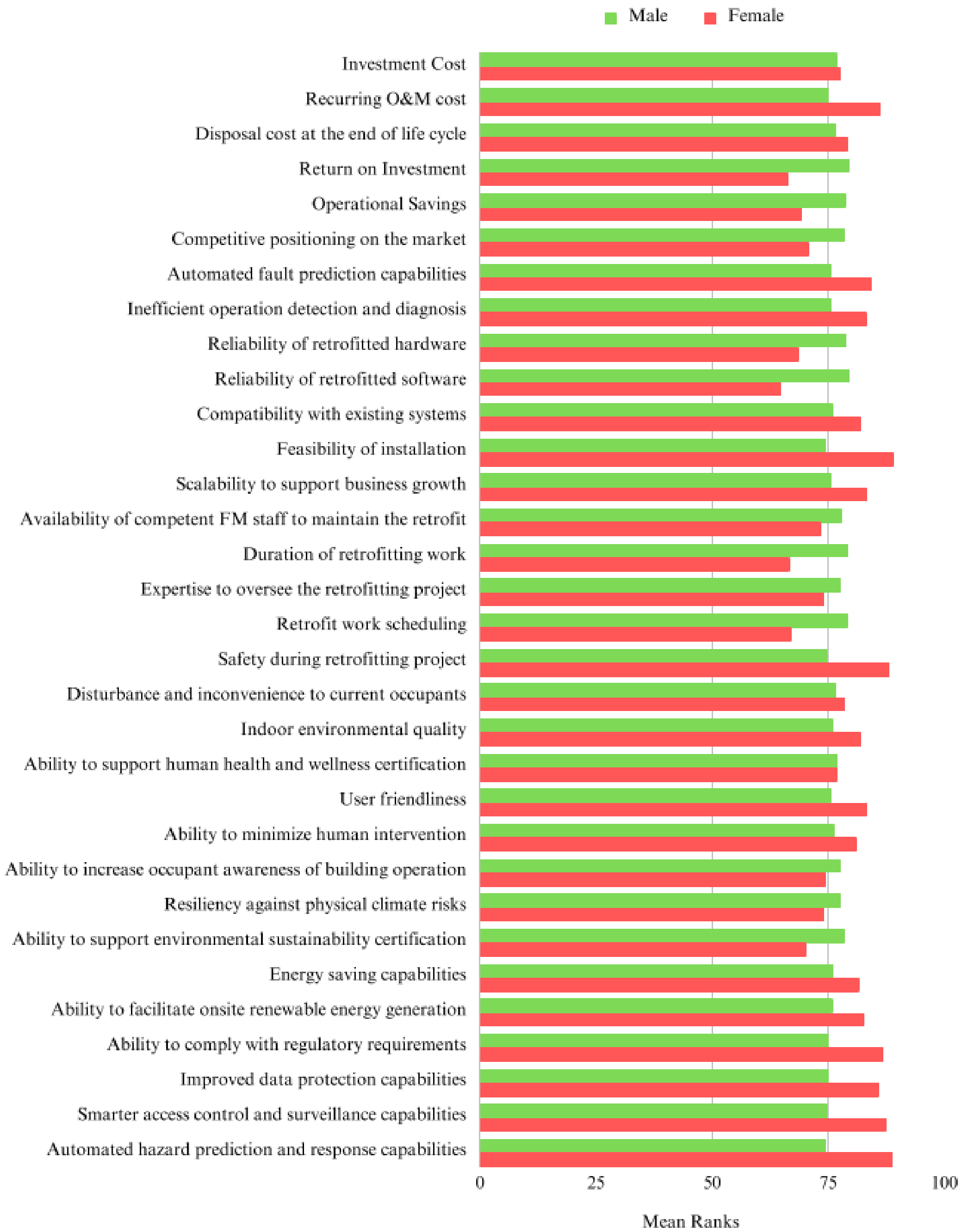
Please specify any other criteria which are important to select the most suitable option among different smart retrofitting solutions.

Your answer

We thank you for your time, responses and willingness to participate in the survey!

A4.2: Results of Statistical Analysis on SPSS

A4.2.1: Mean Importance Ranks of G1 (Gender)



A4.2.2: Mann–Whitney U-test results of G1 (Gender)

		U Value	p - Value (two tailed)
1	Investment Cost	1690.000	0.954
2	Recurring O&M cost	1453.500	0.184
3	Disposal cost at the end of life cycle	1643.000	0.772
4	Return on Investment	1410.000	0.128
5	Operational Savings	1491.000	0.262
6	Competitive positioning on the market	1532.500	0.378
7	Automated fault prediction capabilities	1510.000	0.298
8	Inefficient operation detection and diagnosis	1536.000	0.390
9	Reliability of retrofitted hardware	1472.000	0.210
10	Reliability of retrofitted software	1373.500	0.082
11	Compatibility with existing systems	1566.000	0.476
12	Feasibility of installation	1378.500	0.079
13	Scalability to support business growth	1534.500	0.367
14	Availability of competent FM staff to maintain the retrofit	1602.000	0.595
15	Duration of retrofitting work	1420.000	0.139
16	Expertise to oversee the retrofitting project	1621.500	0.668
17	Retrofit work scheduling	1428.000	0.152
18	Safety during retrofitting project	1399.500	0.113
19	Disturbance and inconvenience to current occupants	1659.500	0.827
20	Indoor environmental quality	1565.500	0.455
21	Ability to support human health and wellness certification	1698.000	0.987
22	User friendliness	1535.000	0.348
23	Ability to minimize human intervention	1594.500	0.561
24	Ability to increase occupant awareness of building operation	1630.500	0.708
25	Resiliency against physical climate risks	1619.500	0.671
26	Ability to support environmental sustainability certification	1514.500	0.333
27	Energy saving capabilities	1579.000	0.516
28	Ability to facilitate onsite renewable energy generation	1551.000	0.437
29	Ability to comply with regulatory requirements	1435.000	0.154
30	Improved data protection capabilities	1464.500	0.209
31	Smarter access control and surveillance capabilities	1420.500	0.119
32	Automated hazard prediction and response capabilities	1381.000	0.079

*Significance at the 0.05 level (2-tailed)

A4.2.3: Mean Importance Ranks of G5 (Academic Qualification)

A4.2.4: Mann–Whitney U-test results of G5 (Academic Qualification)

		U Value	p - Value (two tailed)
1	Investment Cost	2110.000	0.159
2	Recurring O&M cost	2403.500	0.886
3	Disposal cost at the end of life cycle	2422.500	0.956
4	Return on Investment	2426.000	0.966
5	Operational Savings	2227.000	0.360
6	Competitive positioning on the market	2357.000	0.733
7	Automated fault prediction capabilities	2094.000	0.127
8	Inefficient operation detection and diagnosis	2231.500	0.382
9	Reliability of retrofitted hardware	2213.000	0.320
10	Reliability of retrofitted software	2256.000	0.435
11	Compatibility with existing systems	2303.500	0.567
12	Feasibility of installation	2153.000	0.212
13	Scalability to support business growth	2120.500	0.164
14	Availability of competent FM staff to maintain the retrofit	1981.000	***0.047**
15	Duration of retrofitting work	1959.000	***0.039**
16	Expertise to oversee the retrofitting project	2200.500	0.297
17	Retrofit work scheduling	2303.000	0.570
18	Safety during retrofitting project	1960.000	***0.041**
19	Disturbance and inconvenience to current occupants	2134.000	0.194
20	Indoor environmental quality	2403.500	0.883
21	Ability to support human health and wellness certification	2329.500	0.647
22	User friendliness	2426.000	0.963
23	Ability to minimize human intervention	2366.000	0.755
24	Ability to increase occupant awareness of building operation	2371.000	0.776
25	Resiliency against physical climate risks	2225.500	0.367
26	Ability to support environmental sustainability certification	2347.500	0.705
27	Energy saving capabilities	2080.500	0.121
28	Ability to facilitate onsite renewable energy generation	2078.500	0.128
29	Ability to comply with regulatory requirements	1928.000	***0.026**
30	Improved data protection capabilities	2436.000	1.000
31	Smarter access control and surveillance capabilities	2420.000	0.942
32	Automated hazard prediction and response capabilities	2421.000	0.946

*Significance at the 0.05 level (2-tailed)

A4.2.5: Mean Importance Ranks of G2 (Work experience)

A4.2.6: Kruskal–Wallis H-test results of G2 (Work experience)

		H Value	p - Value (two tailed)
1	Investment Cost	0.543	0.909
2	Recurring O&M cost	3.789	0.285
3	Disposal cost at the end of life cycle	4.628	0.201
4	Return on Investment	1.206	0.752
5	Operational Savings	0.578	0.901
6	Competitive positioning on the market	3.364	0.339
7	Automated fault prediction capabilities	1.017	0.797
8	Inefficient operation detection and diagnosis	0.714	0.870
9	Reliability of retrofitted hardware	4.551	0.208
10	Reliability of retrofitted software	0.212	0.976
11	Compatibility with existing systems	3.391	0.335
12	Feasibility of installation	2.118	0.548
13	Scalability to support business growth	2.972	0.396
14	Availability of competent FM staff to maintain the retrofit	0.930	0.818
15	Duration of retrofitting work	4.136	0.247
16	Expertise to oversee the retrofitting project	1.720	0.632
17	Retrofit work scheduling	2.609	0.456
18	Safety during retrofitting project	1.907	0.592
19	Disturbance and inconvenience to current occupants	0.960	0.811
20	Indoor environmental quality	0.757	0.860
21	Ability to support human health and wellness certification	2.914	0.405
22	User friendliness	0.794	0.851
23	Ability to minimize human intervention	0.492	0.921
24	Ability to increase occupant awareness of building operation	4.974	0.174
25	Resiliency against physical climate risks	1.029	0.794
26	Ability to support environmental sustainability certification	2.251	0.522
27	Energy saving capabilities	4.085	0.252
28	Ability to facilitate onsite renewable energy generation	2.251	0.522
29	Ability to comply with regulatory requirements	1.412	0.703
30	Improved data protection capabilities	3.559	0.313
31	Smarter access control and surveillance capabilities	3.291	0.349
32	Automated hazard prediction and response capabilities	2.304	0.512

*Significance at the 0.05 level (2-tailed)

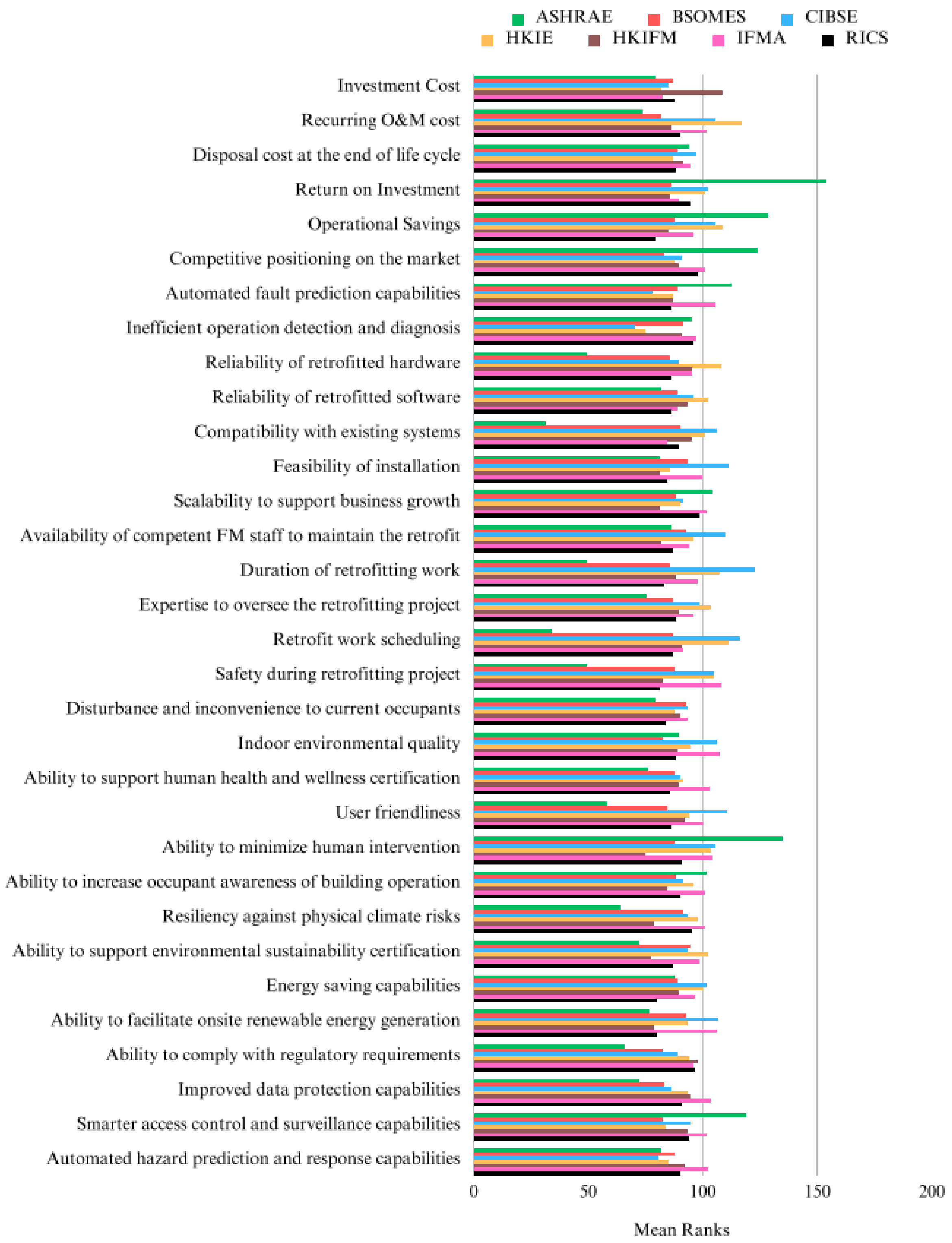
A4.2.7: Mean Importance Ranks of G3 (Job level)

A4.2.8: Kruskal–Wallis H-test results of G3 (Job level)

		H Value	p - Value (two tailed)
1	Investment Cost	4.592	0.101
2	Recurring O&M cost	0.842	0.656
3	Disposal cost at the end of life cycle	2.307	0.316
4	Return on Investment	0.996	0.608
5	Operational Savings	1.699	0.428
6	Competitive positioning on the market	1.060	0.589
7	Automated fault prediction capabilities	3.226	0.199
8	Inefficient operation detection and diagnosis	3.750	0.153
9	Reliability of retrofitted hardware	2.265	0.322
10	Reliability of retrofitted software	0.031	0.985
11	Compatibility with existing systems	1.028	0.598
12	Feasibility of installation	1.982	0.371
13	Scalability to support business growth	0.912	0.634
14	Availability of competent FM staff to maintain the retrofit	2.386	0.303
15	Duration of retrofitting work	0.992	0.609
16	Expertise to oversee the retrofitting project	0.097	0.953
17	Retrofit work scheduling	1.270	0.530
18	Safety during retrofitting project	0.815	0.665
19	Disturbance and inconvenience to current occupants	0.251	0.882
20	Indoor environmental quality	0.174	0.917
21	Ability to support human health and wellness certification	0.084	0.959
22	User friendliness	0.438	0.803
23	Ability to minimize human intervention	0.343	0.843
24	Ability to increase occupant awareness of building operation	0.571	0.752
25	Resiliency against physical climate risks	0.449	0.799
26	Ability to support environmental sustainability certification	0.412	0.814
27	Energy saving capabilities	3.043	0.218
28	Ability to facilitate onsite renewable energy generation	1.273	0.529
29	Ability to comply with regulatory requirements	1.116	0.572
30	Improved data protection capabilities	1.269	0.530
31	Smarter access control and surveillance capabilities	1.945	0.378
32	Automated hazard prediction and response capabilities	1.485	0.476

*Significance at the 0.05 level (2-tailed)

A4.2.9: Mean Importance Ranks of G4 (Professional Qualification)



A4.2.10: Kruskal–Wallis H-test results of G4 (Professional Qualification)

		U Value	p - Value (two tailed)
1	Investment Cost	7.992	0.239
2	Recurring O&M cost	9.548	0.145
3	Disposal cost at the end of life cycle	0.563	0.997
4	Return on Investment	7.404	0.285
5	Operational Savings	7.206	0.302
6	Competitive positioning on the market	5.235	0.514
7	Automated fault prediction capabilities	5.183	0.521
8	Inefficient operation detection and diagnosis	3.723	0.714
9	Reliability of retrofitted hardware	5.926	0.432
10	Reliability of retrofitted software	1.381	0.967
11	Compatibility with existing systems	6.867	0.333
12	Feasibility of installation	5.342	0.501
13	Scalability to support business growth	4.267	0.641
14	Availability of competent FM staff to maintain the retrofit	3.247	0.777
15	Duration of retrofitting work	10.006	0.124
16	Expertise to oversee the retrofitting project	2.514	0.867
17	Retrofit work scheduling	9.710	0.137
18	Safety during retrofitting project	10.225	0.116
19	Disturbance and inconvenience to current occupants	0.896	0.989
20	Indoor environmental quality	7.090	0.313
21	Ability to support human health and wellness certification	2.881	0.824
22	User friendliness	6.363	0.384
23	Ability to minimize human intervention	11.954	0.063
24	Ability to increase occupant awareness of building operation	2.531	0.865
25	Resiliency against physical climate risks	5.394	0.494
26	Ability to support environmental sustainability certification	5.632	0.466
27	Energy saving capabilities	2.649	0.851
28	Ability to facilitate onsite renewable energy generation	7.927	0.244
29	Ability to comply with regulatory requirements	4.547	0.603
30	Improved data protection capabilities	4.428	0.619
31	Smarter access control and surveillance capabilities	5.740	0.453
32	Automated hazard prediction and response capabilities	2.822	0.831

*Significance at the 0.05 level (2-tailed)

Appendices for Chapter 5

A5.1: Interview Guide used for Expert Interviews

Developing a Holistic Decision-Making Model for Smart Retrofitting for Office Buildings

Objectives of Study:

1. Identify, refine and structure a comprehensive set of criteria for evaluating SR alternatives in office buildings
2. **Establish the relative importance of the identified criteria by capturing their interdependence**
3. Develop an SRDSS through the integration of MCDM methods
4. Apply the SRDSS to real-world case studies from both developed and developing regions and compare the findings between the regions
5. Validate the usability, reliability and practicality of the SRDSS and refine the system based on validation outcomes

The Objective of Expert Interviews:

- The expert interviews will be conducted in order to attain **Objective No. 2**.
- First, the existing setting of the SR decision-making procedure in commercial buildings will be explored.
- The Analytic Network Process (ANP) will then be used to determine the relative importance of SR decision-making criteria based on expert opinion.

(Please see next page)

Personal Particulars

Job Title		Professional memberships	
Work experience		Highest academic qualification	Dip/BSc/MSc/PhD

Part I – Current Situation of SR Projects

1. What is the current decision-making procedure when retrofitting a commercial building with smart building features?
    a. What is the procedure for identifying areas of the building that require improvement?
    b. What is the process for identifying smart building features that can meet these requirements?
    c. What is the procedure for prioritising the most suitable and timely option from the different options available?

2. What are the challenges faced during this decision-making process?
    a. Are there any internal constraints/ issues within the organisation that restrict optimising the retrofit project? If yes, what are they?
    b. Are there any external constraints/ issues that restrict optimising the retrofit project? If yes, what are they?
    c. What are the other barriers, if any, that may be faced during this decision-making process

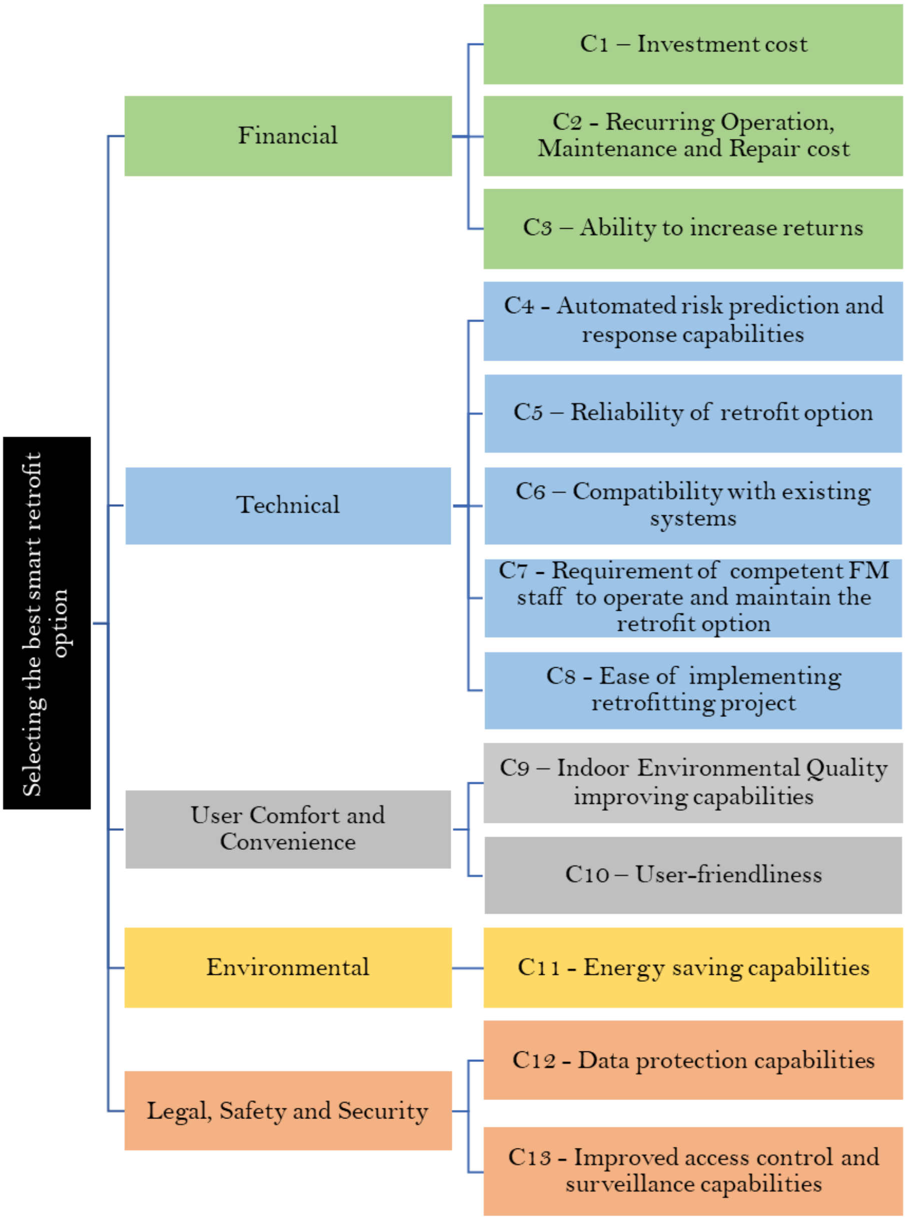
(Please see next page)

Part II – Relative Importance of Decision-Making Criteria

Part II of the interview is based on the hierarchy shown in figure 1. The criteria are categorised into five clusters.

The hierarchy shows a list of criteria that affect the choice of the most appropriate and timely smart retrofit option out of several smart retrofit options that the landlord organisation wants to implement in an office building (that is either completely or partially occupied; leasehold).

The purpose of part II of the interview is to rank these criteria according to their relative importance.



SR decision making criteria

Ranking criteria according to their relative importance:

Kindly answer the following questions based on the scenario of selecting/prioritising the most suitable and timely smart retrofit option in office buildings.

For instance, question 1 can be interpreted as follows:

"When considering the **Energy saving capabilities** of a particular smart retrofit option, which of the following two criteria are more important than the other? Is it the investment cost of the smart retrofit option, or its ability to increase returns?

1. With respect to "**C11 - Energy saving capabilities**" node in "Financial" cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

Number 1 on the rating scale means that both 'investment cost' and 'ability to increase returns' are equally important. But rating on the left half of the scale means that 'investment cost' is more important than 'ability to increase returns'. Rating on the right half the scale means that 'ability to increase returns' is more important than 'investment cost'. Numbers 2 – 9 on the scale indicates the different levels of relative importance with '2' being "weak importance of one criterion over the other" and '9' being "absolute importance of one criterion over the other"

Based on your ratings, the relative importance will be determined by a software application titled, 'Super Decisions'.

Please rate the following accordingly:

1. With respect to "**C11 - Energy saving capabilities**" node in "Financial" cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

2. With respect to "**C1 – Investment Cost**" node in "Financial" cluster, choose the perceived relative importance between:		
(C-2) Recurring Operation, Maintenance and Repair cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

3. With respect to "**C1 – Investment Cost**" node in "Financial" cluster, choose the perceived relative importance between:		
(C-5) Reliability of retrofit option	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-6) Compatibility with existing systems

4. With respect to "**C2 – Recurring Operation, Maintenance and Repair cost**" node in "Financial" cluster, choose the perceived relative importance between:		
(C-5) Reliability of retrofit option	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-7) Requirement of competent FM staff

5. With respect to “**C3 – Ability to increase returns**” node in “Financial” cluster, choose the perceived relative importance between:		
(C-1) Investment Cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-2) Recurring Operation, Maintenance and Repair cost

6. With respect to “**C12 - Data protection capabilities**” node in “Financial” cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

7. With respect to “**C12 - Data protection capabilities**” node in “Technical” cluster, choose the perceived relative importance between:		
(C-4) Automated risk prediction and response capabilities	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-5) Reliability of retrofit option

8. With respect to “**C13 - Improved access control and surveillance**” node in “Technical” cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

9. With respect to “**C4 - Automated risk prediction and response capabilities**” node in “Financial” cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-2) Recurring Operation, Maintenance and Repair cost

10. With respect to “**C5 - Reliability of retrofit option**” node in “Financial” cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-2) Recurring Operation, Maintenance and Repair cost

11. With respect to “**C5 - Reliability of retrofit option**” node in “Financial” cluster, choose the perceived relative importance between:		
(C-12) Data protection capabilities	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-13) Improved access control and surveillance

12. With respect to "**C5 - Reliability of retrofit option**" node in "Human" cluster, choose the perceived relative importance between:		
(C-9) Indoor Environmental Quality improving capabilities	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-10) User-friendliness

13. With respect to "**C6 – Compatibility with existing systems"** node in "Technical" cluster, choose the perceived relative importance between:		
(C-5) Reliability of retrofit option	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-8) Ease of implementing retrofitting project

14. With respect to "**C7 - Requirement of competent FM staff**" node in "Financial" cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-2) Recurring Operation, Maintenance and Repair cost

15. With respect to "**C8 - Ease of implementing retrofitting project"** node in "Financial" cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

16. With respect to "**C9 – Indoor Environmental Quality improving capabilities"** node in "Financial" cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

17. With respect to "**C10 – User-friendliness**" node in "Financial" cluster, choose the perceived relative importance between:		
(C-1) Investment cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	(C-3) Ability to increase returns

18. With respect to "**Legal, Safety and Security**" cluster, choose the perceived relative importance between:		
Financial	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Legal, Safety and Security
Financial	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Technical
Financial	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User Comfort and Convenience
Legal, Safety and Security	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Technical
Legal, Safety and Security	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User Comfort and Convenience
Technical	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User Comfort and Convenience

19. With respect to "**Technical**" cluster, choose the perceived relative importance between:		
Environmental	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Financial
Environmental	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Legal, Safety and Security
Environmental	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Technical
Environmental	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User Comfort and Convenience
Financial	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Legal, Safety and Security
Financial	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Technical
Financial	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User Comfort and Convenience
Legal, Safety and Security	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Technical
Legal, Safety and Security	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User Comfort and Convenience
Technical	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User Comfort and Convenience

20. With respect to "**Financial**" cluster, choose the perceived relative importance between:		
Financial	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Technical

A5.2: Important Quotes from Expert Interviews

Theme 1: Drivers and Motivations

Sub Theme 1.1: Financial Performance and Market Positioning

Sub Theme 1.1.1: Business value, revenue and branding

Sri Lanka	SL-10	Another factor is how well they can market these smart features to attract buyers or tenants.
	SL-12	Cost considerations, especially reducing service charges driven by electricity costs, are significant for tenants.
	SL-07	Certification also benefits commercial property owners, as it increases rental value and tenant retention.
		In Singapore, many luxury buildings focus on green certifications due to customer demand. Renewable energy adoption is often driven by the need for sustainability branding. Data-driven decision-making ensures energy efficiency in commercial buildings. Buildings must focus on reliability, resilience, and overall performance. Advanced detection systems can improve diagnostics and automated work verification.
Hong Kong	HK-09	Usually when the marketing department sees that there is trend in the market, e.g., cinema becomes more popular than restaurants in the market, then they will do retrofitting and convert shopping areas from restaurants to cinemas.
		Developers are more concerned about the image when it comes to ESG.
		The third reason is of course marketing. So whichever retrofit option they think that brings a higher revenue, is selected in the marketing perspective.
	HK-08	If you have a very old building in a central location, it still holds value due to its location. The landlord might be more willing to invest in upgrades to attract higher rental fees. They may be more inclined to upgrade the building to a "smart building," which is a popular term among international investors looking to invest in central areas.
		If I'm the landlord, my ultimate aim is to increase revenue from my rental office space. I would consider how to upgrade my rental fees. What makes tenants willing to pay more?
	HK-06	They will market those items that they did to attract more tenants and at the same time to increase the rental.
	HK-07	So the main purpose of the decisions would be making money. So obviously it is not for self-use. So how to attract the tenants, how to bring up the value of the premises to get a higher rent and get a better return.
	HK-11	But about user experience, tenant realisations. If there are customer attracting systems, they you can rent the property for an attracting rent.
		When we did the HVAC optimisation retrofitting with a particular client, I think what the client tried to prioritise was, like the first question they asked us were, 'so is this new in Hong Kong?'. So they wanted to do something new. So it depends on the company goal. So if we take this as a case study, they wanted to do something innovative and they wanted to show their top management that they are doing something that has never been done in Hong Kong before, and its suitable because its new.

Sub Theme 1.1.2: Competitive benchmarking

Sri Lanka	SL-07	Countries like Singapore are setting ambitious goals, by 2030, they aim to have super low-energy buildings and net-zero buildings.
		Singapore is setting the benchmark, and surrounding countries like Malaysia, Indonesia, and Thailand are beginning to follow its example.
		Although there is no government mandate in Sri Lanka yet, we should look at Singapore's model, where the government has created energy reference models for different types of spaces.
	SL-03	When comparing energy consumption in buildings, benchmarking is crucial. For instance, in similar buildings in Singapore, energy consumption is measured in kilowatt-hours per square meter. Understanding these benchmarks helps evaluate the efficiency of local buildings. A comprehensive analysis of the existing scenario is necessary. Benchmarking should include key indices and range comparisons. Identifying major system components and inefficiencies is a crucial step.
		HVAC systems are a significant energy consumer. The efficiency ratio of plants in Singapore, for example, is typically around 1.4 to 1.6. Comparing these figures helps in optimizing operational efficiency.
Hong Kong	HK-09	Developers are more and more concerned about the image when it comes to ESG.
		Usually they will spot on the market, what the other developers are doing, what their competitors are doing and they will follow.
		The second step is they will carry out a market survey and identify what is available in the market which can improve the ESG image. For example, Some bigger developers in the last 10 years have installed solar panels in the roof tops. And in the last 2-3 years, many small developers, seeing that the bigger developers have installed solar panels in the roof tops, so they are starting to do so right now as well. So that is how they learn from other competitors. Another example is electrical vehicles and they need charging facilities in the car park. So the bigger developers have installed EV chargers in their carparks. And then the smaller developers follow because they see the bigger developers have this.
	HK-08	Additionally, I would look into features that could enhance the building's reputation and competitiveness compared to other buildings in central locations. I would research what other buildings are doing and adopt similar strategies. Current trends include environmental control measures related to indoor air quality, temperature, humidity, and lighting levels that can be adjusted according to different times of the day. These are becoming standard in smart buildings.
		Selection is based on benchmarking and comparison. Since these upgrades are not regulatory requirements, we have the freedom to choose. I would compare my building's features with those of neighbouring buildings. If they have certain features, I would consider implementing them to keep my building competitive. This is especially important for buildings in central locations.
	HK-01	They need to meet current regulations, ESG requirements, and maintain competitiveness with other buildings.
	HK-03	They typically benchmark against other new buildings.
		In Hong Kong, associations like the Quality Building Award encourage this. If a building is new or retrofitted, stakeholders might seek awards or funding from the government or professional bodies.
	HK-07	You need to find the best time to implement something. If you miss the opportunity then you will be behind the frontier.
		If you are behind the market, then you have to catch up, then you have to re-prioritize, re-schedule your plan to in to the market competition.

	HK-10	Most listed companies release ESG reports because their competitors do, and it's also linked to investment. Investors look at ESG, so even if it's not compulsory, companies voluntarily release these reports. Most developers in Hong Kong, especially big ones, release ESG reports.

Sub Theme 1.1.3: Energy efficiency and cost savings

Sri Lanka	SL-01	For instance, if we take a chiller, if the COP values deviate a lot from the benchmark values, it means that its time to take a decision.
	SL-10	One of the main concerns is power consumption, with a significant portion of energy use coming from air conditioning.
		We can also integrate sensors to enhance efficiency. For example, light and occupancy sensors can adjust illumination levels based on real-time movement.
		Cost is the primary consideration.
	SL-11	For example, we had an 800-ton air conditioning unit in the past, which was wasteful because it ran constantly. Now, we use a centrifugal chiller, which operates at different capacities: 25%, 50%, 75%, or 100%. This way, we can adjust based on the demand, like for a single tenant or a portion of a floor, without wasting energy.
		So, the first step is to remove waste. The company might say, “Let’s start with removing waste first, then we can see how to gain something from it.”
	SL-05	So, it’s not just about the equipment you use; it's also about controlling how and when they operate to avoid wastage.
		Many processes are manual, and the systems in place are underperforming. IoT could be a game-changer, providing independent, accurate systems that gather a large amount of data. The factory environment doesn't need to be massively modified to integrate IoT; it can start with simple monitoring systems. I believe this could be a turning point for any organization, especially in terms of monitoring, quality improvement, and productivity.
	SL-02	Additionally, energy efficiency standards play a key role. For example, in Singapore, the energy efficiency standard for cooling systems is around 0.3 kW per TR, whereas some buildings in Sri Lanka consume 0.45 kW per TR. This indicates a significant energy loss and an opportunity for improvement through SR.
	SL-07	Reducing energy consumption and lowering our carbon footprint are essential steps toward creating a sustainable society.
		Commercial buildings contribute to approximately 40% of overall emissions. If we do not reduce this, there will be a significant impact on society.
	SL-08	The primary motivation for these businesses is to lower operational costs.
		Cost savings remain the main driver. Companies invest in smart retrofitting when they face high operational expenses, particularly in areas like energy consumption and workforce costs.

		Businesses aiming to save energy focus on high-energy-consuming equipment, with air conditioning being the primary concern. They may introduce occupancy sensors and automated controls to optimize energy use.
Hong Kong	HK-08	I would consider what smart features could be added to enhance convenience for tenants and achieve energy savings, which is important for reducing costs and improving returns. Energy conservation measures are crucial, as they can significantly impact my bottom line.
	HK-05	Cost savings, such as reducing manpower by upgrading security systems, can also motivate landlords to implement smart features.

Sub Theme 1.2: Operational Challenges and Technology Needs

Sub Theme 1.2.1: Aging systems and maintenance issues

Sri Lanka	SL-01	When the systems are outdated, the breakdown rate will be high.
		Also, the energy consumption will be high. For instance, if we take a chiller, if the COP values deviates a lot from the benchmark values, it means that its time to take a decision.
		Sometimes, the spare parts also become unavailable.
	SL-10	Additionally, we need to involve the technical team to analyse what issues exist within the building's infrastructure.
	SL-06	Systems which are 15-20 years old do not have communication facilities. In this case, we need to find alternatives for that.
		Existing electrical panels have not been designed for a BMS remote operation. In this case, we try to modify them.
	SL-04	Most of its systems are around 20 years old, and some are no longer in production. If a critical component, such as a control unit, fails, we face significant challenges in sourcing replacements.
		Therefore, as engineers, we must plan upgrades in advance to prevent failures and ensure building operations remain smooth.
	SL-07	Level 1 Audit – A preliminary inspection to assess existing systems and operating conditions.; Level 2 Audit – A more detailed analysis that includes evaluating chillers, efficiency levels, commissioning history, and building management system (BMS) data. This audit also establishes a baseline using historical energy consumption data.; Level 3 Audit – A comprehensive assessment that identifies potential improvements, categorized as no-cost, low-cost, and high-cost measures.
Hong Kong	HK-02	Retrofitting becomes necessary when a building is aging, and its original design no longer meets current compliance requirements or technical standards.
		Facility management teams often conduct energy audits to assess performance and identify necessary improvements.
	HK-08	If my building is old, I would consider improving lift traffic to ensure tenants can reach their offices quickly. Reliable electricity supply is also crucial.
	HK-03	Additionally, when equipment reaches the end of its life, upgrades are necessary.

	HK-04	The very basic and fundamental one is you having a checklist and you need to do a due diligence exercise and see what are the shortfalls.
	HK-07	I think efficiency is one the factors mainly considered in this aspect. If the building is not operated efficiently and there are some inherent efficiency problems, going into smart systems is one way how they can resolve the existing problems.
		So normally as we just mentioned, they need to do a due diligence. Some of the very common ones in the market are energy audit, carbon audit, or sometimes in a bigger scale the FM audit. To identify the current problems they are having and what are the opportunities based on different benchmarking exercises.
	HK-10	Another point is the equipment lifecycle. Every system and building component, even facades, have a lifespan. When they reach the end of their lifespan, retrofitting is necessary. The procedures involve ensuring reliability through preventive maintenance, replacing equipment around its lifespan, even if it still works.

Sub Theme 1.2.2: Security, resilience and risk reduction

Sri Lanka	SL-09	Priority should be based on the nature of incidents, implying that the system should adapt depending on the severity or importance of the situation.
	SL-05	It's important to monitor whether the expected conditions are met. The temperature needs to be kept below 25°C, and the Relative Humidity (RH) level must stay under 55%. If this isn't maintained, it could compromise $1,000,000 worth of data stored in the server room.

Sub Theme 1.3: Sustainability and Policy Drivers

Sub Theme 1.3.1: ESG, Net-Zero and sustainability commitments

Sri Lanka	SL-07	Ultimately, the goal is to reduce energy waste, improve operational efficiency, and work toward achieving net-zero emissions.
		Green certifications are now a key motivation for adopting renewable energy.
Hong Kong	HK-02	One common reason is to improve energy efficiency and sustainability. In such cases, landlords allocate a budget, explore available technologies, and then proceed with implementation.
		Energy and Sustainability Benefits: These include reductions in energy consumption and carbon footprint.
	HK-09	So bigger developer usually sets aside budget for retrofitting to suit ESG requirement.
	HK-08	Another consideration is pursuing certifications, such as green building or smart building certifications. These can enhance the building's appeal and serve as evidence of meeting certain standards. Certifications like LEED or WELL can be attractive to international investors, reducing their need to conduct extensive research on the building.

	HK-01	Additionally, ESG (Environmental, Social, and Governance) requirements are becoming important. Many corporations are looking at ESG requirements for older buildings that don't have a green certificate, like BEAM Plus or LEED.
	HK-04	Because people now a days are concerned about WELL, Green and this will depend on the corporation's goal or promise on how they would contribute to the society. And that is something that could align with the corporation's objectives.
		But in Hong Kong there are already some famous or top five developers trying to sell that they have the social responsibility, what they are trying to achieve and provide to there tenants, not just provisions but they demand on what their tenants should do to achieve the common goal.
	HK-06	And also most of the tenants now in Hong Kong, no matter whether they are large corporation or small company, they also have the idea to save more energy, to make our life more green, in the perspective of ESG.
	HK-07	And also now a days, they also need to do the ESG. So, the triple bottom line would be something they also need to consider.
		Like a developer would position them as a very environmental conscious company. So they heavily invest in it and this one of the market positions they want to maintain.
		So if there are some companies who have committed to the net zero, then how do they achieve the net zero status by the committed date, that is also something they need to take in to consideration. Lets say they publicly announced that they are going to achieve net zero by 2030, so now its already 2023 right? So they only have a few more years. So this is something they need to rush up to do and this would be a very major determinant.
	HK-10	First of all, one aspect is driven by ESG. Definitely, you know that some building owners are listed companies, so they have to release their ESG report and also their performance. In Hong Kong, listed companies need to release their ESG report. Once you have the report, you need to set targets, like energy saving or water reduction targets. They benchmark whether they can meet these targets by 2030 or 2050, with short-term and long-term goals. To meet these targets, they need to make improvements. One significant way to reduce energy consumption is by replacing equipment, which involves retrofitting existing equipment like chillers and pumps, as these consume a large amount of energy in the building. So, ESG is one driver.
		Most listed companies release ESG reports because their competitors do, and it's also linked to investment. Investors look at ESG, so even if it's not compulsory, companies voluntarily release these reports. Most developers in Hong Kong, especially big ones, release ESG reports.
	HK-11	They have certain ESG related requirements and they say that they need to save this many tons of CO_2.

Sub Theme: 1.3.2: Government regulations and incentives

Hong Kong	HK-02	Additionally, government bodies and organizations like the Green Building Council actively promote energy-saving initiatives and virtual commissioning.
		Some retrofits are required to meet updated compliance standards.
	HK-09	The selection process that I observed is first of all, whether there are any government requirements. If the government requires them to do so, then there is no excuse that they avoid from doing this.

		Incentives given by the government. One such incentive given by the government is actually solar panels. The government in Hong Kong forces the power companies to buy the electricity produced by solar panels at a price much higher than the price consumer pays the power company. Now for example, if you live on the Kowloon side, you pay HKD 1.20 per kWh to CLP you use. But the government forces China Light and Power to buy the electricity generated by solar panels at 4 HKD per kWh. So it is several times higher than the consumer price. So this is one incentive. And therefore developers installing solar panels will have income from the power company. The same incentive applies to wind turbine as well.
	HK-01	The main objective is to comply with up-to-date regulations, such as fire regulations, and to remain competitive with surrounding buildings.
	HK-03	Based on statutory regulations, landlords need to make upgrades to comply.
	HK-05	For example, the government might require upgrades to air conditioning systems to save energy. In such cases, landlords might receive subsidies for using energy-efficient equipment, which can influence their decisions.
	HK-06	Because you know we've got MBIS. Mandatory Building Order, like that. So I think, the first thing is we need to comply with that. To check the building condition.
	HK-10	Another factor is subsidies from power companies. In Hong Kong, there are two power companies: CLP Power for the New Territories and Hong Kong Electric for Hong Kong Island. The government encourages these companies to help building owners with retrofitting by providing subsidies. For example, CLP offers an Eco Building Fund, which building owners can apply for to upgrade equipment. This funding is a driving force for retrofitting because it provides financial support.

Sub Theme 1.4: Tenant-driven Factors

Sub Theme 1.4.1: Tenant Comfort, satisfaction and requests

Sri Lanka	SL-10	If possible, we should also gather feedback from customers. Through these discussions, we can identify the shortcomings of the existing design and assess the features currently in use. Conducting a survey can also help us gather relevant data.
	SL-11	This can involve providing comfort to the tenants or using it as an attraction to bring in new tenants.
	SL-12	Tenants become attached to a building when they are comfortable, even resisting rent increases to stay.
		The interviewee stresses that the feedback from the building's customers (occupants, tenants, or users) is essential in identifying smart solutions that will improve operations.
	SL-04	One approach is through frequent complaints from building tenants, department members, or other stakeholders. If we receive repeated concerns about specific issues, that signals a need for investigation.
	SL-03	A well-integrated smart system ensures better decision-making, reduces operational costs, and improves the overall building experience for occupants.
		Customer satisfaction is an important factor.

Hong Kong	HK-02	Operational Enhancements: Smart retrofits can improve building operations, making facilities more efficient and beneficial for tenants.
	HK-08	Tenants have certain demands, such as comfort levels and adaptability. The HVAC system should be easy to adjust without much disturbance to tenants, possibly through a BMS system for centralized control.
	HK-03	On the tenant side, they often have expectations regarding indoor air quality. Nowadays, everyone is focused on occupant comfort and air quality to maintain good conditions.
		The building's characteristics and stakeholder expectations also play a role.
	HK-04	And also it would depend on how big a space you are going to lease, from that landlord and how big an impact you are requesting to put in to the existing system.
	HK-05	If an IT firm needs to move into a new office within three months, and the upgrades take longer, they might not consider that location.
		Internally, landlords aim to attract anchor tenants, like well-known global brands. Having such tenants can reduce internal constraints because they enhance the building's reputation and attract more tenants. The bargaining power of international groups is strong, allowing them to negotiate more than smaller firms. If a global firm wants a specific floor arrangement, the landlord might need to relocate other tenants to accommodate them.
		Tech companies often work late, so extended air conditioning hours might be necessary.
		Tech firms might require more power for servers. If the existing facilities can't meet future demands, upgrades are essential. Otherwise, the building can only cater to tenants with lower requirements.
	HK-10	Another driver for retrofitting is client demand for improved service levels, like advanced lighting functions. Prestigious developers might retrofit to enhance service levels, even if not necessary.

Theme 2: Challenges and Barriers

Sub Theme 2.1: Financial and Investment Barriers

Sub Theme 2.1.1: Difficulty Justifying intangible benefits

Sri Lanka	SL-12	Intangible benefits, such as improved customer satisfaction, can be indirectly measured.
		A key indicator is positive customer feedback from surveys, which often correlates with tenant retention and willingness to pay higher rents.
		Though these are classified as intangible benefits, they ultimately translate into tangible financial gains through higher property values and tenant retention.
Hong Kong	HK-06	they also think something they cannot calculate if they really make the building like smart: how much will be the increase in their rental; its difficult for them to have the key numbers that if I renovate the building, tomorrow if it becomes a smart building, then what is the

		return in increasing the rental? If we can give them the definite answer, then all the landlords and the owners, they will consider. It is a difficult to answer.
	HK-10	For example, IoT sensors and networks provide valuable data, enabling analytics and insights for building owners and tenants. New technologies like machine learning and big data allow predictive analytics, enhancing service levels. These long-term, intangible benefits are important, even if immediate ROI isn't clear. Some companies may try pilot schemes for digital twins, linking construction BIM models to facility management. Digital twins offer a comprehensive platform, aligning with trends like the metaverse. Companies may adopt these technologies to lead the market and enhance their reputation.
		Intangible benefits are considered if they directly impact tenants, but benefits for staff may not be prioritized.

Sub Theme 2.1.2: Financial constraints and budget approval

Sri Lanka	SL-01	Difficulty to get financial approval
	SL-10	The consultants propose solutions, but sometimes the decision-making process prioritizes architectural aspects over technological requirements. For example, the client might allocate a significant portion of the budget to architectural finishes, such as decorative elements and furniture, instead of investing in technological improvements. Since the overall budget is fixed, this reduces the funds available for smart retrofit solutions.
	SL-11	The accounts department may be hesitant due to budget concerns. They worry about spending too much, especially if it could impact the business's financial stability.
		If a landlord plans to retrofit, they may need to take out loans, which could restrict their financial flexibility. The availability of loans from banks can affect the project's execution.
	SL-12	Strict maintenance regulations and approvals can delay basic repairs.
		One of the primary constraints identified is the limited funds available for retrofitting projects. This financial limitation is particularly acute for older buildings or projects that require significant investment, making it difficult to allocate resources efficiently.
	SL-05	The main problem is the initial cost.
	SL-08	The biggest constraint is cost. Budget limitations are the most significant barrier in retrofit projects.
		Many clients have a predefined budget in mind, but it is often lower than what is required to achieve the desired transformation.
Hong Kong	HK-12	And secondly, it would be the cost.
	HK-02	The availability of investment funds can limit the scope of retrofitting projects.
	HK-08	Funding is a major issue. As a landlord, we need to secure financing for these upgrades, whether from banks or other sources. Without funding, we can't proceed
		Another internal challenge is long-term planning. If we plan to hold the building for a long time, it's easier to justify the investment. However, if we intend to sell the building soon, spending money on upgrades might not make sense.
	HK-03	Investment cost is a constraint because budgets are often limited. If a proposal exceeds the budget, it impacts the project.
	HK-05	budget constraints can limit upgrades. Each year, there is a budget for electricity and maintenance. If upgrades exceed this budget, they might not proceed.
	HK-07	Internally of course budget is the biggest challenge I would say.

	HK-10	Another constraint is budgeting. Projects require presenting plans at least a year in advance to convince the Chief Financial Officer (CFO) of reasonable ROI. Approval from the board of directors is necessary for funding.

Sub Theme 2.1.3: ROI and justification challenges

Sri Lanka	SL-06	IAQ and comfort are all considered as benefits but these intangible benefits are considered as value added benefits, we cannot show a payback from these benefits. When we try to justify many benefits, we get stuck in meetings because some are intangible.
	SL-04	We conduct surveys when needed, especially when we need strong evidence to justify a retrofitting project to top management. Decisions require clear technical and financial justification and having supporting data helps secure approval from both management and directors.
		convincing management is a major challenge, especially when a project is necessary but expensive. Even when we are certain a particular system is the best option, cost constraints may prevent us from proposing it directly.
		Since management views projects through a financial lens, we must present a strong business case with cost-benefit analysis. In some cases, if the preferred solution is not feasible due to budget limitations, we explore alternative options based on past experiences.
Hong Kong	HK-02	Uncertain Payback Periods: Landlords need to evaluate how long it will take to recover their investment, which influences decision-making.

Sub Theme 2.2: Institutional and Organisational Challenges

Sub Theme 2.2.1: Complexities in building ownership structure

Sri Lanka	SL-12	Resource-wise, a building can have either a single owner or multiple owners under a strata title. That is a more common term in Hong Kong, I suppose. They call it strata title, which means, for example, a 50-storey building owned by four different owners, but none of them may actually occupy it. They own parts of it. A 25% stake in such a building is considered under strata title ownership.
		This ownership structure can make processes even more difficult and complicated because each owner has their own strengths, weaknesses, and objectives. One owner may be a purely financial organization. Another might be a property developer and manager, like our competitor, so their strategic thinking is completely different. Another owner might be just a business entity focused on buying and selling properties, possibly having purchased it solely because the share value was rising. So, their objectives will be quite different, and management becomes a challenge. You need a very strong managing agent to handle these complexities properly.
		The presence of multiple stakeholders leads to conflicting priorities.
		Some owners lack experience or interest in managing buildings, making it harder to reach agreements on retrofitting projects.
Hong Kong	HK-09	The issue is many office buildings in Hong Kong are actually not owned by one company. Even for office buildings owned by big developers like Sun Hung Kai they might have already sold part of their office to individual organisations. So there is an incorporate of owners' corporation. So investments in to such types of smart retrofitting, for example, if there is a project to replace lighting in to more energy efficient LED, you need money and if it is not owned by one company but if there is a owners' corporation, then they have to go through the approvals by the owners corporation while consuming lots of time but might not be approved at the end of the day. So I notice that the biggest constraint so far. And even if you go to a vote and if you win, the losing owner might refuse to pay. So it is not by simple majority. So getting the approval of all owners in difficult.

	HK-08	For example, if a building has many small tenants, upgrading systems like HVAC might be challenging, as it requires access to tenant areas.

Sub Theme 2.2.2: Institutional inertia and change resistance

Sri Lanka	SL-10	Additionally, decision-makers are often hesitant to adopt new technologies.
	SL-11	Similarly, the facility manager may be reluctant because retrofitting is complex and time-consuming.
	SL-12	Some stakeholders questioned replacing equipment because it still appeared new, even though it had reached the end of its efficient lifecycle.
		This narrow mindset delayed the upgrade, despite clear evidence that the replacement would improve reliability and energy efficiency.
	SL-05	People are reluctant to change. Even when a company like Elephant asked me to give a presentation on factory automation and IoT, the project eventually didn't move forward.
Hong Kong	HK-04	That governments are a bit conservative and reluctant to make changes or setting new examples, setting new precedence, so that is something we might encounter.
	HK-06	Because the BMO like to stay easy. If the owners and the landlord, if they want to change the building, there will a lot of things that the BMO needs to do to support. So I think is very natural that people don’t like to change. So I think change management is one of the challenges for the existing BMO.

Sub Theme 2.2.3: Internal organisational and stakeholder misalignment

Sri Lanka	SL-10	Another challenge arises when different departments propose separate smart solutions—such as a smart elevator system or smart lighting. Before making a decision, we need to evaluate how much energy savings each option provides and assess the long-term benefits for the building.
	SL-12	The interviewee emphasizes the respect and understanding between a CEO and their second-in-command, stating that such trust enables bold decision-making.
		Marketing professionals in Sri Lanka focus on what makes customers happy (lower charges), while facility managers focus on cost reduction, potentially leading to deviations from standard procedures.
		Employees often prioritize departmental interests over interdepartmental collaboration, creating inefficiencies.
		Engineers, in particular, tend to operate in silos, failing to appreciate the interdependence between departments.
		This contrasts with adversarial approaches where stakeholders treat discussions as a competition rather than a joint problem-solving effort.
		Retrofitting project initially approved in 2008 but only implemented in 2012 due to internal miscommunication and misinformation.
		Even when a project has sound financial and technical justifications (e.g., payback calculations), internal conflicts and bureaucracy can significantly delay execution.
		A lack of understanding at the CEO level, combined with misinformation from internal sources, can lead to confusion and hesitation in decision-making.

		Long-term working relationships foster trust, reducing the risk of misinformation influencing decision-makers.
		Internal engineers for obstructing the project, stating that their reluctance and lack of vision delayed it by two years.
Hong Kong	HK-07	Because normally a company might have different businesses and how they want to invest the money is one thing internally they need to resolve and align with all the stakeholders and also the like the directors.
	HK-10	Sustainability teams aim to achieve ESG targets and streamline FM processes, like deploying digital twins or replacing chillers. However, the operations team may resist these changes due to tenant demands and workload.
		Successful projects often credit the sustainability team, creating potential conflicts with operations. Cooperation depends on organizational structure. If the FM head leads both teams, cooperation is easier. Separate teams with individual bosses may face implementation challenges.
		Another issue is the lack of a dedicated team for smart technologies. Facility management companies typically focus on FM and energy management, not IT, so they need to collaborate with internal IT teams. However, IT teams may be reluctant to cooperate closely due to cybersecurity concerns and increased workload.
	HK-11	In Asia, everything is very boss driven. If the boss doesn't like it, then that's the biggest restriction. This Asian boss culture can really kill innovation.

Sub Theme 2.3: Knowledge, Culture and Perception Barriers

Sub Theme 2.3.1: Knowledge and skill gaps

Sri Lanka	SL-09	The interviewee mentions Closed Circuit Television (CCTV) in passing, but it's not clear whether it's a recommendation or a general statement. It seems like the interviewee is referring to CCTV as part of a security system, but they are uncertain about its use.
		The interviewee mentions the need for an access control system with automatic attendance functionality. However, they don't actively or effectively use it.
	SL-10	Yes, but another key aspect is the client's understanding of smart technologies. Without proper knowledge, they might struggle to make informed decisions or anticipate future trends. For example, high-rise buildings take about two to three years to complete. By the time construction is finished, the initially selected smart features may be outdated. Early-stage decisions might not align with later-stage requirements.
		Another issue is that internal teams may lack the necessary technical knowledge to understand the long-term benefits of smart retrofitting. They might not fully grasp how these upgrades will impact the building's future performance.
		For smart building systems, the integrators need proper training from their suppliers.
	SL-11	With automation, you need to train the existing staff. You can't just assume they will know how to handle it.
	SL-12	A major issue in office buildings is the lack of knowledge and appropriate attitudes among employees.
		There is a lack of availability of genuine consultants and contractors with the required expertise in some regions. The absence of commitment, initiative, and proper knowledge in retrofitting processes from both internal stakeholders and external consultants can create additional barriers.

	SL-06	The lack of technical know how in Sri Lanka. In a retrofitting project, we need to deal with multiple suppliers. However, in order to facilitate this, the supplier needs to well-versed with these technologies. However, there are some lags in the process because most suppliers lack knowledge.
	SL-02	However, I agree that there is a skills gap in Sri Lanka. While we have many competent professionals in building services engineering and facilities management, there is still room for improvement. We need better training and exposure to smart building systems to fully utilize available technology. If necessary, we can also engage firms from India or other regions to support retrofitting projects.
		The first challenge is identifying the most suitable system. This largely depends on the organization's awareness of both the existing systems and the available alternatives.
	SL-04	The necessary technology is not available here, that's the main issue.
	SL-03	Smart features need constant updates to stay relevant and effective. Government ministries must focus on knowledge and training for smart infrastructure adoption.
	SL-08	Most businesses analyze past data to recognize that there is a problem, but they often struggle to pinpoint the exact cause. While they can compare their building's performance with similar buildings, they typically lack the expertise to conduct in-depth analysis.
		When we get involved, we educate consultants and clients on new technologies. If the client and consultant are flexible, they consider these additional solutions. However, some proposals we receive from clients and consultants are outdated, and while we cannot challenge them directly, we professionally guide them towards better alternatives.
		That being said, there are also well-informed clients who carefully evaluate what is being installed.
Hong Kong	HK-10	This lack of expertise in IT within FM companies is a constraint, especially when implementing new systems like digital twins, which require data storage and protection. The shift from traditional retrofitting to installing completely new systems presents challenges due to the lack of domain knowledge.
		A newer challenge is the lack of understanding of new technologies by clients or FM teams.

Sub Theme 2.3.2: Lack of reference projects or market confidence

Sri Lanka	SL-10	For instance, when introducing smart building concepts in Sri Lanka, there are few reference projects to demonstrate success. This lack of precedent makes stakeholders sceptical about implementing smart solutions due to concerns about potential failures.
	SL-04	Before finalizing a product, we conduct market research and seek feedback from other buildings where similar installations have been done. Since we may not have prior experience with a particular supplier, we ensure they have a proven track record before making a decision.
		Past project records are important, but in Sri Lanka, data on large-scale retrofits is limited. Many projects prioritize cost over quality and technical performance, restricting our ability to benchmark against best practices. If more data were available in the future, it would significantly improve our decision-making process.

Sub Theme 2.3.3: Perceptions and attitudes toward smart technologies

Sri Lanka	SL-10	In Sri Lanka, smart technology is commonly used in hotels. For example, when a guest checks in at the reception, they receive a key card that is integrated with mobile apps for seamless access. This key card allows them to control various services, such as IPTV, through which they can order dinner without physically going to the restaurant. Similarly, in Sri Lankan apartment buildings, we are proposing smart locking systems. Each apartment is assigned a smart card that provides seamless access. The resident can use the same card for multiple functions, for instance, tapping the card at the car park entrance, then using it again in the elevator, which will automatically take them to their designated floor.
	SL-12	Even energy-efficient upgrades that improve market value may not appeal to certain owners unless they plan to sell their shares.
		In Sri Lanka, tenants prioritize lower service charges over sustainability or indoor air quality.
		Despite winning multiple energy efficiency awards, sustainability certifications do not heavily influence lease negotiations.
		The adoption of smart technologies should focus on reducing operational costs and improving user comfort rather than just being a technological showcase.
		Stakeholder knowledge, attitudes, and lack of initiative can be barriers to retrofitting.
		Decision-making, even at the CEO level in Sri Lanka, is influenced by emotions rather than purely rational, professional reasoning.
		Many high-level professionals rely on informal networks, such as word-of-mouth (e.g., Kerala), as a primary and trusted source of information.
		This reliance on subjective input can sometimes override structured analytical approaches.
	SL-07	Technology can do a lot, but people need to understand their own contribution. I should feel accountable for my own carbon footprint. Meetings should focus on influencing human behaviour.
		To improve human behaviour, we need to create accountability. That's the key factor. It's about habits, changing them for the better. Companies are now getting connected to energy inefficiencies and ways to reduce them.
	SL-03	However, not all stakeholders fully understand the advantages. Some still prefer conventional setups.
Hong Kong	HK-04	In the real world, I don't think there is any, it all comes to the art of compromise. Because this is a commercial world.
	HK-06	They will argue on is it worth to do so in terms of money and return. And they sometimes they think that the building is too old. Like for example, they may think that the building is too old, they may demolish and rebuild the building, maybe easier. Because I got such client, they have such buildings, a very old building, they demolished the whole building and rebuild it. Quite many in Tsim Sha Tsui. So buildings are purposely built, like one in Tsim Sha Tsui, they wanted to convert it as a medical centre. So their new tenant will be all medical related. Impact to the current tenant, because that will minimise the current income. Minimising the impact to the current tenant is ultimately important.
	HK-10	Contractors need to educate clients on smart features, but if clients don't understand or trust the technology, it poses a challenge. Trust is crucial, especially for data handling and protection. If clients don't trust the contractor's expertise, it becomes a barrier.
	HK-11	I think landlords do not think much about the convenience to the tenants. Maybe convenience to themselves are considered, like whether it provides better maintenance etc. But you know the property management industry is very old fashioned. For example, if you tell them "oh with this system you can save time on reporting and you don't have to do manual reporting", they might wonder, "oh without reporting what do I do? That is my job". So, convenience could be a little bit dangerous for them. So in the supplier's perspective, it is not a good selling point.
		The building owners do not have the urgency to implement retrofitting projects, honestly. It is like us pushing them to implement them as soon as possible and start to save the energy. Because very often, we have already installed the HVAC optimisation system but the

		client would suddenly say "Oh now I want to do the scheduled maintenance of the cooling fan". And from our side, we just installed the new technology and we want to get it started but suddenly they want to do scheduled maintenance. If they would have thought about timeliness then they would say "ok, run pump for a year and then I will change next year, right?". So there is a constant conflict between scheduled maintenance and new technology.
		But many in the FM industry mainly do not get what this SaaS is. They think SaaS is IP or something and if you make any changes. They don't understand SaaS, or technology in general, or new world technology.

Sub Theme 2.4: Operational and Site-Specific Disruptions

Sub Theme 2.4.1: Operational disruptions and tenant sensitivity

Sri Lanka	SL-11	External constraints can come from the neighbourhood or other external parties. For example, the building occupants themselves might pose some challenges.
		We schedule work at night to minimize disruption, as we can't disturb the building's daily operations.
		Even when doing simple tasks like shifting equipment or replacing old systems, timing is key. The work should be done in the night when the building is less occupied, so people won't be disturbed.
	SL-02	in office buildings, HVAC systems cannot be switched off during working hours. If replacing equipment takes three days, we must consider whether temporary solutions, such as backup systems, can be arranged. If not, discussions with tenants may be necessary to manage disruptions. For instance, in our building, we have around 37 server rooms, including the main servers for the Colombo Stock Exchange. Retrofitting decisions must consider such operational constraints.
Hong Kong	HK-12	Its mainly about the operations. Because you know, every works will may potentially arise the need to stop the daily operations. For example, if it is about HVAC systems, you might need to close down the entire chiller system. So the interruptions to the operation would be the main constraint.
		SR disturbs their operation. So the external constraint refers to the tenant's side.
	HK-02	Disruptions to Operations: Retrofitting work often affects tenants, which can lead to resistance.
		Retrofitting can impact daily operations and even conflict with existing service agreements. For instance, if a landlord upgrades an HVAC system, they may need to temporarily shut it down, which could lead to service disruptions and tenant complaints. These factors must be carefully managed to ensure a smooth process.
	HK-01	During the past three years, many people worked from home, allowing for upgrades without affecting operations. For example, the Hang Seng Bank headquarters in Central used this time to refurbish and relocate staff due to remote work.
		One barrier is losing loyal tenants during renovations, but upgrades are necessary to improve the building.
		Another barrier is rental loss during renovations, which means no income.
		Additionally, renovations disturb existing tenants, even if work is done outside office hours or on weekends. Minimizing disturbances and compensating tenants for inconveniences is a challenge.
	HK-06	Options that have less impact to the existing tenants would also be prioritized.
	HK-11	Tenant could be another barrier. Lets say we do air side optimization, then we need to go to the office, and it is mostly during a renovation that the retrofitting happens and we need to work with the designer. And most importantly, during the retrofit/renovation,

		timing is a very critical factor. Sometimes the designer has already been hired and then the customer comes and says things like "Hey I want smart lighting, HVAC optimization, smart office", and then we become a disturbance to the original plan.

Sub Theme 2.4.2: Supply chain and market limitations

Sri Lanka	SL-10	The industry lacks well-known system integrators, and there are not many established brands in the market. For example, if we talk about CCTV cameras or fire safety systems, we can easily source well-known brands. However, for smart lighting and other automation technologies, there are fewer established options available locally. This makes it difficult to ensure reliability and quality in the supply chain. The problem is that the customer can't expand in the future. They are limited to certain brands, which causes issues worldwide. For example, with Ethernet, we're talking about the same protocol. There's no compatibility issue with the brand. What I'm saying is that it can be difficult to find the right solution. If it's a well-known brand, it's easier, but if it's not, then the client may run into issues.
		Before placing the order, the consultant should ensure that they are confident in the brand choice. If the local agent is reliable, it makes things easier. We are also considering the payment terms because some systems may not be stable in the next few years.
	SL-11	Other constraints can come from external suppliers, such as the difficulty of getting the correct materials on time. Logistics can also be an issue, particularly with the removal of debris.
	SL-06	And also sometimes suppliers ask for unexpected amounts, which is a disadvantage for the client.
	SL-02	In Sri Lanka, supply chain issues, inflation, and economic instability impact the availability of spare parts and support services.
		Additionally, some restrictions imposed during COVID-19 are still affecting supply chains. Sometimes, the best alternative is significantly more expensive, perhaps 50% higher, making it an impractical solution. Decision-makers must carefully consider which options are feasible under these constraints.
		Another issue is delays in procurement. Since many materials and equipment are imported, we often find ourselves reconsidering our decisions. Previously, suppliers would offer quotations valid for 12 or 13 months. Now, some quotations are valid for just a week—or even a single day. This is a serious problem because getting approvals for procurement takes time, yet prices fluctuate rapidly. Suppliers themselves are struggling with these uncertainties, making the planning stage increasingly complex.
		Another challenge is pricing. Suppliers are inflating prices significantly. For instance, if an item should cost around 70% of a standard rate, they might increase the price by 300% or even 350% to make quick profits. This creates an unfair and unrealistic price inflation in the market.
		Additionally, logistics disruptions are a major concern. Previously, multiple containers arrived daily from China, allowing for quick procurement. Even if costs were high, it was still possible to expedite shipments via services like DHL. However, now, supply chains are unreliable. Even if suppliers promise delivery within a month or three months, delays are common.
		This is especially problematic for advance payments. Once a payment is made and a commitment is established, cancellations are difficult. We recently faced this issue when purchasing smart energy meters for lifts and electrical tagging systems. After six to eight months, the supplier informed us that prices had increased by 50-60%. We couldn't justify such a steep increase, so we had to mutually cancel the order.
	SL-04	For example, some parts are not always compatible with existing systems. Recently, we had an issue with the HVAC system at one of our branches. We needed to replace the condenser unit, so we ordered it. However, when it arrived, it wasn't fully compatible because some parts were missing from the shipment.

		This kind of issue becomes more common as systems age. Older equipment often requires parts that are harder to find or may no longer be manufactured.
		It hasn't been resolved yet, we're still waiting for the missing parts to arrive.
Hong Kong	HK-02	Even when landlords are willing to invest, delays in equipment delivery and market resource shortages can hinder progress.
	HK-09	I think the external constraint is more related to government approval and availability of good vendors.
	HK-01	Currently, there's a labour shortage in the construction industry, including refurbishment. This shortage affects general labour more than specialized expertise.
	HK-11	How trustworthy is the service provider to maintain the system in the long run? Is it 24/7 and lots of our products are software accessories right?

Sub Theme 2.5: Policy, Regulatory and Procedural Constraints

Sub Theme 2.5.1: Low policy and regulatory pressure

Sri Lanka	SL-12	In Sri Lanka, green building certifications (e.g., LEED, Green Mark) are not as impactful on tenants compared to cost savings.
		Government organizations and industries may care about sustainability, but the general public does not place high importance on it.
		In contrast, European cities are actively greening their capitals, with infrastructure favouring bicycles and walking paths over vehicle routes, reflecting a shift in priorities after experiencing the negative effects of industrialization.
	SL-06	But there are no external funding sources or subsidies for such projects in Sri Lanka.
	SL-07	As a country, we always need to be forward-looking, and the government must take the lead in this effort. Achieving a net-zero state is not something that can happen overnight. However, reducing energy consumption and lowering our carbon footprint are essential steps toward creating a sustainable society.
		there is no government mandate in Sri Lanka yet
Hong Kong	HK-04	In some countries they are very advanced and it is not the private sector but the government sectors who are taking the lead. They try to influence the industry that we might not have the priviledge to building a lot of new buildings but you need to start by making plans to reform the existing buildings and they set down the criteria even regulation or maybe bonus systems that they can enjoy certain benefits if they keep certain standards, so a target. So the ideal situation would be the government taking the lead and they have a campaign and that landlord is part of that campaign and they are eager to work with their potential tenants with common goals, then that would be the top priority.
	HK-11	So I think the issue is, unlike Singapore, we don't have a Government standard. Singapore requires you to look in to HVAC system every X years, so every one needs to do retro commissioning. But in HK, if I don't do it, no one would yell at me. So the government drive is not there.
	HK-09	Unluckily for the time being I believe that there is not actually any government requirement on smart retrofitting.

Sub Theme 2.5.2: Procurement, policy and bureaucracy

Sri Lanka	SL-01	Normally we prepare specifications. We are a subsidiary of a public bank so we have to follow the standard procurement procedure.
		Long procurement process: select consultant, spec and bidding document, draft the press releases and so on (8-10 months)
	SL-11	the government’s regulations and import duties play a significant role. In Sri Lanka, building regulations are influenced by the government. So, there will be challenges like duty issues and other regulatory matters related to imports.
	SL-12	Maintenance processes are bureaucratic, causing inefficiencies.
	SL-02	The biggest issue is policy inconsistency. Regulations and rules keep changing, creating uncertainty. No one knows what will happen next, which makes long-term planning difficult.
	SL-04	These days, there are self-imposed restrictions as well. For instance, we can’t easily purchase items like HVAC systems or security systems due to import restrictions. There are also financial constraints, companies can’t open Letters of Credit (LC) as freely as they want. Some items have been categorized as restricted, meaning they cannot be imported at all.
		Additionally, certain systems, like FM-200 fire suppression systems, are affected by environmental regulations. In some cases, we can't simply repair or modify these systems locally. Instead, we have to remove the entire unit, send it to India or China for servicing, and then bring it back. This significantly increases costs compared to just replacing the damaged part.
	SL-07	Writing proper tender specifications is crucial.
	SL-08	For new projects, specifications are usually well-defined. However, for retrofits, clear specifications are rare.
		I have rarely seen organizations take the time to define a detailed specification before starting a retrofit project.
Hong Kong	HK-09	Many companies, I mean many developers nowadays like to install solar panels on the roof of a building. However, in HK there is what we call the Potential Datum (PD) limit. When you build a new building, you will not be allowed to exceed a certain height. Usually they will maximise the use of the available height. So usually the roof has already reached the highest height allowed by the government. And when you add PV panels on top, and you exceed this height limit. If you go to government to seek approval on relaxing the height limit, then that would take several years.
	HK-03	associations, like environmental groups, may campaign against projects near sensitive areas.
	HK-07	the Governmental influences, the regulations and also the other factors, the community, will that be something that will affect the community, say for example they want to implement something that would influence the company, that would require environmental impact assessment.
	HK-11	Procurement procedure: Whether they need a tender, what is the payback.

Sub Theme 2.6: Technical and Integration Limitations

Sub Theme 2.6.1: Fear of unused technology and wasted investment

Sri Lanka	SL-11	I've had experience with projects where the system stopped functioning soon after installation. This is common, especially if proper testing isn't done after installation.
	SL-12	Advanced smart systems, like destination-controlled elevators, can be expensive and may not always be effective. Even in developed cities like Singapore, their implementation has been challenging.
		Smart technology should be introduced only when it aligns with the needs of a diverse group of users in a building, from CEOs to cleaners.

Sub Theme 2.6.2: Technology compatibility and integration limitations

Sri Lanka	SL-10	When implementing smart systems, we also need to consider whether they should be wired or wireless. If not planned properly from the beginning, retrofitting wired systems later can damage the building structure. That's why we recommend installing necessary cabling even if the full smart system isn't implemented immediately. For smaller houses, we don't necessarily recommend analogue cameras, but we do suggest installing Category 6 (Cat 6) cabling. This ensures they have the infrastructure to upgrade to a more advanced system in the future.
	SL-04	The new system must integrate seamlessly with our existing infrastructure. Compatibility is crucial, especially when dealing with intelligent systems.
	SL-07	A modern BMS should have the right inputs to enable accurate energy analysis and predictions. Many existing systems are quite basic and lack the necessary data points.
Hong Kong	HK-12	Most of these SR rely on the data from the building operations. So usually for buildings, especially for the new ones, they installed the BMS. But that system is usually operated by some third parties like atel or Honeywell etc. So when we want to extract the data from that they usually charge the client for that. So that extra batch of money is usually another constraint.
	HK-02	Smart retrofitting often involves integrating advanced digital solutions, which raises concerns about IT security and system compatibility.
	HK-11	One of the examples is the BMS industry. It is mostly driven by the big companies. They all have their own closed loop system. And they don't want to open the system to the market. They will ask the landlord to open a very expensive API for this specific site itself. A lot of the protocols have been BACnet, Modbus that we can communicate with and even still we need a specific pathway to gather data. But due this high cost, it is not possible to us. And the next question is, who will pay this 100,000 to get access.

Theme 3: Stakeholder Roles and Influence

Sub Theme 3.1: Consultants and Auditors

Sri Lanka	SL-01	So to prepare the specifications we get the expertise of the consultants.
	SL-10	But as consultants, we must consider global advancements, emerging technologies, and technical evaluations of proposed solutions. For example, if a department proposes smart lighting, we should first perform a detailed cost-benefit analysis to determine its feasibility. Only after conducting proper calculations can we decide which solutions should be prioritized.
		Before placing the order, the consultant should ensure that they are confident in the brand choice. If the local agent is reliable, it makes things easier. We are also considering the payment terms because some systems may not be stable in the next few years.
		As consultants, we keep track of this information by reading online resources and consulting professional bodies.
	SL-11	Sometimes, they even hire a value engineer to ensure the best value for money. When you're dealing with a major investment like this, it's important to have multiple perspectives before making a decision. A value engineer also assesses the value for money by considering both the amount spent and the long-term benefits. They analyze the cost and the efficiency gained, ensuring that the investment results in tangible improvements. Value engineering will consider all these aspects.
		Sometimes, older systems may need to be replaced completely, especially if they are outdated and cannot support newer technologies. A consultant can help determine whether upgrades or full replacements are needed. For example, if you need a sophisticated control system, it may be necessary to replace the old system with a newer one that is compatible with modern smart building technologies.
	SL-12	Influence of consultants in decision-making, particularly in situations where senior management trusts external consultants more than internal staff. This dynamic can shape how decisions are made, and the consultant's expertise and initiative are crucial for gaining respect and support from the management.
	SL-07	For instance, a company specializing in software solutions might provide technology recommendations, but they do not conduct energy audits themselves. Instead, they partner with certified energy auditors to evaluate buildings and propose retrofit solutions.
Hong Kong	HK-12	Because you know when they hire consultants to do the work, they usually already considered whether it is available in the market, or is it obeying the law of the Hong Kong government.
	HK-01	Yes, proactively, often with the help of a consultant. Consultants provide input on design and advise on current market demands.
	HK-03	Consultants assess investment costs against payback periods, which can be lengthy for some smart features.
	HK-06	BMO and consultant, because it's an additional project knowledge for which the BMO might not have, to carry out such a feasibility study.
	HK-07	We need to get the involvement of a consultant or a real estate advisor, to give some suggestions and they will need to do the due diligence review.

Sub Theme 3.2: Contractors and Solution Providers

Sri Lanka	SL-01	We study the available systems in the world and integrated them into the building.
	SL-12	A thorough market survey is important to identify potential service providers. However, the interviewee suggests that too much focus on the details of service providers is unnecessary as practical insights can be gained by speaking with others in the field who have had experience with certain contractors or service providers.
	SL-05	When the inquiry came in, it was our job to find the right technology. Usually, clients won't specify the exact technology; it's up to the engineer to select the appropriate, affordable solution.
	SL-08	contractors and technology providers often have more advanced knowledge due to their exposure to global suppliers and cutting-edge solutions. Sometimes, these foreign suppliers are ahead of local consultants in terms of technology.
		For example, our company has been in business since 2004. If I don't hear any feedback about a project after three or four years, I ask my team to follow up with the client to ensure everything is running smoothly. Automation projects, especially retrofits, rarely operate indefinitely without any issues. Failures, whether in the hardware, software, or components like Printed Circuit Board (PCB) boards, are inevitable.
		The key question is: How frequently does the system fail? That's why it's crucial to select a product that is stable and robust.
		From my experience, some of the products we use have remained functional for years without issues. Residential projects, in particular, require highly reliable products because the occupants aren't trained maintenance personnel. In commercial buildings, facility management teams can be trained to replace or maintain components, but in residential settings, robustness is paramount.
		Even if a product lacks advanced features like touchscreens or app integrations, its long-term durability is what truly matters.
Hong Kong	HK-02	Another source of retrofit initiatives comes from external service providers, such as energy management companies or contractors. Many of these providers now offer tailored solutions to landlords.
	HK-10	Contractors and solution providers also approach companies with new solutions.
		Contractors need to educate clients on smart features
		We help clients understand the ROI and feasibility, often starting with pilot projects to demonstrate benefits. We also provide guidance on new technologies, but if clients lack understanding or trust, it remains a challenge.
	HK-11	Also depends on the relationship with the vendors as well. If you have close contacts with the vendors you can ask "what are you doing lately" and they might say "we are working on airside control hunting prediction algorithms", and you might say, "oh, interesting! Tell me more". So it is very personal.

Sub Theme 3.3: Cross-Department and Internal Dynamics

Sri Lanka	SL-11	All the departments come together, project teams, the accountant, and the legal department. We discuss any new projects or updates.
		There are several departments involved
	SL-12	Facility decisions should involve multiple departments, including Building Services, Facilities Management, and Marketing.
		The Marketing Department plays a crucial role in understanding and representing customer needs.
		Effective decision-making in retrofitting requires open discussions and respect between stakeholders.
		a professional approach is important where both parties debate constructively, ultimately arriving at a shared solution.
	SL-04	The decision-making process involves multiple stakeholders, engineers, accountants, and management, each with different priorities. Engineers focus on technical reliability, accountants prioritize cost-effectiveness, and management considers budget allocation. Balancing these perspectives is crucial when proposing a retrofit project.
Hong Kong	HK-12	So, I think it depends on the, perhaps the marketing team or the leasing team recommends the need of the smart car park system operation. So if they think that it is needed, and it is easier, then they might recommend to proceed with such systems.
	HK-07	Because normally a company might have different businesses and how they want to invest the money is one thing internally they need to resolve and align with all the stakeholders.

Sub Theme 3.4: Facility Managers

Sri Lanka	SL-10	Additionally, we need to involve the technical team to analyze what issues exist within the building's infrastructure.
		Facility managers typically rely on their own experience and knowledge.
	SL-11	The facility management team, would report the issue to management and propose solutions.
		Yes, the team can recommend a few companies.
	SL-12	There is a risk when external consultants initiate retrofit projects as they may lack a deep understanding of the building and its requirements. Consultants may also take shortcuts to show quick savings, which could potentially lead to negative long-term consequences for the building.
		The interviewee highlights how solving complex problems, such as the hybrid BMS upgrade, can lead to professional growth. The young engineer involved in the project became an expert in BMS systems due to the experience of navigating these challenges.
	SL-04	That's where our engineering expertise comes in. We conduct market research and consult with our registered suppliers, who are experts in their respective fields. They introduce us to the latest products, helping us evaluate potential solutions.
	SL-03	Facility managers are now actively looking for smart solutions to improve efficiency and operations.
		By collecting and analyzing data, facility managers can make more informed decisions regarding building operations, maintenance, and energy consumption.

Hong Kong	HK-12	Usually the FM team comes to us to discuss the potential improvements.
	HK-02	The facility management team, especially if they have the necessary technical expertise. They may conduct an energy audit to assess the building's performance and identify areas for improvement.
		Facility management teams often conduct energy audits to assess performance and identify necessary improvements.
		If the facility management team lacks technical expertise, they may rely on these experts to propose suitable solutions.
	HK-06	It's all about building reliability. For example, is the lift safe for people to use? Is the HVAC system providing a stable supply? These aspects fall under the responsibilities of facility and property management, rather than third-party providers.
	HK-10	The question of who conducts this analysis depends on the company size. Large companies, like major property developers, often have sustainability teams with the expertise to perform these analyses.
		Building owners often have FM companies, either internal or engaged externally. Internal FM companies, like those of major developers, have senior staff who attend conferences to learn about new technologies.
		Engaged FM companies propose new solutions to provide value to building owners, offering consultancy services on market trends and new technologies.

Sub Theme 3.5: Management, Owners and Decision-Making Bodies

Sri Lanka	SL-01	Once the bids are submitted, a Technical Evaluation Committee (TEC) will make recommendations, then the management checks and the financial approval from the board of directors.
	SL-10	Additionally, decision-makers are often hesitant to adopt new technologies.
	SL-11	The company management will ultimately make the decision. So, if you're making a decision to implement any changes, it's about evaluating the waste and potential gains. This is where the company's management will make their decision.
	SL-12	So, when you look at all four owners, their stakes are relatively small, and when it comes to decision-making, the majority shareholder often dominates the process.
		A strong managing agent represented by the FM team is crucial to navigating these differences and ensuring effective building management.
		Even in the private sector, unless a business leader is personally driven, they may avoid extra effort beyond their basic job responsibilities.
		A successful retrofitting initiative requires individuals who go beyond their job scope, take ownership, and drive the project forward.
		The interviewee emphasizes that for retrofitting to be successful, the initiative must come from the internal management of the building or property. Consultants should not be the ones to drive the project; rather, it should be the internal stakeholders who understand the building better and are aware of the actual needs.

	SL-06	Funding, layman, why should I invest in this? What is the benefit that I get. These are the questions the director board might wonder.
Hong Kong	HK-08	The landlord's willingness to upgrade to a smart building might be less.
		If I'm the landlord, my ultimate aim is to increase revenue from my rental office space. I would consider how to upgrade my rental fees. What makes tenants willing to pay more? Identifying areas that tenants are willing to pay more for is crucial. This includes the rental area and some landlord areas that tenants use, such as public areas like the lobby and common areas.
		The landlord usually decides on his own. It's not a statutory requirement to upgrade to a smart building; it's a commercial decision. Especially in central locations, landlords think about how to make their buildings more competitive.
		If new technology or requirements are trending, the landlord will invest in improvements.
	HK-06	So they will do the prominent ones first and the rest later or may not do the rest at all.
	HK-07	whether the organisation wants to achieve the green building certification or whether they just want to focus on the commercial aspects, that would be the owner's or the developers or the landlords decisions

Sub Theme 3.6: Building Occupants or Tenants

Sri Lanka	SL-01	We have to tackle/manage our occupants/tenants. So the struggle or restrictions coming from them is a big challenge.
	SL-11	For instance, when starting a program, it's important to inform the occupants. We need to explain the process, and tell them which floors are being retrofitted. If we are retrofitting the toilets, tenants in other areas may be affected, which can cause issues. We need to manage those expectations. For example, when one toilet is closed, we offer alternative toilets, but some tenants may object.
	SL-04	Frequent complaints from building tenants.
		If we receive repeated concerns about specific issues, that signals a need for investigation.
Hong Kong	HK-12	Because I think for the tenants, most of the time are from big group of companies. They already got their own design teams there.
	HK-02	Some tenants may not fully understand the benefits of retrofitting or may oppose changes due to perceived inconveniences.
	HK-03	Tenants have expectations based on rent and location.
	HK-04	I believe so and the other consideration is like it comes to whether you are getting in to the building and starting the lease in an ideal timing because it could be like you could be having a similar starting commencement and commencement period with other anchor tenant or a big name tenant, so any big project or any campaign can be started at the same time, not just providing benefits to one tenant but a few and it would make things a lot easier.
	HK-05	Internally, landlords aim to attract anchor tenants, like well-known global brands. Having such tenants can reduce internal constraints because they enhance the building's reputation and attract more tenants.

		The bargaining power of international groups is strong, allowing them to negotiate more than smaller firms. If a global firm wants a specific floor arrangement, the landlord might need to relocate other tenants to accommodate them.
	HK-10	Tenants usually make complaints or requests to the facility management (FM) company. For example, a tenant like a banking company may need ESG data, such as energy usage or indoor air quality. If the FM company can't provide this data due to lack of submeters, tenants may request improvements. The FM company then escalates these requests to the building owner to allocate resources for new technologies or retrofitting, driven by tenant needs.
	HK-11	There was this logistics company and they almost rented this whole building in Sha Tin. And then they said, "Oh we want to be green, we have these ESG goals". They wanted smart technologies based on their goals.
		But in this case, I believe they need to be the majority to have a say and request such retrofits.

Theme 4: Decision Criteria and Evaluation Factors

Sri Lanka	SL-09	The interviewee briefly discusses security incidents, but they emphasize that security incidents should be a priority, likely within the context of the overall security system implementation.
	SL-10	Ease of control
		Consider an office setting: if a meeting is scheduled to start at 10:00 AM, we can program the air conditioning to turn on at 9:55 AM. This ensures that the room reaches the desired temperature when the meeting begins. Similarly, we can automate lighting based on occupancy or schedule.
		but another key aspect is the client's understanding of smart technologies. Without proper knowledge, they might struggle to make informed decisions or anticipate future trends.
		Cost is the primary consideration. For instance, in apartment buildings and condominiums, investors evaluate the return on investment. They assess how much they are spending and what benefits they will gain.
	SL-11	Time required for installation and completion of the system
		Quality of the system itself
		The engineers will also recommend considering the availability of spare parts.
		Disruption to building occupants
		Before starting, we also need to address issues like pressure washing of panels. Vehicles moving downstairs could be a concern, so we'd need to cover the area to avoid dust or damage to neighbouring properties.
		Noise is another issue. During retrofitting, we must manage the noise levels, as it can affect neighbouring properties. The authorities often have noise level regulations, which we need to keep in mind.
		The retrofit options must be compatible with the existing systems.

		Even when doing simple tasks like shifting equipment or replacing old systems, timing is key. The work should be done in the night when the building is less occupied, so people won't be disturbed.
		As for data protection, the system ensures that the security of tenant data is handled within the tenant's own area. The landlord's system does not have access to this data.
		Finance is always the first consideration, then we evaluate the benefit.
		Then, we analyse the cost-benefit ratio for various systems. There are so many elements to consider, including the Internet of Things (IoT) integration. For example, we could implement sensors for water leaks, temperature control in work areas, and automatic adjustments. There are many options to consider, and we look at each one's cost and benefit. Sometimes, management may decide to prioritize an item with clear benefits, like automating lighting or air conditioning.
		Decision-making is based on removing waste and then determining what benefits can be gained.
		For example, if there's a complaint about the ventilation system, the first step is to estimate the cost of improving the system.
		Once you've estimated the cost, you evaluate the potential benefits of making the improvements. The board of directors will prioritize actions based on the return on investment, removing waste, improving efficiency, and the potential gains from retrofitting. For example, if there are constant complaints about the air conditioning system being too hot or too cold, management may prioritize fixing this issue before anything else.
		The most important factor is the benefit we get from the installation, specifically its efficiency. A more efficient system will bring long-term cost benefits compared to the current one.
		In office buildings, there are many visitors. The parking system must be convenient for everyone, ensuring visitors have a place to park while allowing employees to easily find spaces as well. Everything comes down to the benefits we get. The most important thing is analysing the benefits. If there's no benefit from the installation, then there's no point. The benefit should be considered first when assessing the equipment and what we gain from it.
		The management will review the benefits, what we get from customer gates and visitor access, and they will start analysing these benefits.
		We will begin by asking why we are doing this and what immediate benefits you will get. For example, authority issues are a major concern.
		We should analyse the benefits of each item to determine the return on investment.
	SL-12	Practical evaluation is crucial to ensuring facilities are functional and user-friendly.
		Security is a critical factor for tenants, especially in uncertain environments. Even the perception of security can be influential.
		Reducing operational costs
		User comfort
		Organizations look for either tangible or intangible payback when investing in smart systems.
		The track record and expertise of the service provider, especially with large equipment, are critical.

		The efficiency of new chillers can be easily calculated to determine potential energy savings. A significant improvement in energy efficiency (e.g., reducing power consumption from 0.83 to 0.53 kilowatt per ton) can be translated directly into cost savings, making it easy to justify retrofitting decisions in a short time.
		The payback period for replacing old equipment with more efficient models is crucial for justifying the investment. The interviewee stresses that with simple calculations, one can assess whether the retrofit makes financial sense and will have a short enough payback period (e.g., within a few years).
	SL-05	The costs involved in implementing IoT are still a significant hurdle. The return on investment (ROI) might not seem worth it for smaller-scale operations. That's why IoT adoption in Sri Lanka is slower compared to other countries.
	SL-06	Data protection capabilities
		But in a retrofit, we need to justify the system, including the payback.
	SL-02	Before implementing retrofitting solutions, we must assess their technical feasibility. If the technology is available and compatible, we then evaluate the financial viability.
		After-sales service and long-term technical support
		With smart buildings relying heavily on electronics, sensors, controllers, and actuators, regular calibration and maintenance are essential. Therefore, ensuring long-term technical support is critical for sustainable retrofitting.
		Yes, user-friendliness is a key factor.
		Conduct a proper technical evaluation first. If you introduce financial considerations too early, you might overlook crucial technical aspects. So, focus solely on the technical evaluation first.
		The key factor is often the payback period, if it's less than three or four years, most people proceed with the retrofit.
		Financial feasibility is also key. If, for example, we aim to improve the efficiency of an HVAC system from 0.45 kW per TR to 0.3 kW per TR, the resulting energy savings must justify the investment. If the payback period exceeds four years, say, eight to ten years, it may not be viable, as technology evolves rapidly. In three to four years, new solutions may emerge that provide even better efficiency. Hence, retrofitting projects with long payback periods may not always be financially justifiable.
	SL-04	These are not formal audits but in-house inspections to assess whether improvements are necessary.
		Our engineers use specialized equipment to determine whether the complaints are valid and if action is needed.
		Before approaching suppliers for quotations, we first define our requirements.
		The selection process considers cost-effectiveness, technical suitability, and supplier reliability.
		If a supplier introduces a new concept or an alternative solution with long-term benefits, we may conduct a Proof of Concept (POC) trial.
		the new system must integrate seamlessly with our existing infrastructure. Compatibility is crucial, especially when dealing with intelligent systems.
		We also assess the availability of spare parts, after-sales service, and warranty terms.
	SL-07	These technologies analyse real-time data to determine when servicing is actually needed.

		A top-level dashboard can provide real-time insights.
		Prioritizing cost efficiency in energy management is essential. High ratings in energy efficiency contribute to a building's brand reputation.
		A layperson can then review these findings and decide which measures to implement. No-cost and low-cost measures can usually be adopted quickly, while high-cost measures require a payback analysis to determine financial feasibility.
	SL-03	Customer satisfaction is a key measure of effectiveness.
	SL-08	Some businesses prioritize the appearance of smartness.
		As I mentioned earlier, one key factor is the level of involvement the contractor will have in the renovation process. For example, if structural changes, ceiling modifications, or rewiring are required, that becomes a major criterion.
		Of course, cost is another significant factor.
		However, if it's a modern touchpad or if the system allows them to control the building through an app, they are more likely to choose it, even if the product itself isn't the most robust. Sometimes, the ability to say, "I can control everything through an app," becomes a deciding factor for these clients.
		One of the most important aspects of any automation project is long-term reliability.
Hong Kong	HK-12	I'll say that it is depending on the cost and the effectiveness of that systems. So usually we will do something like a value engineering studies.
		Operational implications
		life cycle of the equipment (even though we suggest to change the chillers, but if the chillers were just there for like 5-10 years, the client will not consider immediate changes)
		Ability to help in meeting decarbonization targets
	HK-02	Balance the payback period with the difficulty of implementation.
		They assess whether a solution is financially viable and practical to execute.
		Landlords need to evaluate how long it will take to recover their investment, which influences decision-making.
		One common source is the facility management team, especially if they have the necessary technical expertise. They may conduct an energy audit to assess the building's performance and identify areas for improvement. In most cases, HVAC systems are the primary focus since they account for over 60% of a building's energy consumption. Other systems, such as lighting and elevators, often have fewer opportunities for significant technological upgrades.
	HK-03	Investment cost and the ability to increase returns are also considered.
	HK-05	The landlord might calculate the cost and adjust the rent accordingly.
	HK-06	This cost is as return and also they want it to be more prominent, significant that people can see.
		Whether it is more biased on investment cost or the ability to increase returns will depend on the size of the building.
		From the landlord, they will think about the cost first.

	HK-07	And when we are talking about smart, that will also tie into the return.
	HK-10	The decision on which chiller to replace depends on the actual performance data collected. They analyse this data and calculate the payback period. For example, if replacing one chiller has a payback period of five years and another has seven years, they might choose the option with the shorter payback period if funds are limited.
		They study each option by analysing the return on investment (ROI) and prioritize accordingly.
	HK-11	and (c) viability; (d) money (payback: mostly in energy saving products). But we should understand that it is not only about saving energy
		Also I do not recommend just looking at ROI, I think it is not reasonable to make decisions by just looking at ROI.

Appendices for Chapter 7

A7.1: Questionnaire for expert feedback on SRDSS

Kindly provide answers to the following questions based on your understanding of the smart retrofit decision-making model presented at the beginning of this meeting.

Methodology:

1	How would you rate the clarity of the methodology used to design this decision-making model?	Very high 5	High 4	Average 3	Low 2	Very low 1
2	Have you used or are aware of any other methodologies for smart retrofit decision-making processes? If so, how do they compare?	Please state your answer here				

Criteria:

1	How would you rate the general coverage of relevant criteria in the decision-making model?	Very high 5	High 4	Average 3	Low 2	Very low 1
2	How appropriate do you find the approach for weighting the criteria?	Very high 5	High 4	Average 3	Low 2	Very low 1
3	Are there any additional criteria that you think should be included in the model?	Please state your answer here.				

Reasonableness of results:

1	How reasonable do you find the results obtained from the model?	Very high 5	High 4	Average 3	Low 2	Very low 1
2	Were there any results that you found surprising or questionable?	Please state your answer here.				

Applicability:

1	How practical and applicable do you find the process of using the model in real-world scenarios?	Very high 5	High 4	Average 3	Low 2	Very low 1

Recommendations:

1	Do you have any suggestions for improving the model or the methodology?	Please state your answer here.				
2	Do you have any other comments on the model?	Please state your answer here.				
3	How likely are you to recommend this model to others in the industry?	Very high 5	High 4	Average 3	Low 2	Very low 1

A7.2: Complete VBA Code

Module 1

```
Sub UpdateAndNormalizeData()

    Dim ws As Worksheet
    Dim LastRow As Long
    Dim lastCol As Long
    Dim col As Long
    Dim row As Long
    Dim totalsRow As Long
    Dim normalizedStartRow As Long

    ' Define the worksheet (update name as needed)
    On Error Resume Next
    Set ws = ThisWorkbook.Sheets("SupplierDetails") ' Change to your sheet name
    If ws Is Nothing Then
        MsgBox "Worksheet 'SupplierDetails' not found!", vbCritical
        Exit Sub
    End If
    On Error GoTo 0

    ' Find the last row and column with data
    LastRow = ws.Cells(ws.Rows.Count, 1).End(xlUp).row
    lastCol = ws.Cells(1, ws.Columns.Count).End(xlToLeft).Column

    ' Ensure there is data to process
    If LastRow < 2 Or lastCol < 2 Then
        MsgBox "No sufficient data to process!", vbExclamation
        Exit Sub
    End If

    ' Identify totals and normalized data rows
    totalsRow = LastRow + 1
    normalizedStartRow = totalsRow + 2

    ' Clear existing totals and normalized data
    ws.Rows(totalsRow & ":" & ws.Rows.Count).ClearContents

    ' Recalculate totals for each column (starting from column 2)
    For col = 2 To lastCol
        ws.Cells(totalsRow, col).Value =
Application.WorksheetFunction.Sum(ws.Range(ws.Cells(2, col), ws.Cells(LastRow,
col)))
    Next col

    ' Add a header for normalized data
    ws.Cells(normalizedStartRow - 1, 1).Value = "Normalized Data"

    ' Normalize each value
    For col = 2 To lastCol
        For row = 2 To LastRow
            If ws.Cells(totalsRow, col).Value <> 0 Then
                ws.Cells(normalizedStartRow + row - 2, col).Value = ws.Cells(row,
col).Value / ws.Cells(totalsRow, col).Value
            Else
                ws.Cells(normalizedStartRow + row - 2, col).Value = 0 ' Handle
divide by zero
            End If
        Next row
    Next col

    ' Copy headers for normalized data
    For col = 1 To lastCol
        ws.Cells(normalizedStartRow - 1, col).Value = ws.Cells(1, col).Value
```

```
    Next col

    ' Format normalized data for clarity
    ws.Rows(normalizedStartRow - 1 & ":" & normalizedStartRow + LastRow -
2).Font.Bold = True
    ws.Rows(normalizedStartRow & ":" & normalizedStartRow + LastRow -
2).NumberFormat = "0.00000"

    MsgBox "Data updated and normalized successfully!", vbInformation

End Sub
```

Module 2

```
Sub Calculate()

    Dim wsForm As Worksheet, wsData As Worksheet
    Dim wsCalc As Worksheet, wsDashboard As Worksheet
    Dim wsCalcSupplementary As Worksheet

    Dim LastRow As Long, lastCol As Long
    Dim col As Long, row As Long
    Dim totalsRow As Long, normalizedStartRow As Long
    Dim entropyRow As Long, negativeEntropyRow As Long
    Dim additionalCalculationStartRow As Long, newCalculationStartRow As Long
    Dim entropyWeightsStartRow As Long, staticValuesStartRow As Long
    Dim combinedWeightsStartRow As Long, supplierWeightedValuesStartRow As Long
    Dim idealValuesStartRow As Long, negativeIdealValuesStartRow As Long
    Dim distanceToIdealStartRow As Long, distanceToNegIdealStartRow As Long
    Dim performanceScoreStartRow As Long, rankStartRow As Long
    Dim alternativesCount As Long, dashboardStartRow As Long
    Dim entropyValue As Double, sumOfNewCalcValues As Double
    Dim actualStaticSum As Double
    Dim headerList As Variant
    Dim LastRowNew As Long, supplierCount As Long
    Dim chObj As ChartObject, ch As Chart
    Dim i As Long, seriesIndex As Long, pointIndex As Long
    Dim critCount As Long
    Dim critLabels() As String
    Dim values() As Double
    Dim cellVal As String
    Dim s As Series, pt As Point
    Dim val As Double

    ' Define the sheets
    Set wsForm = ThisWorkbook.Sheets("Evaluation Form")
    Set wsData = ThisWorkbook.Sheets("SupplierDetails")
    Set wsCalc = ThisWorkbook.Sheets("Calculations")
    Set wsCalcSupplementary = ThisWorkbook.Sheets("Calculations Supplementary")
    Set wsDashboard = ThisWorkbook.Sheets("Dashboard")

    ' Clear the sheets
    wsCalcSupplementary.Cells.ClearContents
    wsCalc.Cells.ClearContents
    wsDashboard.Cells.ClearContents

    ' STEP 1: Save data from the form to the data storage sheet
    LastRow = wsData.Cells(wsData.Rows.Count, 1).End(xlUp).row + 1
    wsData.Cells(LastRow, 1).Value = wsForm.Range("J3").Value
    wsData.Cells(LastRow, 2).Value = wsForm.Range("J5").Value
    wsData.Cells(LastRow, 3).Value = wsForm.Range("J7").Value
    wsData.Cells(LastRow, 4).Value = wsForm.Range("J9").Value
    wsData.Cells(LastRow, 5).Value = wsForm.Range("J11").Value
    wsData.Cells(LastRow, 6).Value = wsForm.Range("J13").Value
    wsData.Cells(LastRow, 7).Value = wsForm.Range("J15").Value
    wsData.Cells(LastRow, 8).Value = wsForm.Range("J17").Value
```

```
    wsData.Cells(LastRow, 9).Value = wsForm.Range("J19").Value
    wsData.Cells(LastRow, 10).Value = wsForm.Range("J21").Value
    wsData.Cells(LastRow, 11).Value = wsForm.Range("J23").Value
    wsData.Cells(LastRow, 12).Value = wsForm.Range("J25").Value
    wsData.Cells(LastRow, 13).Value = wsForm.Range("J27").Value
    wsData.Cells(LastRow, 14).Value = wsForm.Range("J29").Value

    MsgBox "Supplier Data Saved Successfully!", vbInformation

    ' Reset the form fields
    wsForm.Range("J3:J29").ClearContents

    ' STEP 2: Perform calculations in the "Calculations" sheet
    LastRow = wsData.Cells(wsData.Rows.Count, 1).End(xlUp).row
    lastCol = wsData.Cells(1, wsData.Columns.Count).End(xlToLeft).Column
    alternativesCount = LastRow - 1

    ' Calculate number of alternatives (excluding header row)
    alternativesCount = LastRow - 1

    totalsRow = 2
    normalizedStartRow = totalsRow + 2
    entropyRow = normalizedStartRow + alternativesCount + 1
    negativeEntropyRow = entropyRow + 1
    additionalCalculationStartRow = negativeEntropyRow + 2
    newCalculationStartRow = additionalCalculationStartRow + 4
    entropyWeightsStartRow = newCalculationStartRow + 3
    staticValuesStartRow = entropyWeightsStartRow + 3
    normalizedStaticValuesStartRow = staticValuesStartRow + 3
    combinedWeightsStartRow = normalizedStaticValuesStartRow + 3
    supplierWeightedValuesStartRow = combinedWeightsStartRow + 4
    idealValuesStartRow = supplierWeightedValuesStartRow + alternativesCount + 2
    negativeIdealValuesStartRow = idealValuesStartRow + 4
    distanceToIdealStartRow = negativeIdealValuesStartRow + 4
    distanceToNegIdealStartRow = distanceToIdealStartRow + 4
    performanceScoreStartRow = distanceToNegIdealStartRow + 4
    rankStartRow = performanceScoreStartRow + alternativesCount + 2

    ' Add headers to the Calculations sheet
    wsCalc.Rows(1).Value = wsData.Rows(1).Value

    ' Copy the totals row
    wsCalc.Cells(totalsRow, 1).Value = "Totals"
    For col = 2 To lastCol
        wsCalc.Cells(totalsRow, col).Value =
Application.WorksheetFunction.Sum(wsData.Range(wsData.Cells(2, col),
wsData.Cells(LastRow, col)))
    Next col

    ' Define header list for matching column headers that require negative values
    headerList = Array("INVESTMENT COST", "OPERATIONAL COST", "FINANCIAL RETURN",
"REQUIREMENT OF COMPETENT FM STAFF")

    ' Normalize each value
    For col = 2 To lastCol
        Dim headerText As String
        headerText = UCase(Trim(wsData.Cells(1, col).Value)) ' Get the header of
the current column

        Dim isNegative As Boolean
        isNegative = Not IsError(Application.Match(headerText, headerList, 0)) '
Check if this column needs to be negative

        For row = 2 To LastRow
            ' Calculate the normalized value
            If wsCalc.Cells(totalsRow, col).Value <> 0 Then
                normalizedValue = wsData.Cells(row, col).Value /
wsCalc.Cells(totalsRow, col).Value
```

```
            Else
                normalizedValue = 0
            End If

            ' Write normalized value to Calculation sheet
            wsCalc.Cells(normalizedStartRow + row - 2, col).Value = normalizedValue

            ' Apply negative sign if the column header matches one from headerList
            If isNegative Then
                normalizedValue = -Abs(normalizedValue)
            End If

            ' Write modified value to Supplementary sheet
            wsCalcSupplementary.Cells(normalizedStartRow + row - 2, col).Value =
normalizedValue
        Next row
    Next col

    ' Copy Supplier Names to both Calculation sheets
    For row = 2 To LastRow
        wsCalc.Cells(normalizedStartRow + row - 2, 1).Value = wsData.Cells(row,
1).Value
        wsCalcSupplementary.Cells(normalizedStartRow + row - 2, 1).Value =
wsData.Cells(row, 1).Value
    Next row

    ' Copy headers from SupplierDetails to both Calculation sheets
    wsCalc.Rows(normalizedStartRow - 1).Value = wsData.Rows(1).Value
    wsCalcSupplementary.Rows(normalizedStartRow - 1).Value = wsData.Rows(1).Value

    ' Apply percentage format to Supplementary Sheet
    With wsCalcSupplementary.Range(wsCalcSupplementary.Cells(normalizedStartRow,
2), wsCalcSupplementary.Cells(normalizedStartRow + LastRow - 2, lastCol))
        .NumberFormat = "0.00%"  ' Set the number format to percentage
    End With

    ' Entropy calculations
    wsCalc.Cells(entropyRow, 1).Value = "Pos. Entropy Factor"
    wsCalc.Cells(negativeEntropyRow, 1).Value = "Neg. Entropy Factor"

    If alternativesCount > 1 Then
        entropyValue = 1 / Application.WorksheetFunction.Ln(alternativesCount)
    Else
        entropyValue = 0
    End If

    wsCalc.Cells(entropyRow, 2).Value = entropyValue
    wsCalc.Cells(negativeEntropyRow, 2).Value = -entropyValue

    ' Additional entropy calculation
    wsCalc.Cells(additionalCalculationStartRow, 1).Value = "Positive Entropy"
    wsCalc.Rows(additionalCalculationStartRow + 1).Value = wsData.Rows(1).Value

    For col = 2 To lastCol
        Dim additionalSumValue As Double
        additionalSumValue = 0

        ' If the total sum of the column is zero, set entropy to zero
        If wsCalc.Cells(totalsRow, col).Value = 0 Then
            wsCalc.Cells(additionalCalculationStartRow + 2, col).Value = 0
        Else
            ' Compute entropy
            For row = 2 To LastRow
                proportion = wsData.Cells(row, col).Value / wsCalc.Cells(totalsRow,
col).Value
                If proportion > 0 Then
                    logProportion = Application.WorksheetFunction.Ln(proportion)
```

```
                    additionalSumValue = additionalSumValue + (proportion *
logProportion)
                End If
            Next row

            If alternativesCount > 1 Then
                wsCalc.Cells(additionalCalculationStartRow + 2, col).Value = -(1 /
Application.WorksheetFunction.Ln(alternativesCount)) * additionalSumValue
            Else
                wsCalc.Cells(additionalCalculationStartRow + 2, col).Value = 0
            End If
        End If
    Next col

    ' New entropy-based calculation
    wsCalc.Rows(newCalculationStartRow).Value = wsData.Rows(1).Value
    sumOfNewCalcValues = 0

    For col = 2 To lastCol
        Dim newCalcValue As Double
        newCalcValue = 0

        ' If the total sum of the column is zero, set the calculation to zero
        If wsCalc.Cells(totalsRow, col).Value = 0 Then
            wsCalc.Cells(newCalculationStartRow + 1, col).Value = 0
        Else
            ' Compute new entropy-related values
            For row = 2 To LastRow
                proportion = wsData.Cells(row, col).Value / wsCalc.Cells(totalsRow,
col).Value
                If proportion > 0 Then
                    logProportion = Application.WorksheetFunction.Ln(proportion)
                    newCalcValue = newCalcValue + (proportion * logProportion)
                End If
            Next row

            If alternativesCount > 1 Then
                wsCalc.Cells(newCalculationStartRow + 1, col).Value = 1 - (-(1 /
Application.WorksheetFunction.Ln(alternativesCount)) * newCalcValue)
            Else
                wsCalc.Cells(newCalculationStartRow + 1, col).Value = 0
            End If
        End If
        sumOfNewCalcValues = sumOfNewCalcValues +
wsCalc.Cells(newCalculationStartRow + 1, col).Value
    Next col

    ' Calculate Entropy Weights
    wsCalc.Cells(entropyWeightsStartRow, 1).Value = "Entropy Weights"
    wsCalc.Rows(entropyWeightsStartRow + 1).Value = wsData.Rows(1).Value
    For col = 2 To lastCol
        If sumOfNewCalcValues <> 0 Then
            wsCalc.Cells(entropyWeightsStartRow + 1, col).Value =
wsCalc.Cells(newCalculationStartRow + 1, col).Value / sumOfNewCalcValues
        Else
            wsCalc.Cells(entropyWeightsStartRow + 1, col).Value = 0
        End If
    Next col

    ' Display Static Values
    wsCalc.Cells(staticValuesStartRow, 1).Value = "Static Values"
    wsCalc.Rows(staticValuesStartRow + 1).Value = wsData.Rows(1).Value

    Dim staticValues As Variant
    staticValues = Array(0.20269, 0.18897, 0.16042, 0.01882, 0.15524, 0.038,
0.07776, 0.02132, 0.00955, 0.01251, 0.02648, 0.03867, 0.04956)

    actualStaticSum = 0 ' Initialize sum
```

```
    For col = 2 To lastCol
        Dim allZero As Boolean
        allZero = True

        ' Check all values in the column
        For row = 2 To LastRow
            If wsData.Cells(row, col).Value <> 0 And wsData.Cells(row, col).Value
<> "" Then
                allZero = False
                Exit For
            End If
        Next row

        ' Assign static value only if not all zeros
        If allZero Then
            wsCalc.Cells(staticValuesStartRow + 1, col).Value = 0
        Else
            wsCalc.Cells(staticValuesStartRow + 1, col).Value = staticValues(col -
2)
            actualStaticSum = actualStaticSum + staticValues(col - 2)
        End If
    Next col

    ' Display Normalized Static Values
    wsCalc.Cells(normalizedStaticValuesStartRow, 1).Value = "Normalized Static
Values"
    wsCalc.Rows(normalizedStaticValuesStartRow + 1).Value = wsData.Rows(1).Value '
Copy headers

    For col = 2 To lastCol
        If actualStaticSum <> 0 Then
            wsCalc.Cells(normalizedStaticValuesStartRow + 1, col).Value = _
                wsCalc.Cells(staticValuesStartRow + 1, col).Value / actualStaticSum
        Else
            wsCalc.Cells(normalizedStaticValuesStartRow + 1, col).Value = 0
        End If
    Next col

    ' Calculate Combined Weights
    wsCalc.Cells(combinedWeightsStartRow, 1).Value = "Combined Weights"
    wsCalc.Rows(combinedWeightsStartRow + 1).Value = wsData.Rows(1).Value
    For col = 2 To lastCol
        wsCalc.Cells(combinedWeightsStartRow + 1, col).Formula = "=(0.5*" &
wsCalc.Cells(normalizedStaticValuesStartRow + 1, col).Address & ")+((1-0.5)*" &
wsCalc.Cells(entropyWeightsStartRow + 1, col).Address & ")"
    Next col

    ' Calculate Supplier Weighted Values
    wsCalc.Cells(supplierWeightedValuesStartRow, 1).Value = "Combined Weighted
Normalized Decision Matrix"
    For row = 2 To LastRow
        wsCalc.Cells(supplierWeightedValuesStartRow + row - 1, 1).Value =
wsCalc.Cells(normalizedStartRow + row - 2, 1).Value
        For col = 2 To lastCol
            wsCalc.Cells(supplierWeightedValuesStartRow + row - 1, col).Formula =
"=" & wsCalc.Cells(normalizedStartRow + row - 2, col).Address & "*" &
wsCalc.Cells(combinedWeightsStartRow + 1, col).Address
        Next col
    Next row

    ' Calculate Ideal Values (Min or Max)
    wsCalc.Cells(idealValuesStartRow, 1).Value = "Positive Ideal"
    wsCalc.Rows(idealValuesStartRow + 1).Value = wsData.Rows(1).Value

    For col = 2 To lastCol
        Select Case col
            Case 2, 3, 4, 8 ' Columns for Min calculation
```

```
                wsCalc.Cells(idealValuesStartRow + 1, col).Formula = "=MIN(" &
wsCalc.Cells(supplierWeightedValuesStartRow + 1, col).Address & ":" &
wsCalc.Cells(supplierWeightedValuesStartRow + alternativesCount, col).Address & ")"
            Case 5, 6, 7, 9, 10, 11, 12, 13, 14 ' Columns for Max calculation
                wsCalc.Cells(idealValuesStartRow + 1, col).Formula = "=MAX(" &
wsCalc.Cells(supplierWeightedValuesStartRow + 1, col).Address & ":" &
wsCalc.Cells(supplierWeightedValuesStartRow + alternativesCount, col).Address & ")"
        End Select
    Next col

    ' Calculate Negative Ideal Values (Min or Max)
    wsCalc.Cells(negativeIdealValuesStartRow, 1).Value = "Negative Ideal"
    wsCalc.Rows(negativeIdealValuesStartRow + 1).Value = wsData.Rows(1).Value ' Add
headers for negative ideal values

    For col = 2 To lastCol
        Select Case col
            Case 2, 3, 4, 8 ' Columns for Max calculation
                wsCalc.Cells(negativeIdealValuesStartRow + 1, col).Formula =
"=MAX(" & wsCalc.Cells(supplierWeightedValuesStartRow + 1, col).Address & ":" &
wsCalc.Cells(supplierWeightedValuesStartRow + alternativesCount, col).Address & ")"
            Case 5, 6, 7, 9, 10, 11, 12, 13, 14 ' Columns for Min calculation
                wsCalc.Cells(negativeIdealValuesStartRow + 1, col).Formula =
"=MIN(" & wsCalc.Cells(supplierWeightedValuesStartRow + 1, col).Address & ":" &
wsCalc.Cells(supplierWeightedValuesStartRow + alternativesCount, col).Address & ")"
        End Select
    Next col

    currentRow = negativeIdealValuesStartRow + alternativesCount + blankRowOffset '
Move to the next section

    ' Calculate Distance to Positive Ideal Solution
    wsCalc.Cells(currentRow, 1).Value = "Euclidean Distance from PI solution (PIS)"
    currentRow = currentRow + 1
    For row = 2 To alternativesCount + 1
        Dim distanceFormula As String
        distanceFormula = "=((" & wsCalc.Cells(supplierWeightedValuesStartRow + row
- 1, 2).Address & "-" & wsCalc.Cells(idealValuesStartRow + 1, 2).Address & ")^2"
        For col = 3 To lastCol
            distanceFormula = distanceFormula & "+(" &
wsCalc.Cells(supplierWeightedValuesStartRow + row - 1, col).Address & "-" &
wsCalc.Cells(idealValuesStartRow + 1, col).Address & ")^2"
        Next col
        distanceFormula = distanceFormula & ")^0.5"
        wsCalc.Cells(currentRow, 2).Formula = distanceFormula
        wsCalc.Cells(currentRow, 1).Value =
wsCalc.Cells(supplierWeightedValuesStartRow + row - 1, 1).Value ' Copy Supplier
Name
        currentRow = currentRow + 1
    Next row
    currentRow = currentRow + blankRowOffset ' Move to the next section

    ' Calculate Distance to Negative Ideal Solution
    wsCalc.Cells(currentRow, 1).Value = "Euclidean Distance from NI solution (NIS)"
    currentRow = currentRow + 1
    For row = 2 To alternativesCount + 1
        Dim NegdistanceFormula As String
        NegdistanceFormula = "=((" & wsCalc.Cells(supplierWeightedValuesStartRow +
row - 1, 2).Address & "-" & wsCalc.Cells(negativeIdealValuesStartRow + 1,
2).Address & ")^2"
        For col = 3 To lastCol
            NegdistanceFormula = NegdistanceFormula & "+(" &
wsCalc.Cells(supplierWeightedValuesStartRow + row - 1, col).Address & "-" &
wsCalc.Cells(negativeIdealValuesStartRow + 1, col).Address & ")^2"
        Next col
        NegdistanceFormula = NegdistanceFormula & ")^0.5"
        wsCalc.Cells(currentRow, 2).Formula = NegdistanceFormula
```

```
        wsCalc.Cells(currentRow, 1).Value =
wsCalc.Cells(supplierWeightedValuesStartRow + row - 1, 1).Value ' Copy Supplier
Name
        currentRow = currentRow + 1
    Next row
    currentRow = currentRow + blankRowOffset ' Move to the next section

    ' Calculate Performance Score
    ' Locate the starting rows for NIS and PIS
    Dim nisStartRow As Long, pisStartRow As Long

    ' Search for the rows where "Euclidean Distance from NI solution (NIS)" and
"Euclidean Distance from PI solution (PIS)" are located
    nisStartRow = wsCalc.Columns(1).Find("Euclidean Distance from NI solution
(NIS)", LookIn:=xlValues, LookAt:=xlWhole).row + 1
    pisStartRow = wsCalc.Columns(1).Find("Euclidean Distance from PI solution
(PIS)", LookIn:=xlValues, LookAt:=xlWhole).row + 1

    ' Calculate Performance Score
    wsCalc.Cells(currentRow, 1).Value = "Performance Score"
    currentRow = currentRow + 1 ' Move to the next row for performance score
calculation

    For row = 0 To alternativesCount - 1
        ' Copy the supplier/alternative name
        wsCalc.Cells(currentRow, 1).Value = wsCalc.Cells(nisStartRow + row,
1).Value ' Copy Alternative Name from NIS section

        ' Calculate Performance Score dynamically using correct starting rows and
offsets
        wsCalc.Cells(currentRow, 2).Formula = _
            "=" & wsCalc.Cells(nisStartRow + row, 2).Address & _
            "/(" & wsCalc.Cells(nisStartRow + row, 2).Address & "+" & _
            wsCalc.Cells(pisStartRow + row, 2).Address & ")"

        ' Increment the current row for the next alternative
        currentRow = currentRow + 1
    Next row

    currentRow = currentRow + blankRowOffset ' Add blank row after Performance
Score section


    ' Add Rank Calculation Title and Headers
    wsCalc.Cells(currentRow, 1).Value = "Rank Calculation"
    currentRow = currentRow + 1 ' Move to the next row

    ' Add headers for the Rank Calculation section
    wsCalc.Cells(currentRow, 1).Value = "Supplier Name"
    wsCalc.Cells(currentRow, 2).Value = "Rank"
    wsCalc.Cells(currentRow, 3).Value = "Percentage Difference of Proximity to PIS"
    currentRow = currentRow + 1 ' Move to the next row for data

    ' Find the range for Performance Scores
    Dim performanceStartRow As Long, performanceEndRow As Long
    performanceStartRow = wsCalc.Columns(1).Find("Performance Score",
LookIn:=xlValues, LookAt:=xlWhole).row + 1

    ' Find the last row of Performance Scores dynamically (row before "Rank
Calculation")
    performanceEndRow = wsCalc.Columns(1).Find("Rank Calculation",
LookIn:=xlValues, LookAt:=xlWhole).row - 1

    ' Add Rank and Percentage Difference Calculation for each alternative
    For row = 0 To alternativesCount - 1
        ' Copy Supplier Name
        wsCalc.Cells(currentRow, 1).Value = wsCalc.Cells(performanceStartRow + row,
1).Value
```

```
        ' Calculate Rank using the Performance Scores range
        wsCalc.Cells(currentRow, 2).Formula = _
            "=RANK.EQ(" & wsCalc.Cells(performanceStartRow + row, 2).Address & ", "
& _
            wsCalc.Range(wsCalc.Cells(performanceStartRow, 2),
wsCalc.Cells(performanceEndRow, 2)).Address & ")"

        ' Calculate Percentage Difference of Proximity to PIS
        wsCalc.Cells(currentRow, 3).Formula = "=1 - " &
wsCalc.Cells(performanceStartRow + row, 2).Address

        ' Move to the next row
        currentRow = currentRow + 1
    Next row

    currentRow = currentRow + blankRowOffset ' Add blank row after the Rank
Calculation section

    ' Format the calculations sheet
    wsCalc.Rows(totalsRow & ":" & (performanceScoreStartRow +
alternativesCount)).Font.Bold = False
    wsCalc.Rows(normalizedStartRow & ":" & (performanceScoreStartRow +
alternativesCount)).NumberFormat = "0.00000"


    ' Define criteria types (adjust these arrays based on your actual criteria)
    ' Cost criteria (negative values, red color)
    Dim costCriteria As Variant
    costCriteria = Array("Investment Cost", "Operational Cost", "Financial Return",
"Requirement of Competent FM Staff")

    ' Benefit criteria (positive values, green color)
    Dim benefitCriteria As Variant
    benefitCriteria = Array("Automated Risk Prediction", "Reliability of retrofit
Option", "Compatibility with Existing Systems", _
                           "Ease of Implementing Retrofitting Project", "Indoor
Environmental Quality", "User Friendliness", _
                           "Energy Saving Capabilities")

    ' Get last row of data (Column A must be filled)
    LastRowNew = wsCalcSupplementary.Cells(wsCalcSupplementary.Rows.Count,
1).End(xlUp).row
    supplierCount = LastRowNew - 3 ' Data starts from row 4

    ' Clear existing charts AND text boxes/shapes
    For Each chObj In wsDashboard.ChartObjects
        chObj.Delete
    Next chObj

    ' Clear all shapes (including text boxes)
    Dim shp As Shape
    For Each shp In wsDashboard.Shapes
        shp.Delete
    Next shp

    ' === CHECK FOR NON-ZERO COLUMNS ===
    Dim validColumns As Collection
    Set validColumns = New Collection
    Dim validCritLabels As Collection
    Set validCritLabels = New Collection

    For col = 2 To 16
        Dim hasNonZeroValue As Boolean
        hasNonZeroValue = False

        ' Check if any cell in this column has a non-zero value
        For row = 4 To LastRowNew
```

```
            cellVal = wsCalcSupplementary.Cells(row, col).Text
            cellVal = Replace(cellVal, "%", "")

            If IsNumeric(cellVal) And cellVal <> "" Then
                If CDbl(cellVal) <> 0 Then
                    hasNonZeroValue = True
                    Exit For
                End If
            End If
        Next row

        ' If column has non-zero values, add it to valid columns
        If hasNonZeroValue Then
            validColumns.Add col
            validCritLabels.Add wsCalcSupplementary.Cells(3, col).Value
        End If
    Next col

    ' If no valid columns found, exit
    If validColumns.Count = 0 Then
        MsgBox "No columns with non-zero values found. Chart cannot be created."
        Exit Sub
    End If

    ' Create new horizontal bar chart
    Set chObj = wsDashboard.ChartObjects.Add(Left:=80, Top:=120, Width:=800,
Height:=600)
    Set ch = chObj.Chart
    ch.ChartType = xlBarClustered ' Horizontal bar chart

    ' Chart title
    ch.HasTitle = True
    ch.ChartTitle.Text = "Performance Comparison of Alternatives across Criteria" &
vbCrLf & _
                         "(based on the normalised scores of alternatives under
each criterion)"

    ' === Add Series for Each Alternative (only for non-zero columns) ===
    For i = 1 To supplierCount
        ' Prepare values for this alternative across valid criteria only
        ReDim values(1 To validColumns.Count)

        For j = 1 To validColumns.Count
            col = validColumns(j)
            cellVal = wsCalcSupplementary.Cells(i + 3, col).Text
            cellVal = Replace(cellVal, "%", "")

            If IsNumeric(cellVal) And cellVal <> "" Then
                Dim rawValue As Double
                rawValue = CDbl(cellVal)

                ' Determine if this is a cost or benefit criteria
                Dim criteriaName As String
                criteriaName = wsCalcSupplementary.Cells(3, col).Value

                ' Make cost criteria negative for left side display
                If IsInArray(criteriaName, costCriteria) Then
                    values(j) = -Abs(rawValue) ' Negative for cost criteria
                Else
                    values(j) = Abs(rawValue) ' Positive for benefit criteria
                End If
            Else
                values(j) = 0
            End If
        Next j

        ' Add new series for this alternative
        ch.SeriesCollection.NewSeries
```

```
        With ch.SeriesCollection(ch.SeriesCollection.Count)
            .Name = wsCalcSupplementary.Cells(i + 3, 1).Value ' Alternative name
for legend
            .values = values ' Performance values across criteria

            ' Convert collection to array for XValues
            ReDim critLabelsArray(1 To validCritLabels.Count)
            For k = 1 To validCritLabels.Count
                critLabelsArray(k) = validCritLabels(k)
            Next k
            .XValues = critLabelsArray ' Criteria names for Y-axis (since it's
horizontal)
        End With
    Next i

    ' === Apply Color Coding Based on Value Sign ===
    For seriesIndex = 1 To ch.SeriesCollection.Count
        Set s = ch.SeriesCollection(seriesIndex)

        For pointIndex = 1 To s.Points.Count
            Set pt = s.Points(pointIndex)
            val = s.values(pointIndex)

            With pt.Format.Fill
                .Visible = msoTrue
                .Solid
                ' Color coding: Red for negative (cost), Green for positive
(benefit)
                If val < 0 Then
                    .ForeColor.RGB = RGB(220, 20, 20) ' Red for cost criteria
                Else
                    .ForeColor.RGB = RGB(34, 139, 34) ' Green for benefit criteria
                End If

                ' Add patterns for different alternatives
                Select Case seriesIndex
                    Case 1 ' Alternative 1 - Solid
                        ' Keep solid fill
                    Case 2 ' Alternative 2 - Dots
                        .Patterned msoPatternSmallCheckerBoard
                        .BackColor.RGB = RGB(255, 255, 255)
                    Case 3 ' Alternative 3 - Diagonal lines
                        .Patterned msoPatternDiagonalBrick
                        .BackColor.RGB = RGB(255, 255, 255)
                    Case Else ' Additional alternatives
                        .Patterned msoPatternHorizontalBrick
                        .BackColor.RGB = RGB(255, 255, 255)
                End Select
            End With
        Next pointIndex
    Next seriesIndex

    ' === Configure Chart Formatting ===
    With ch
        ' Axis titles
        .Axes(xlCategory).HasTitle = True
        .Axes(xlCategory).AxisTitle.Text = ""
        .Axes(xlValue).HasTitle = True
        .Axes(xlValue).AxisTitle.Text = "Normalized Score"

        ' Move Y-axis labels to the left side
        .Axes(xlCategory).TickLabelPosition = xlTickLabelPositionLow

        ' Add vertical line at zero
        .Axes(xlValue).HasMajorGridlines = True
        .Axes(xlValue).MajorGridlines.Format.Line.ForeColor.RGB = RGB(0, 0, 0)
        .Axes(xlValue).MajorGridlines.Format.Line.Weight = 1
```

```
        ' Hide Excel's default legend (we'll create custom legend)
        .HasLegend = False

        ' Format chart and plot area
        .ChartArea.Format.Fill.Visible = msoFalse
        .PlotArea.Format.Fill.Visible = msoFalse

        ' Reverse category order to match your image
        .Axes(xlCategory).ReversePlotOrder = True
    End With

    ' === ENHANCED DUAL LEGEND SYSTEM ===
    ' Create custom legend area with TWO SEPARATE SETS for Cost and Benefit
    Dim legendStartX As Single, legendStartY As Single
    legendStartX = 80
    legendStartY = 720

    ' === LEGEND SET 1: COST CRITERIA ALTERNATIVES ===
    ' Cost criteria header
    Dim costHeaderShape As Shape
    Set costHeaderShape =
wsDashboard.Shapes.AddTextbox(msoTextOrientationHorizontal, legendStartX,
legendStartY, 400, 15)
    With costHeaderShape
        .Line.Visible = msoFalse
        .Fill.Visible = msoFalse
        With .TextFrame2.TextRange
            .Text = "Cost Criteria (lower values preferred):"
            .Font.Size = 11
            .Font.Fill.ForeColor.RGB = RGB(220, 20, 20)
            .Font.Bold = True
        End With
    End With

    ' Cost criteria alternatives legend
    Dim costLegendY As Single
    costLegendY = legendStartY + 20

    For i = 1 To supplierCount
        ' Create RED colored rectangle for each alternative (cost criteria)
        Dim costAltRect As Shape
        Set costAltRect = wsDashboard.Shapes.AddShape(msoShapeRectangle,
legendStartX + (i - 1) * 180, costLegendY, 15, 12)

        With costAltRect.Fill
            .Visible = msoTrue
            .Solid
            .ForeColor.RGB = RGB(220, 20, 20) ' Red color for cost criteria

            ' Apply same patterns as in chart
            Select Case i
                Case 1 ' Alternative 1 - Solid
                    ' Keep solid
                Case 2 ' Alternative 2 - Pattern
                    .Patterned msoPatternSmallCheckerBoard
                    .BackColor.RGB = RGB(255, 255, 255)
                Case 3 ' Alternative 3 - Different pattern
                    .Patterned msoPatternDiagonalBrick
                    .BackColor.RGB = RGB(255, 255, 255)
                Case Else
                    .Patterned msoPatternHorizontalBrick
                    .BackColor.RGB = RGB(255, 255, 255)
            End Select
        End With

        costAltRect.Line.Visible = msoTrue
        costAltRect.Line.ForeColor.RGB = RGB(0, 0, 0)
        costAltRect.Line.Weight = 1
```

```
        ' Add alternative label for cost
        Dim costAltLabel As Shape
        Set costAltLabel =
wsDashboard.Shapes.AddTextbox(msoTextOrientationHorizontal, _
                                                   legendStartX + (i - 1) * 180 +
20, costLegendY - 2, 150, 15)
        With costAltLabel.TextFrame2.TextRange
            .Text = wsCalcSupplementary.Cells(i + 3, 1).Value
            .Font.Size = 9
            .Font.Fill.ForeColor.RGB = RGB(0, 0, 0)
        End With
        costAltLabel.Line.Visible = msoFalse
        costAltLabel.Fill.Visible = msoFalse
    Next i

    ' === LEGEND SET 2: BENEFIT CRITERIA ALTERNATIVES ===
    Dim benefitLegendY As Single
    benefitLegendY = costLegendY + 40

    ' Benefit criteria header
    Dim benefitHeaderShape As Shape
    Set benefitHeaderShape =
wsDashboard.Shapes.AddTextbox(msoTextOrientationHorizontal, legendStartX,
benefitLegendY, 400, 15)
    With benefitHeaderShape
        .Line.Visible = msoFalse
        .Fill.Visible = msoFalse
        With .TextFrame2.TextRange
            .Text = "Benefit Criteria (higher values preferred):"
            .Font.Size = 11
            .Font.Fill.ForeColor.RGB = RGB(34, 139, 34)
            .Font.Bold = True
        End With
    End With

    ' Benefit criteria alternatives legend
    Dim benefitAltLegendY As Single
    benefitAltLegendY = benefitLegendY + 20

    For i = 1 To supplierCount
        ' Create GREEN colored rectangle for each alternative (benefit criteria)
        Dim benefitAltRect As Shape
        Set benefitAltRect = wsDashboard.Shapes.AddShape(msoShapeRectangle,
legendStartX + (i - 1) * 180, benefitAltLegendY, 15, 12)

        With benefitAltRect.Fill
            .Visible = msoTrue
            .Solid
            .ForeColor.RGB = RGB(34, 139, 34) ' Green color for benefit criteria

            ' Apply same patterns as in chart
            Select Case i
                Case 1 ' Alternative 1 - Solid
                    ' Keep solid
                Case 2 ' Alternative 2 - Pattern
                    .Patterned msoPatternSmallCheckerBoard
                    .BackColor.RGB = RGB(255, 255, 255)
                Case 3 ' Alternative 3 - Different pattern
                    .Patterned msoPatternDiagonalBrick
                    .BackColor.RGB = RGB(255, 255, 255)
                Case Else
                    .Patterned msoPatternHorizontalBrick
                    .BackColor.RGB = RGB(255, 255, 255)
            End Select
        End With

        benefitAltRect.Line.Visible = msoTrue
```

```
        benefitAltRect.Line.ForeColor.RGB = RGB(0, 0, 0)
        benefitAltRect.Line.Weight = 1

        ' Add alternative label for benefit
        Dim benefitAltLabel As Shape
        Set benefitAltLabel =
wsDashboard.Shapes.AddTextbox(msoTextOrientationHorizontal, _
                                                   legendStartX + (i - 1) * 180 +
20, benefitAltLegendY - 2, 150, 15)
        With benefitAltLabel.TextFrame2.TextRange
            .Text = wsCalcSupplementary.Cells(i + 3, 1).Value
            .Font.Size = 9
            .Font.Fill.ForeColor.RGB = RGB(0, 0, 0)
        End With
        benefitAltLabel.Line.Visible = msoFalse
        benefitAltLabel.Fill.Visible = msoFalse
    Next i


    ' Display table on the "Dashboard" sheet
    dashboardStartRow = 4

    ' Clear existing data in the Dashboard
    wsDashboard.Cells.ClearContents

    ' Add static headers to the Dashboard
    With wsDashboard
        .Cells(dashboardStartRow - 1, 1).Value = "Supplier Name"
        .Cells(dashboardStartRow - 1, 2).Value = "Rank"
        .Cells(dashboardStartRow - 1, 3).Value = "Percentage Difference of
Proximity to PIS"
    End With

    ' Locate the data in the Calculations sheet (after "Rank Calculation" text)
    Dim rankCalculationStartRow As Long
    rankCalculationStartRow = wsCalc.Columns(1).Find(What:="Rank Calculation",
LookIn:=xlValues, LookAt:=xlWhole).row + 2

    ' Determine the range of rank calculation data
    Dim rankDataEndRow As Long
    rankDataEndRow = wsCalc.Cells(rankCalculationStartRow, 1).End(xlDown).row

    ' Copy data from Calculations to Dashboard
    Dim currentDashboardRow As Long
    currentDashboardRow = dashboardStartRow
    For row = rankCalculationStartRow To rankDataEndRow
        wsDashboard.Cells(currentDashboardRow, 1).Value = wsCalc.Cells(row,
1).Value ' Supplier Name
        wsDashboard.Cells(currentDashboardRow, 2).Value = wsCalc.Cells(row,
2).Value ' Rank
        wsDashboard.Cells(currentDashboardRow, 3).Value = wsCalc.Cells(row,
3).Value ' Percentage Difference
        currentDashboardRow = currentDashboardRow + 1
    Next row

    ' Format the Dashboard
    With wsDashboard
        ' Bold the headers
        .Range(.Cells(dashboardStartRow - 1, 1), .Cells(dashboardStartRow - 1,
3)).Font.Bold = True

        ' Format the Percentage Difference column as percentage
        .Range(.Cells(dashboardStartRow, 3), .Cells(currentDashboardRow - 1,
3)).NumberFormat = "0%"

        ' Ensure Rank values are integers
        .Range(.Cells(dashboardStartRow, 2), .Cells(currentDashboardRow - 1,
2)).NumberFormat = "0"
```

```
        ' Add orange borders around the data
        With .Range(.Cells(dashboardStartRow - 1, 1), .Cells(currentDashboardRow -
1, 3)).Borders
            .LineStyle = xlContinuous
            .Weight = xlThin
            .Color = RGB(255, 165, 0) ' Orange color
        End With
    End With

    ' Sort the data by the Rank column (Column B)
    With wsDashboard.Sort
        .SortFields.Clear
        .SortFields.Add Key:=wsDashboard.Range(wsDashboard.Cells(dashboardStartRow,
2), _

wsDashboard.Cells(currentDashboardRow - 1, 2)), _
                        Order:=xlAscending
        .SetRange wsDashboard.Range(wsDashboard.Cells(dashboardStartRow - 1, 1), _
                                    wsDashboard.Cells(currentDashboardRow - 1, 3))
        .Header = xlYes ' Indicates that the first row contains headers
        .MatchCase = False
        .Orientation = xlTopToBottom
        .Apply
    End With


    ' Clean up object references
    Set chObj = Nothing
    Set ch = Nothing
    Set s = Nothing
    Set pt = Nothing
    Set altRect = Nothing
    Set altLabel = Nothing
    Set costRect = Nothing
    Set costLabel = Nothing
    Set benefitRect = Nothing
    Set benefitLabel = Nothing
    Set shp = Nothing
    Set wsCalcSupplementary = Nothing
    Set wsDashboard = Nothing

End Sub

' Helper function to check if a value exists in an array
Function IsInArray(valToBeFound As Variant, arr As Variant) As Boolean
    Dim i As Long
    For i = LBound(arr) To UBound(arr)
        If arr(i) = valToBeFound Then
            IsInArray = True
            Exit Function
        End If
    Next i
    IsInArray = False
End Function
```

REFERENCES

Abedi, A., Gaudard, L. & Romerio, F. 2019. Review of major approaches to analyze vulnerability in power system. *Reliability Engineering & System Safety,* 183**,** 153–172.

Abidin, N. I. A., Zakaria, R., Aminuddin, E., Shamsuddin, S. M., Mustafa, M. & Khan, J. S. 2019. Decision making tool for retrofitting of existing building for energy reduction in higher learning institution. *IOP Conference Series: Materials Science and Engineering,* 615**,** 012069.

Adamson, K. A. & Prion, S. 2013. Reliability: Measuring Internal Consistency Using Cronbach's α. *Clinical Simulation in Nursing,* 9**,** e179–e180.

Adegoriola, M. I., Lai, J. H. K., Chan, E. H. & Darko, A. 2021. Heritage building maintenance management (HBMM): A bibliometric-qualitative analysis of literature. *Journal of Building Engineering,* 42**,** 102416.

Aghaei Chadegani, A., Salehi, H., Yunus, M., Farhadi, H., Fooladi, M., Farhadi, M. & Ale Ebrahim, N. 2013. A comparison between two main academic literature collections: Web of Science and Scopus databases. *Asian social science,* 9**,** 18–26.

Ahmed, H., Edwards, D. J., Lai, J. H. K., Roberts, C., Debrah, C., Owusu-Manu, D.-G. & Thwala, W. D. 2021a. Post Occupancy Evaluation of School Refurbishment Projects: Multiple Case Study in the UK. *Buildings,* 11**,** 169.

Ahmed, R., Nasiri, F. & Zayed, T. 2021b. A novel Neutrosophic-based machine learning approach for maintenance prioritization in healthcare facilities. *Journal of Building Engineering,* 42**,** 11.

Al-Kodmany, K. 2015. Tall Buildings and Elevators: A Review of Recent Technological Advances. *Buildings,* 5**,** 1070–1104.

Al Dakheel, J., Del Pero, C., Aste, N. & Leonforte, F. 2020. Smart buildings features and key performance indicators: A review. *Sustainable Cities and Society,* 61**,** 102328.

Al Dakheel, J., Del Pero, C., Leonforte, F., Aste, N. & El Mankibi, M. 2024. Assessing the performance of smart buildings and smart retrofit interventions through key performance indicators: Defining minimum performance thresholds. *Energy and Buildings,* 325**,** 114988.

Alam, M., Zou, P. X. W., Stewart, R. A., Bertone, E., Sahin, O., Buntine, C. & Marshall, C. 2019. Government championed strategies to overcome the barriers to public building energy efficiency retrofit projects. *Sustainable Cities and Society,* 44**,** 56–69.

Albatici, R., Gadotti, A., Baldessari, C. & Chiogna, M. 2016. A Decision Making Tool for a Comprehensive Evaluation of Building Retrofitting Actions at the Regional Scale. *Sustainability,* 8**,** 17.

Albayrak, Y. E., Erensal, Y. C. & Gurbuz, T. A Risk Management Model for Energy Planning Using Analytic Network Process Approach. 2nd International Conference on Risk Analysis and Crisis Response, 2009 Beijing, China. Atlantis Press, 173–179.

Alberg Mosgaard, M., Kerndrup, S. & Riisgaard, H. 2016. Stakeholder constellations in energy renovation of a Danish Hotel. *Journal of Cleaner Production,* 135**,** 836–846.

Alcalá, R., Casillas, J., Cordón, O., González, A. & Herrera, F. 2005. A genetic rule weighting and selection process for fuzzy control of heating, ventilating and air conditioning systems. *Engineering Applications of Artificial Intelligence,* 18**,** 279–296.

Alfaiz, S. K., Abd Karim, S. B. & Alashwal, A. M. 2021. Critical success factors of green building retrofitting ventures in Iraq. *International Journal of Sustainable Construction Engineering and Technology,* 12**,** 12–17.

Aliero, M. S., Qureshi, K. N., Pasha, M. F., Ghani, I. & Yauri, R. A. 2021. Systematic Mapping Study on Energy Optimization Solutions in Smart Building Structure: Opportunities and Challenges. *Wireless Personal Communications,* 119**,** 2017–2053.

Aliyu, S., Yusuf, A., Abdullahi, U. & Hafiz, M. 2017. Development of a low-cost GSM-bluetooth home automation system.

Altomonte, S. & Schiavon, S. 2013. Occupant satisfaction in LEED and non-LEED certified buildings. *Building and Environment,* 68**,** 66–76.

Anarene, B. 2024. Advanced Decision- Making Framework for Sustainable Energy Retrofit of Existing Commercial Office Buildings. *International Journal of Scientific Research and Management (IJSRM),* 12**,** 7269–7297.

Anderson, S. T. & Newell, R. G. 2004. Information programs for technology adoption: the case of energy-efficiency audits. *Resource and Energy Economics,* 26**,** 27–50.

Andrić, I., Koc, M. & Al-Ghamdi, S. G. 2019. A review of climate change implications for built environment: Impacts, mitigation measures and associated challenges in developed and developing countries. *Journal of Cleaner Production,* 211**,** 83–102.

Apostolopoulos, V., Giourka, P., Martinopoulos, G., Angelakoglou, K., Kourtzanidis, K. & Nikolopoulos, N. 2022. Smart readiness indicator evaluation and cost estimation of smart retrofitting scenarios - A comparative case-study in European residential buildings. *Sustainable Cities and Society,* 82**,** 103921.

Araszkiewicz, K. 2017. Digital Technologies in Facility Management – The state of Practice and Research Challenges. *Procedia Engineering,* 196**,** 1034–1042.

Arbizzani, E., Civiero, P., Madrigal, L. O. & Lanzarote, B. S. 2015. Smart solutions for low-income buildings rehabilitation: international researches and experiences. *TECHNE-Journal of Technology for Architecture and Environment***,** 222–231.

Asadian, E., Karji, A. & Leicht, R. 2023. Building Energy Retrofits: A Review of Decision-Making Models. Springer Nature Singapore.

ASITE 2020. Smart Retrofitting - The Key to Decarbonizing the Built Environment.

Attia, S., Eleftheriou, P., Xeni, F., Morlot, R., Ménézo, C., Kostopoulos, V., Betsi, M., Kalaitzoglou, I., Pagliano, L. & Cellura, M. 2017. Overview and future challenges of nearly zero energy buildings (nZEB) design in Southern Europe. *Energy and Buildings,* 155**,** 439–458.

Aye, G. C., Gupta, R. & Wanke, P. 2018. Energy efficiency drivers in South Africa: 1965-2014. *Energy Efficiency,* 11**,** 1465–1482.

Bach, B., Wilhelmer, D. & Palensky, P. Smart buildings, smart cities and governing innovation in the new millennium. 2010 8th IEEE International Conference on Industrial Informatics, 2010. IEEE, 8–14.

Bai, L., Wang, H., Huang, N., Du, Q. & Huang, Y. 2018. An Environmental Management Maturity Model of Construction Programs Using the AHP-Entropy Approach. *International Journal of Environmental Research and Public Health,* 15**,** 1317.

Balasbaneh, A. T., Yeoh, D., Ramli, M. Z. & Valdi, M. H. T. 2022. Different alternative retrofit to improving the sustainability of building in tropical climate: multi-criteria decision-making. *Environmental Science and Pollution Research,* 29**,** 41669–41683.

Barnaś, K., Jeleński, T., Nowak-Ocłoń, M., Racoń-Leja, K., Radziszewska-Zielina, E., Szewczyk, B., Śladowski, G., Toś, C. & Varbanov, P. S. 2023. Algorithm for the comprehensive thermal retrofit of housing stock aided by renewable energy supply: A sustainable case for Krakow. *Energy,* 263**,** 125774.

Baseer, M., Ghiaus, C., Viala, R., Gauthier, N. & Daniel, S. 2023. pELECTRE-Tri: Probabilistic ELECTRE-Tri Method—Application for the Energy Renovation of Buildings. *Energies,* 16**,** 5296.

Baset, A. & Jradi, M. 2025. Data-Driven Decision Support for Smart and Efficient Building Energy Retrofits: A Review. *Applied System Innovation,* 8**,** 5.

Basso, P., Mililli, M., Herrero, F. J., Sanz, R. & Casaldiga, P. 2017. E2VENT–design and integration of an adaptable module for residential building renovation. *Journal of Facade Design and Engineering,* 5**,** 7–23.

Basu, C., Caubel, J. J., Kim, K., Cheng, E., Dhinakaran, A., Agogino, A. M. & Martin, R. A. 2014. Sensor-based predictive modeling for smart lighting in grid-integrated buildings. *IEEE Sensors Journal,* 14**,** 4216–4229.

Beccali, M., Finocchiaro, P., Ippolito, M. G., Leone, G., Panno, D. & Zizzo, G. 2018. Analysis of some renewable energy uses and demand side measures for hotels on small Mediterranean islands: A case study. *Energy,* 157**,** 106–114.

Bell, J. 2005. Is 'Smart' Always 'Sustainable' in Building Design and Construction. *Smart & Sustainable Built Environments.*

Bird, M., Daveau, C., O'dwyer, E., Acha, S. & Shah, N. 2022. Real-world implementation and cost of a cloud-based MPC retrofit for HVAC control systems in commercial buildings. *Energy and Buildings,* 270**,** 112269.

Bocaneala, N., Mayouf, M., Vakaj, E. & Shelbourn, M. 2025. Artificial Intelligence Based Methods for Retrofit Projects: A Review of Applications and Impacts. *Archives of Computational Methods in Engineering,* 32**,** 899–926.

Bolomope, M., Amidu, A.-R., Filippova, O. & Levy, D. 2021. Property investment decision-making behaviour amidst market disruptions: an institutional perspective. *Property Management,* 39**,** 1–21.

Boyatzis, R. E. 1998. *Transforming qualitative information : thematic analysis and code development,* Thousand Oaks, CA, Sage Publications.

Braams, R. B., Wesseling, J. H., Meijer, A. J. & Hekkert, M. P. 2024. Institutional conditions for governments working on sustainability transitions. *Science and Public Policy,* 51**,** 836–849.

Braun, V. & Clarke, V. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3**,** 77–101.

Brough, P. & Neuendorf, K. A. 2018. *Content analysis and thematic analysis,* Abingdon, Oxon :, Routledge.

Buckingham, A. & Saunders, P. 2004. *The survey methods workbook: From design to analysis*, Polity Press.

Buckman, A. H., Mayfield, M. & B.M. Beck, S. 2014. What is a Smart Building? *Smart and Sustainable Built Environment,* 3**,** 92–109.

Buildings Department HKSAR. 2025. *Mandatory Building Inspection Scheme* [Online]. Available: https://www.bd.gov.hk/en/safety-inspection/mbis/index.html [Accessed 22 April 2025].

Butler, L. & Visser, M. S. 2006. Extending citation analysis to non-source items. *Scientometrics,* 66**,** 327–343.

Caldera, U., Gulagi, A., Jayasinghe, N. & Breyer, C. 2023. Looking island wide to overcome Sri Lanka's energy crisis while gaining independence from fossil fuel imports. *Renewable Energy,* 218**,** 119261.

Canale, L., De Monaco, M., Di Pietra, B., Puglisi, G., Ficco, G., Bertini, I. & Dell'isola, M. 2021. Estimating the Smart Readiness Indicator in the Italian Residential Building Stock in Different Scenarios. *Energies,* 14**,** 6442.

Capeluto, G. 2019. Adaptability in envelope energy retrofits through addition of intelligence features. *Architectural Science Review,* 62**,** 216–229.

CBRE 2025. Decarbonising Asia Pacific's Office Buildings.

Çelikbilek, Y. & Tüysüz, F. 2020. An in-depth review of theory of the TOPSIS method: An experimental analysis. *Journal of Management Analytics,* 7**,** 281–300.

Centre For Policy Alternatives. 2025. *Navigating Sri Lanka's Economic Precarity: The Need to Address Foundational Issues in Governance* [Online]. Available: https://www.cpalanka.org/navigating-sri-lankas-economic-precarity-the-need-to-address-foundational-issues-in-governance/ [Accessed 22 April 2025].

Chamberlain, D. A., Edwards, D., Lai, J. & Thwala, W. D. 2019. Mega event management of formula one grand prix: an analysis of literature. *Facilities,* 37**,** 1166–1184.

Chan, Y. H. 2003. Biostatistics 102: Quantitative Data - Parametric & Non-parametric Tests. *Singapore Medical Journal,* 44**,** 391–396.

Che, W. W., Tso, C. Y., Sun, L., Ip, D. Y. K., Lee, H., Chao, C. Y. H. & Lau, A. K. H. 2019. Energy consumption, indoor thermal comfort and air quality in a commercial office with retrofitted heat, ventilation and air conditioning (HVAC) system. *Energy and Buildings,* 201**,** 202–215.

Chen, C.-H. 2021. A Hybrid Multi-Criteria Decision-Making Approach Based on ANP-Entropy TOPSIS for Building Materials Supplier Selection. *Entropy,* 23**,** 1597.

Chien, S.-F. & Wang, H.-J. 2014. Smart partition system – A room level support system for integrating smart technologies into existing buildings. *Frontiers of Architectural Research,* 3**,** 376–385.

Cho, K., Yang, J., Kim, T. & Jang, W. 2021. Influence of building characteristics and renovation techniques on the energy-saving performances of EU smart city projects. *Energy and Buildings,* 252**,** 111477.

CLP Power Hong Kong Limited. 2023. *Eco Building Fund* [Online]. Available: https://www.clp.com.hk/en/business/low-carbon-solutions/funds-and-subsidies/eco-building-fund [Accessed 22 April 2025].

Collins, L. M. 2007. Research Design and Methods. *In:* BIRREN, J. E. (ed.) *Encyclopedia of Gerontology (Second Edition).* New York: Elsevier.

Construction Industry Council 2018. Retrofitting existing building (energy efficiency) - A quantitative approach.

Cook, D. & Das, S. K. 2004. *Smart environments: technology, protocols, and applications*, John Wiley & Sons.

Creswell, J. W. & Creswell, J. D. 2023. *Research design : qualitative, quantitative, and mixed methods approaches,* Los Angeles, California ;, SAGE Publications, Inc.

Croce, D., Giuliano, F., Bonomolo, M., Leone, G., Musca, R. & Tinnirello, I. 2020. A decentralized load control architecture for smart energy consumption in small islands. *Sustainable Cities and Society,* 53**,** 101902.

D-Sight. 2025. *D-Sight* [Online]. Available: https://www.d-sight.com/ [Accessed 22 April 2025].

D'oca, S., Ferrante, A., Ferrer, C., Pernetti, R., Gralka, A., Sebastian, R. & Op 'T Veld, P. 2018. Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects. *Buildings,* 8**,** 174.

Dangana, Z., Pan, W. & Goodhew, S. A decision making system for selecting sustainable technologies for retail buildings. Energy and the Built Environment Proceedings, 2013.

Daniel, S. & Ghiaus, C. 2023. Multi-Criteria Decision Analysis for Energy Retrofit of Residential Buildings: Methodology and Feedback from Real Application. *Energies (Basel),* 16**,** 902.

Darko, A., Chan, A. P. C., Ameyaw, E. E., He, B.-J. & Olanipekun, A. O. 2017. Examining issues influencing green building technologies adoption: The United States green building experts' perspectives. *Energy and Buildings,* 144**,** 320–332.

Darko, A., Chan, A. P. C., Ameyaw, E. E., Owusu, E. K., Pärn, E. & Edwards, D. J. 2019. Review of application of analytic hierarchy process (AHP) in construction. *International journal of construction management,* 19**,** 436–452.

Dawson, C. 2002. *Practical research methods: A user-friendly guide to mastering research*, How to books.

De Bock, Y., Auquilla, A., Bracquené, E., Nowé, A. & Duflou, J. R. 2021. The energy saving potential of retrofitting a smart heating system: A residence hall pilot study. *Sustainable Computing: Informatics and Systems,* 31**,** 100585.

De Oliveira Fernandes, M. A., Keijzer, E., Van Leeuwen, S., Kuindersma, P., Melo, L., Hinkema, M. & Gonçalves Gutierrez, K. 2021. Material-versus energy-related impacts: Analysing environmental trade-offs in building retrofit scenarios in the Netherlands. *Energy and Buildings,* 231**,** 110650.

De Vasconcelos, A. B., Cabaco, A., Pinheiro, M. D. & Manso, A. 2016. The impact of building orientation and discount rates on a Portuguese reference building refurbishment decision. *Energy Policy,* 91**,** 329–340.

De Winter, J. C. & Dodou, D. 2010. Five-point Likert items: t test versus Mann-Whitney-Wilcoxon. *Practical Assessment, Research & Evaluation,* 15**,** 1–12.

Decisionlab. 2000. *DecisionLab* [Online]. Available: https://www.decisionlab.se/about.html [Accessed 22 April 2025].

Dey, M., Rana, S. P. & Dudley, S. 2020. Smart building creation in large scale HVAC environments through automated fault detection and diagnosis. *Future Generation Computer Systems,* 108**,** 950–966.

Diakoulaki, D., Mavrotas, G. & Papayannakis, L. 1995. Determining objective weights in multiple criteria problems: The critic method. *Computers & Operations Research,* 22**,** 763–770.

Dincer, I. 2018. *Comprehensive energy systems*, Elsevier.

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N. & Lim, W. M. 2021a. How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research,* 133**,** 285–296.

Donthu, N., Kumar, S. & Pandey, N. 2021b. A retrospective evaluation of Marketing Intelligence and Planning: 1983–2019. *Marketing Intelligence & Planning,* 39**,** 48–73.

Drisko, J. W. & Maschi, T. 2016. *Content analysis*, Pocket Guide to Social Work Re.

Easthope, H., Crommelin, L., Gillon, C., Pinnegar, S., Ruming, K. & Liu, S. 2024. Redeveloping the compact city: the challenges of strata collective sales. *Journal of Property, Planning and Environmental Law,* 16**,** 51–67.

Egiluz, Z., Cuadrado, J., Kortazar, A. & Marcos, I. 2021. Multi-Criteria Decision-Making Method for Sustainable Energy-Saving Retrofit Façade Solutions. *Sustainability,* 13**,** 13168.

Ejidike, C. C. & Mewomo, M. C. 2023. Benefits of adopting smart building technologies in building construction of developing countries: review of literature. *SN Applied Sciences,* 5**,** 52.

Engelsgaard, S., Alexandersen, E. K., Dallaire, J. & Jradi, M. 2020. IBACSA: An interactive tool for building automation and control systems auditing and smartness evaluation. *Building and Environment,* 184**,** 107240.

EU Directorate-General For Climate Action. 2020. *2030 Climate Target Plan* [Online]. Available: https://climate.ec.europa.eu/eu-action/european-green-deal/2030-climate-target-plan_en [Accessed 22 April 2025].

EU Directorate-General For Communication 2018. General Data Protection Regulation. *In:* COMMUNICATION, E. D.-G. F. (ed.).

EU Directorate-General For Communication. 2023. *European structural and investment funds* [Online]. Available: https://commission.europa.eu/funding-tenders/find-funding/funding-management-mode/2014-2020-european-structural-and-investment-funds_en [Accessed 22 April 2025].

Fairchild, A. 2019. Twenty-First-Century Smart Facilities Management: Ambient Networking in Intelligent Office Buildings. *In:* MAHMOOD, Z. (ed.) *Guide to Ambient Intelligence in the IoT Environment: Principles, Technologies and Applications.* Cham: Springer International Publishing.

Farahani, A., Wallbaum, H. & Dalenbäck, J.-O. 2019. The importance of life-cycle based planning in maintenance and energy renovation of multifamily buildings. *Sustainable Cities and Society,* 44**,** 715–725.

Farsater, K. & Olander, S. 2019. Early decision-making for school building renovation. *Facilities,* 37**,** 981–994.

Fasna, M. F. F. & Gunatilake, S. 2019. The effective outsourcing of building retrofitting: key decisions and motivators. *Journal of Facilities Management,* 17**,** 371–384.

Fasna, M. F. F. & Gunatilake, S. 2020. Overcoming barriers for building energy efficiency retrofits: insights from hotel retrofits in Sri Lanka. *Built Environment Project and Asset Management,* 10**,** 277–295.

Felius, L., Hamdy, M., Dessen, F. & Hrynyszyn, B. 2020. Upgrading the Smartness of Retrofitting Packages towards Energy-Efficient Residential Buildings in Cold Climate Countries: Two Case Studies. *Buildings,* 10**,** 200.

Fernandes, R. A., Gomes, R. C. S., Dias, O. & Carvalho, C. 2022. A Novel Strategy for Smart Building Convergence Based on the SmartLVGrid Metamodel. *Energies,* 15**,** 1016.

Fiorentini, M., Cooper, P. & Ma, Z. 2015. Development and optimization of an innovative HVAC system with integrated PVT and PCM thermal storage for a net-zero energy retrofitted house. *Energy and Buildings,* 94**,** 21–32.

Fisk, W. J. 2000. Health and productivity gains from better indoor environments and their relationship with building energy efficiency. *Annual review of energy and the environment,* 25**,** 537–566.

Foldager, H. E., Jeppesen, R. C. & Jradi, M. 2019. DanRETRO: A decision-making tool for energy retrofit design and assessment of Danish buildings. *Sustainability,* 11**,** 3794.

Formisano, A. & Mazzolani, F. M. 2015. On the selection by MCDM methods of the optimal system for seismic retrofitting and vertical addition of existing buildings. *Computers & Structures,* 159**,** 1–13.

Gal, T., Stewart, T. & Hanne, T. 2013. *Multicriteria decision making: advances in MCDM models, algorithms, theory, and applications*, Springer Science & Business Media.

Gallo, P. & Romano, R. 2018. The SELFIE façade system. From Smart Buildings to Smart grid. *TECHNE-Journal of Technology for Architecture and Environment***,** 166–172.

Gallo, W. W. C., Clemett, N., Gabbianelli, G., O'reilly, G. & Monteiro, R. 2022. Influence of Parameter Uncertainty in Multi-Criteria Decision-Making When Identifying Optimal Retrofitting Strategies for RC Buildings. *Journal of Earthquake Engineering***,** 26.

Gann, D. M., Wang, Y. & Hawkins, R. 1998. Do regulations encourage innovation? - the case of energy efficiency in housing. *Building research and information : the international journal of research, development and demonstration,* 26**,** 280–296.

Gao, C., Rajeswaran, T. & Nakagawa, E. A literature review on smart-well technology. Production and Operations Symposium, 2007. OnePetro.

Gattuso, C., O'loughlinm, L. & Sim, H. 2016. Teaching Pneumatics Controls with New Tricks: Case Study on Existing Buildings Getting Intelligent Solutions. *Energy Engineering,* 113**,** 70–78.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O. & Raahemifar, K. 2017. Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews,* 75**,** 1046–1053.

Ghansah, F. A., Owusu-Manu, D.-G. & Ayarkwa, J. 2021. Project management processes in the adoption of smart building technologies: a systematic review of constraints. *Smart and Sustainable Built Environment,* 10**,** 208–226.

Ghansah, F. A., Owusu-Manu, D.-G., Ayarkwa, J., Edwards, D. J. & Hosseini, M. R. 2022. Assessing the level of awareness of smart building technologies (SBTs) in the developing countries. *Journal of Engineering, Design and Technology,* 20**,** 696–711.

Gilbert, N. & Stoneman, P. 2015. *Researching social life*, Sage.

Gilleard, J. D. 2024. The Development of Facility Management in Hong Kong: A Personal Reflection. *Facilities@ Management: Concept, Realization, Vision-A Global Perspective.*

Gluszak, Gawlik & Zieba 2019. Smart and Green Buildings Features in the Decision-Making Hierarchy of Office Space Tenants: An Analytic Hierarchy Process Study. *Administrative Sciences,* 9**,** 52.

Göhlich, M. 2016. Theories of Organizational Learning as resources of Organizational Education. *In:* SCHRÖER, A., GÖHLICH, M., WEBER, S. M. & PÄTZOLD, H. (eds.) *Organisation und Theorie: Beiträge der Kommission Organisationspädagogik.* Wiesbaden: Springer Fachmedien Wiesbaden.

Gonçalves, D., Sheikhnejad, Y., Oliveira, M. & Martins, N. 2020. One step forward toward smart city Utopia: Smart building energy management based on adaptive surrogate modelling. *Energy and Buildings,* 223**,** 110146.

Gou, Z., Lau, S. S.-Y. & Prasad, D. 2013. Market Readiness And Policy Implications For Green Buildings: Case Study From Hong Kong. *Journal of Green Building,* 8**,** 162–173.

Govindan, K., Rajendran, S., Sarkis, J. & Murugesan, P. 2015. Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. *Journal of Cleaner Production,* 98**,** 66–83.

Greenland, S., Senn, S. J., Rothman, K. J., Carlin, J. B., Poole, C., Goodman, S. N. & Altman, D. G. 2016. Statistical tests, P values, confidence intervals, and power: a guide to misinterpretations. *European Journal of Epidemiology,* 31**,** 337–350.

Griggs, S., Howarth, D., Griggs, S. & Howarth, D. 2023. *Contesting Aviation Expansion: Depoliticisation, Technologies of Government and Post-Aviation Futures*

Contesting Aviation Expansion, Policy Press.

Gunarathna, C., Yang, R. J. & Fernando, N. 2018. Conflicts and management styles in the Sri Lankan commercial building sector. *Engineering, Construction and Architectural Management,* 25**,** 178–201.

Habibi, S., Pons Valladares, O. & Peña, D. 2020. New sustainability assessment model for Intelligent Façade Layers when applied to refurbish school buildings skins. *Sustainable Energy Technologies and Assessments,* 42**,** 100839.

Hainoun, A., Neumann, H.-M., Morishita-Steffen, N., Mougeot, B., Vignali, É., Mandel, F., Hörmann, F., Stortecky, S., Walter, K., Kaltenhauser-Barth, M., Schnabl, B., Hartmann, S., Valentin, M., Gaiddon, B., Martin, S. & Rozel, B. 2022. Smarter Together: Monitoring and Evaluation of Integrated Building Solutions for Low-Energy Districts of Lighthouse Cities Lyon, Munich, and Vienna. *Energies,* 15**,** 6907.

Hargen, A. & Thomas, J. 2010. Mixed Methods and Systematic Reviews: Examples and Emerging Issues. *SAGE Handbook of Mixed Methods in Social & Behavioral Research.* 2 ed. Thousand Oaks, California: SAGE Publications, Inc.

Hashemi, A. & Dungrani, M. 2025. Indoor Environmental Quality and Health Implications of Building Retrofit and Occupant Behaviour in Social Housing. *Sustainability,* 17**,** 264.

He, Q., Hossain, M. U., Ng, S. T. & Augenbroe, G. 2021. Sustainable building retrofit model for high-rise, high-density city: a case in Hong Kong. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability,* 174**,** 69–82.

He, Q., Wang, G., Luo, L., Shi, Q., Xie, J. & Meng, X. 2017. Mapping the managerial areas of Building Information Modeling (BIM) using scientometric analysis. *International Journal of Project Management,* 35**,** 670–685.

Heyvaert, M., Hannes, K. & Onghena, P. 2016. *Using mixed methods research synthesis for literature reviews: the mixed methods research synthesis approach*, Sage Publications.

Hincapie, M. X. & Costa, P. 2024. Fostering hybrid team performance through inclusive leadership strategies. *Organizational Dynamics,* 53**,** 101072.

Ho, A. M. Y., Lai, J. H. K. & Chiu, B. W. Y. 2021a. Key performance indicators for holistic evaluation of building retrofits: Systematic literature review and focus group study. *Journal of Building Engineering,* 43**,** 102926.

Ho, M. Y., Lai, J. H. K., Hou, H. & Zhang, D. 2021b. Key Performance Indicators for Evaluation of Commercial Building Retrofits: Shortlisting via an Industry Survey. *Energies,* 14.

Hong Kong Environment And Ecology Bureau 2021. Hong Kong's Climate Action Plan 2050.

Hong Kong Green Building Council 2023. HKGBC Retrofitting Guidebook HKSAR.

Hong Kong Green Building Council Limited 2021. Hong Kong Smart Green Building Design Best Practice Guidebook.

Hong Kong Green Building Council Limited. 2025. *HKGBC's Response to 2025-26 Budget Public Consultation* [Online]. Available: https://www.hkgbc.org.hk/eng/news-events/news/2025/20250128.jsp?utm [Accessed 22 April 2025].

Hong, Y., Ezeh, C. I., Zhao, H., Deng, W., Hong, S. H. & Tang, Y. 2021. A target-driven decision-making multi-layered approach for optimal building retrofits via agglomerative hierarchical clustering: A case study in China. *Building and environment,* 197**,** 107849.

Hosamo, H., B. A. Coelho, G., Nordahl Rolfsen, C. & Kraniotis, D. 2024. Building performance optimization through sensitivity Analysis, and economic insights using AI. *Energy and Buildings,* 325**,** 114999.

Huang, D. & Nguang, S. K. 2010. Robust fault estimator design for uncertain networked control systems with random time delays: An ILMI approach. *Information Sciences,* 180**,** 465–480.

Huseien, G. F. & Shah, K. W. 2022. A review on 5G technology for smart energy management and smart buildings in Singapore. *Energy and AI,* 7**,** 100116.

Hwang, B.-G., Zhao, X., See, Y. L. & Zhong, Y. 2015. Addressing Risks in Green Retrofit Projects: The Case of Singapore. *Project Management Journal,* 46**,** 76–89.

Hwang, C.-L. & Yoon, K. 1981. Methods for Multiple Attribute Decision Making. *In:* HWANG, C.-L. & YOON, K. (eds.) *Multiple Attribute Decision Making: Methods and Applications A State-of-the-Art Survey.* Berlin, Heidelberg: Springer Berlin Heidelberg.

Ibaseta, D., García, A., Álvarez, M., Garzón, B., Díez, F., Coca, P., Del Pero, C. & Molleda, J. 2021. Monitoring and control of energy consumption in buildings using WoT: A novel approach for smart retrofit. *Sustainable Cities and Society,* 65**,** 102637.

Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L. & Acquaye, A. 2014. Integrating economic considerations with operational and embodied emissions into a decision support system for the optimal ranking of building retrofit options. *Building and environment,* 72**,** 82–101.

International Energy Agency 2021. Net Zero by 2050: A Roadmap for the Global Energy Sector.

International Energy Agency 2022. Technology and innovation pathways for zero-carbon-ready buildings by 2030.

Ishizaka, A. & Labib, A. 2011. Review of the main developments in the analytic hierarchy process. *Expert Systems with Applications,* 38**,** 14336–14345.

Ismaeel, W. S. E. & Mohamed, A. G. 2022. Indoor air quality for sustainable building renovation: A decision-support assessment system using structural equation modelling. *Building and Environment,* 214**,** 15.

Iwuanyanwu, O., Gil-Ozoudeh, I., Okwandu, A. C. & Ike, C. S. 2024. Retrofitting existing buildings for sustainability: Challenges and innovations. *Engineering Science & Technology Journal,* 5**,** 2616–31.

Jafari, A. & Valentin, V. 2017. An optimization framework for building energy retrofits decision-making. *Building and Environment,* 115**,** 118–129.

Jahan, A., Edwards, K. L. & Bahraminasab, M. 2016. 4 - Multi-criteria decision-making for materials selection. *In:* JAHAN, A., EDWARDS, K. L. & BAHRAMINASAB, M. (eds.) *Multi-criteria Decision Analysis for Supporting the Selection of Engineering Materials in Product Design (Second Edition).* Butterworth-Heinemann.

James, P. A. B. & Bahaj, A. S. 2005. Smart glazing solutions to glare and solar gain: a 'sick building' case study. *Energy and Buildings,* 37**,** 1058–1067.

Jaspert, D., Ebel, M., Eckhardt, A. & Poeppelbuss, J. 2021. Smart Retrofitting in Manufacturing: A Systematic Review. *Journal of Cleaner Production***,** 127555.

Jayarathne, G. & De Silva, N. Developing a decision-making model for selecting smart retrofits. 10th World Construction Symposium, 2022 Sri Lanka.

Jayasena, N. S., Peiris, M. P. S. N., Chan, D. W. M., Kumaraswamy, M. M. & Lai, J. 2025. Mapping Public-Private Partnerships with Smart Retrofitting in Built Infrastructure Facilities: A Bibliometric Analysis and Science Mapping Review. *CIB World Building Congress 2025.* Purdue University, USA.

Jensen, P. A. 2009. Design Integration of Facilities Management: A Challenge of Knowledge Transfer. *Architectural Engineering and Design Management,* 5**,** 124–135.

Jharkharia, S. & Shankar, R. 2007. Selection of logistics service provider: An analytic network process (ANP) approach. *Omega,* 35**,** 274–289.

Ji, W. & Chan, E. H. W. 2020. Between users, functions, and evaluations: Exploring the social acceptance of smart energy homes in China. *Energy Research & Social Science,* 69**,** 101637.

Jin, H. F., Zhang, M. Y. & Yuan, Y. B. 2018. Analytic Network Process-Based Multi-Criteria Decision Approach and Sensitivity Analysis for Temporary Facility Layout Planning in Construction Projects. *Applied Sciences-Basel,* 8**,** 20.

Jolliffe, I. T. & Cadima, J. 2016. Principal component analysis: a review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* 374**,** 20150202.

Jones Lang Lasalle Inc. 2024. *JLL Hong Kong Real Estate Market Outlook 2025* [Online]. Available: https://www.jll.com.hk/en/newsroom/jll-hong-kong-real-estate-market-faces-continued-challenges-in-2025? [Accessed 22 April 2025].

Jradi, M. 2020. The trade-off between deep energy retrofit and improving building intelligence in a university building. *E3S Web Conf.,* 172**,** 18002.

Jradi, M., Madsen, B. E. & Kaiser, J. H. 2023. DanRETwin: A Digital Twin Solution for Optimal Energy Retrofit Decision-Making and Decarbonization of the Danish Building Stock. *Applied sciences,* 13**,** 9778.

Kaashi, S. & Vilventhan, A. 2023. Development of a building information modelling based decision-making framework for green retrofitting of existing buildings. *Journal of Building Engineering,* 80**,** 108128.

Kafıloğlu, S. S., GÜR, G. & ALAGÖZ, F. 2021. Connectivity Mode Management for User Devices in Heterogeneous D2D Networks. *IEEE Wireless Communications Letters,* 10**,** 194–198.

Kamberelis, G. & Dimitriadis, G. 2005. Focus groups: strategic articulations of pedagogy, politics, and inquiry.

Kaushik, V. & Walsh, C. A. 2019. Pragmatism as a research paradigm and its implications for Social Work research. *Social sciences (Basel),* 8**,** 255.

Kawasaki, Y., Seki, T., Ogatsu, T., Tojima, K., Yamazaki, S. & Kinjo, H. 2016. Validating the performance of NEC's Tamagawa building smart energy system. *NEC Technical Journal,* 10**,** 46–49.

Kim, A. A., Mccunn, L. J. & Lew, J. 2017. Successful Facility Change-Management Practices for Retrofit Projects: Case Study in Lighting. *Journal of Management in Engineering,* 33**,** 05017001.

Kim, A. A. & Medal, L. 2024. Factors Influencing Energy-Efficiency Retrofits in Commercial and Institutional Buildings: A Systematic Literature Review. *Journal of Facility Management Education and Research,* 7**,** 42–63.

King, J. & Perry, C. 2017. Smart buildings: Using smart technology to save energy in existing buildings. Amercian Council for an Energy-Efficient Economy Washington, DC, USA.

Kokkaliaris, S. & Maria, E.-A. 2015. The legislative initiatives for smart metering as a precondition to zero energy: the case of Greece. *Advances in Building Energy Research,* 9**,** 55–72.

Kolokotsa, D., Rovas, D., Kosmatopoulos, E. & Kalaitzakis, K. 2011. A roadmap towards intelligent net zero- and positive-energy buildings. *Solar Energy,* 85**,** 3067–3084.

Kontokosta, C. E. 2016. Modeling the energy retrofit decision in commercial office buildings. *Energy and Buildings,* 131**,** 1–20.

Kothari, C. R. 2004. *Research methodology: Methods and techniques*, New Age International.

Krarti, M. 2022. Performance of smart glazed overhang systems for US residential buildings. *Building and Environment,* 208**,** 108634.

Kumar, T., Srinivasan, R. & Mani, M. 2022. An Emergy-based Approach to Evaluate the Effectiveness of Integrating IoT-based Sensing Systems into Smart Buildings. *Sustainable Energy Technologies and Assessments,* 52**,** 102225.

Lai, J. H. K. 2010. Building operation and maintenance: education needs in Hong Kong. *Facilities,* 28**,** 475–493.

Lai, J. H. K., Hou, H., Edwards, D. J. & Yuen, P. L. 2022. An analytic network process model for hospital facilities management performance evaluation. *Facilities,* 40**,** 333–352.

Lang, M., Lane, R., Zhao, K., Tham, S., Woolfe, K. & Raven, R. 2021. Systematic review: Landlords' willingness to retrofit energy efficiency improvements. *Journal of Cleaner Production,* 303**,** 127041.

Lawrence, T. M., Boudreau, M.-C., Helsen, L., Henze, G., Mohammadpour, J., Noonan, D., Patteeuw, D., Pless, S. & Watson, R. T. 2016. Ten questions concerning integrating smart buildings into the smart grid. *Building and Environment,* 108**,** 273–283.

Lazar, J., Feng, J. H. & Hochheiser, H. 2017. *Research methods in human-computer interaction*, Morgan Kaufmann.

Lee, E. S., Claybaugh, E. S. & Lafrance, M. 2012. End user impacts of automated electrochromic windows in a pilot retrofit application. *Energy and Buildings,* 47**,** 267–284.

Lee, I. & Lee, K. 2015. The Internet of Things (IoT): Applications, investments, and challenges for enterprises. *Business Horizons,* 58**,** 431–440.

Leon, A. C. 1998. 3.12 - Descriptive and Inferential Statistics. *In:* BELLACK, A. S. & HERSEN, M. (eds.) *Comprehensive Clinical Psychology.* Oxford: Pergamon.

Li, P., Lu, Y., Yan, D., Xiao, J. & Wu, H. 2021. Scientometric mapping of smart building research: Towards a framework of human-cyber-physical system (HCPS). *Automation in Construction,* 129**,** 103776.

Libakova, N. M. & Sertakova, E. A. 2015. The method of expert interview as an effective research procedure of studying the indigenous peoples of the north.

Lin, S., Salles, D., Freitas, W. & Xu, W. 2012. An Intelligent Control Strategy for Power Factor Compensation on Distorted Low Voltage Power Systems. *IEEE Transactions on Smart Grid,* 3**,** 1562–1570.

Liu, S., Ding, R. & Wang, L. 2024. An adaptive simulation based decision support approach to respond risk propagation in new product development projects. *Decision Support Systems,* 183**,** 114270.

Liu, T., Ma, G. & Wang, D. 2022. Pathways to successful building green retrofit projects: Causality analysis of factors affecting decision making. *Energy and Buildings,* 276**,** 112486.

Liu, X., Bollen, J., Nelson, M. L. & Van De Sompel, H. 2005. Co-authorship networks in the digital library research community. *Information processing & management,* 41**,** 1462–1480.

Liu, Y., Ning, P. & Reiter, M. K. False data injection attacks against state estimation in electric power grids. ACM Transactions on Information and System Security (TISSEC), 2011. 1–33.

Loosemore, M. & Hsin, Y. Y. 2001. Customer-focused benchmarking for facilities management. *Facilities,* 19**,** 464–476.

Lu, M. & Lai, J. H. K. 2019. Building energy: a review on consumptions, policies, rating schemes and standards. *Energy Procedia,* 158**,** 3633–3638.

Lu, Y., Li, P., Lee, Y. P. & Song, X. 2021. An integrated decision-making framework for existing building retrofits based on energy simulation and cost-benefit analysis. *Journal of Building Engineering,* 43**,** 103200.

Luddeni, G., Krarti, M., Pernigotto, G. & Gasparella, A. 2018. An analysis methodology for large-scale deep energy retrofits of existing building stocks: Case study of the Italian office building. *Sustainable Cities and Society,* 41**,** 296–311.

Ma, R. & Lam, P. T. I. 2019. Investigating the barriers faced by stakeholders in open data development: A study on Hong Kong as a "smart city". *Cities,* 92**,** 36–46.

Ma, Z., Cooper, P., Daly, D. & Ledo, L. 2012. Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings,* 55**,** 889–902.

Madureira, L., Popovič, A. & Castelli, M. Competitive Intelligence Empirical Construct Validation Using Expert In-Depth Interviews Study. 2021 IEEE International Conference on Technology Management, Operations and Decisions (ICTMOD), 24–26 Nov. 2021 2021. 1–6.

Madushika, U. G. D. & Lu, W. 2023. Green retrofitting application in developing economies: State of the art and future research directions. *Energy and Buildings,* 301**,** 113712.

Mahadevkar, S. V., Patil, S., Kotecha, K., Soong, L. W. & Choudhury, T. 2024. Exploring AI-driven approaches for unstructured document analysis and future horizons. *Journal of Big Data,* 11**,** 92.

Mahmoudian, M. & Sharifikheirabadi, P. 2020. Uses of new/smart materials in the green building with sustainability concerns. *Int. Trans. J. Eng. Manag. Appl. Sci. Technol,* 11**,** 1–12.

Majumdar, S. B. & Choudhury, B. K. 2022. Some Critical Treatise on Greening Building Through Retrofitting HVAC&R Systems. *Journal of The Institution of Engineers (India): Series B,* 103**,** 1781–1791.

Mallikarjuna, B. K. & Kozin, I. 2019. Smart buildings: New application area for safety and security risk analysis. *European Safety and Reliability Association Newsletter,* 2019**,** 2–3.

Mangan, S. D. 2023. A Performance-Based Decision Support Workflow for Retrofitting Residential Buildings. *Sustainability,* 15**,** 2567.

Marler, R. T. & Arora, J. S. 2010. The weighted sum method for multi-objective optimization: new insights. *Structural and Multidisciplinary Optimization,* 41**,** 853–862.

Mcgowan, J. & Sampson, M. 2005. Systematic reviews need systematic searchers. *Journal of the Medical Library Association,* 93**,** 74.

Meade, L. M. & Sarkis, J. 1999. Analyzing organizational project alternatives for agile manufacturing processes: An analytical network approach. *International Journal of Production Research,* 37**,** 241–261.

Medrano-Gómez, L. E., Boarin, P. & Premier, A. 2025. The retrofit puzzle: Connecting practices, retrofit measures, and performance outcomes through socio-technical evaluations. *Energy Research & Social Science,* 120**,** 103924.

Miller, E. & Buys, L. 2008. Retrofitting commercial office buildings for sustainability: tenants' perspectives. *Journal of Property Investment & Finance,* 26**,** 552–561.

Miller, W., Liu, L. A., Amin, Z. & Gray, M. 2018. Involving occupants in net-zero-energy solar housing retrofits: An Australian sub-tropical case study. *Solar Energy,* 159**,** 390–404.

Minichiello, V. & Kottler, J. A. 2009. *Qualitative journeys: Student and mentor experiences with research*, Sage Publications.

Mir, U., Abbasi, U., Mir, T., Kanwal, S. & Alamri, S. 2021. Energy Management in Smart Buildings and Homes: Current Approaches, a Hypothetical Solution, and Open Issues and Challenges. *IEEE Access,* 9**,** 94132–94148.

Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C. & Keshri, A. 2019. Descriptive Statistics and Normality Tests for Statistical Data. *Annals of Cardiac Anaesthesia,* 22.

Mooses, V., Pastak, I., Kamenjuk, P. & Poom, A. 2022. Residents’ Perceptions of a Smart Technology Retrofit Towards Nearly Zero-Energy Performance. *Urban Planning,* 7**,** 20–32.

Moradi, S., Hirvonen, J. & Sormunen, P. 2024. Collaborative and life cycle-based project delivery for environmentally sustainable building construction: views of Finnish project professionals and building operation and maintenance experts. *Smart and Sustainable Built Environment,* ahead-of-print.

Morgan, D. J., Maddock, C. A. & Musselwhite, C. B. A. 2024. These are tenants not guinea pigs: Barriers and facilitators of retrofit in Wales, United Kingdom. *Energy Research & Social Science,* 111**,** 103462.

Morgan, D. L. 2007. Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods. *Journal of mixed methods research,* 1**,** 48–76.

Mu, E. & Pereyra-Rojas, M. 2017. *Practical decision making using super decisions v3: An introduction to the analytic hierarchy process*, Springer.

Nadhim, E. A., Hon, C., Xia, B., Stewart, I. & Fang, D. 2018. Investigating the relationships between safety climate and safety performance indicators in retrofitting works. *Construction Economics and Building,* 18**,** 110–129.

Naji, N., Abid, M. R., Benhaddou, D. & Krami, N. 2020. Context-Aware Wireless Sensor Networks for Smart Building Energy Management System. *Information,* 11**,** 530.

Napoli, G., Bottero, M., Ciulla, G., Dell'anna, F., Figueira, J. R. & Greco, S. 2020. Supporting public decision process in buildings energy retrofitting operations: The application of a Multiple Criteria Decision Aiding model to a case study in Southern Italy. *Sustainable Cities and Society,* 60**,** 15.

National Building Research Organisation. 2023. *Preparation and Establishment of a Unified National Building Code for Sri Lanka* [Online]. Available: https://www.nbro.gov.lk/index.php?Itemid=190&catid=8&id=562%3Apreparation-and-establishment-of-a-unified-national-building-code-for-sri-lanka [Accessed 22 April 2025].

Nielsen, A. N., Jensen, R. L., Larsen, T. S. & Nissen, S. B. 2016. Early stage decision support for sustainable building renovation - A review. *Building and Environment,* 103**,** 165–181.

Nour El-Din, M., Poças Martins, J., Ramos, N. M. & Pereira, P. F. 2024. The Role of Blockchain-Secured Digital Twins in Promoting Smart Energy Performance-Based Contracts for Buildings. *Energies,* 17**,** 3392.

Nyumba, T., Derrick, C. & Mukherjee, N. 2018. The use of focus group discussion methodology: Insights from two decades of application in conservation. *Methods in Ecology and Evolution*.

O'grady, T., Chong, H.-Y. & Morrison, G. M. 2021. A systematic review and meta-analysis of building automation systems. *Building and Environment,* 195**,** 107770.

O'mara, M. & Bates, S. 2012. Why invest in high-performance green buildings.

Obringer, R. & Nateghi, R. 2021. What makes a city 'smart' in the Anthropocene? A critical review of smart cities under climate change. *Sustainable Cities and Society,* 75**,** 103278.

OECD 2022. Global Outlook on Financing for Sustainable Development 2023.

Oh, S., Haberl, J. S. & Baltazar, J.-C. 2020. Analysis of zone-by-zone indoor environmental conditions and electricity savings from the use of a smart thermostat: A residential case study. *Science and Technology for the Built Environment,* 26**,** 285–303.

Okahana, H. & Hao, Y. 2019. Are They Worth it?: Master's Degrees and Labor Market Outcomes in the STEM Workforce. *Innovative Higher Education,* 44**,** 165–185.

Ongpeng, J. M. C., Rabe, B. I. B., Razon, L. F., Aviso, K. B. & Tan, R. R. 2022. A multi-criterion decision analysis framework for sustainable energy retrofit in buildings. *Energy (Oxford),* 239**,** 122315.

Owusu-Manu, D.-G., Ghansah, F. A., Ayarkwa, J., Edwards, D. J. & Hosseini, R. 2022. Factors influencing the decision to adopt Smart Building Technology (SBT) in developing countries. *African Journal of Science, Technology, Innovation and Development,* 14**,** 790–800.

Oxman, A. D. & Guyatt, G. H. 1993. The Science of Reviewing Research. *Annals of the New York Academy of Sciences,* 703**,** 125–134.

Panopoulos, K. & Papadopoulos, A. M. 2017. Smart facades for non-residential buildings: an assessment. *Advances in Building Energy Research,* 11**,** 26–36.

Panteli, C., Kylili, A. & Fokaides, P. A. 2020. Building information modelling applications in smart buildings: From design to commissioning and beyond A critical review. *Journal of Cleaner Production,* 265**,** 121766.

Parson, E. A. & Ernst, L. N. 2013. International Governance of Climate Engineering. *Theoretical Inquiries in Law,* 14**,** 307–338.

Pašek, J. & Sojková, V. 2018. Facility management of smart buildings. *International Review of Applied Sciences and Engineering,* 9**,** 181–187.

Peiris, S., Lai, J. H. K. & Kumaraswamy, M. M. Holistic decision making for smart retrofitting for commercial buildings: literature review and a research methodology. Associated Schools of Facility Management Fall 2020 Colloquium Proceedings, 2020.

Peiris, S., Lai, J. H. K. & Kumaraswamy, M. M. 2024. Smart retrofitting for office buildings: Comparison of decision-making criteria between developing and developed regions. *Journal of Building Engineering,* 97**,** 110957.

Peldschus, F. 2008. Experience of the Game Theory Application in Construction Management. *Technological and Economic Development of Economy,* 14**,** 531–545.

Peng, C., Feng, D. Z. & Guo, S. D. 2021. Material Selection in Green Design: A Method Combining DEA and TOPSIS. *Sustainability,* 13**,** 14.

Perera, B. A. K. S., Ahamed, M. H. S., Rameezdeen, R., Chileshe, N. & Hosseini, M. R. 2016. Provision of facilities management services in Sri Lankan commercial organisations. *Facilities,* 34**,** 394–412.

Periyannan, E., Ramachandra, T. & Geekiyanage, D. 2023. Assessment of costs and benefits of green retrofit technologies: Case study of hotel buildings in Sri Lanka. *Journal of Building Engineering,* 78**,** 107631.

Piira, K., Kantorovitch, J., Kannari, L., Piippo, J. & Vu Hoang, N. 2022. Decision Support Tool to Enable Real-Time Data-Driven Building Energy Retrofitting Design. *Energies,* 15.

Pinch, C. 2022. A Guide to Smart Building Challenges. *iOffice + SpaceIQ* [Online]. Available from: https://spaceiq.com/blog/smart-building-challenges/.

Pinto, M. C., Crespi, G., Dell'anna, F. & Becchio, C. 2023. Combining energy dynamic simulation and multi-criteria analysis for supporting investment decisions on smart shading devices in office buildings. *Applied Energy,* 332**,** 120470.

Pinzon Amorocho, J. A. & Hartmann, T. 2022. A multi-criteria decision-making framework for residential building renovation using pairwise comparison and TOPSIS methods. *Journal of Building Engineering,* 53**,** 104596.

Pohoryles, D. A., Bournas, D. A., Da Porto, F., Caprino, A., Santarsiero, G. & Triantafillou, T. 2022. Integrated seismic and energy retrofitting of existing buildings: A state-of-the-art review. *Journal of Building Engineering,* 61**,** 105274.

Preston, S., Mazhar, M. U. & Bull, R. 2020. Citizen Engagement for Co-Creating Low Carbon Smart Cities: Practical Lessons from Nottingham City Council in the UK. *Energies,* 13**,** 6615.

Pritoni, M., Woolley, J. M. & Modera, M. P. 2016. Do occupancy-responsive learning thermostats save energy? A field study in university residence halls. *Energy and Buildings,* 127**,** 469–478.

Psomas, T., Heiselberg, P., Lyme, T. & Duer, K. 2017. Automated roof window control system to address overheating on renovated houses: Summertime assessment and intercomparison. *Energy and Buildings,* 138**,** 35–46.

Rajasekar, S., Pitchai, P. N. & Veerapadran, C. 2006. Research Methodology.

Ramachandra, T. & Weerasinghe, A. S. 2021. Greening Existing Garment Buildings: A Case of Sri Lanka. *In:* HOWLETT, R. J., LITTLEWOOD, J. R. & JAIN, L. C. (eds.) *Emerging Research in Sustainable Energy and Buildings for a Low-Carbon Future.* Singapore: Springer Singapore.

Ramezani, B., Silva, M. G. D. & Simões, N. 2021. Application of smart readiness indicator for Mediterranean buildings in retrofitting actions. *Energy and buildings,* 249**,** 111173.

Raza, S. A. & Hameed, A. 2021. Models for maintenance planning and scheduling – a citation-based literature review and content analysis. *Journal of Quality in Maintenance Engineering,* ahead-of-print.

Reddy, G. P. & Kumar, Y. P. 2021. Retrofitted IoT based communication network with hot standby router protocol and advanced features for smart buildings. *International Journal of Renewable Energy Research,* 11**,** 1354–1369.

Ritchie, J., Lewis, J., Nicholls, C. M. & Ormston, R. 2013. *Qualitative research practice: A guide for social science students and researchers*, sage.

Roberta, P., Ezilda, C. & Sabrina, R. 2018. Pathways to ZEED. *TECHNE - Journal of Technology for Architecture and Environment*.

Robson, C. 2002. *Real world research: A resource for social scientists and practitioner-researchers*, Wiley-Blackwell.

Rocha, P., Siddiqui, A. & Stadler, M. 2015. Improving energy efficiency via smart building energy management systems: A comparison with policy measures. *Energy and Buildings,* 88**,** 203–213.

Royal Institution Of Chartered Surveyors 2024. Residential retrofit standard.

Saaty, T. L. 1980. *The analytic hierarchy process : planning, priority setting, resource allocation*.

Saaty, T. L. 1996. *Decision making with dependence and feedback : the analytic network process : the organization and prioritization of complexity*, Pittsburgh, Pa. : RWS Publications.

Saaty, T. L. 2004. Fundamentals of the analytic network process — Dependence and feedback in decision-making with a single network. *Journal of Systems Science and Systems Engineering,* 13**,** 129–157.

Saaty, T. L. 2005. *Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks*, RWS publications.

Saaty, T. L. & Vargas, L. G. 2006. *Decision Making with the Analytic Network Process: Economic, Political, Social and Technological Applications with Benefits, Opportunities, Costs and Risks*, Springer US.

Sadeghi, M., Naghedi, R., Behzadian, K., Shamshirgaran, A., Tabrizi, M. R. & Maknoon, R. 2022. Customisation of green buildings assessment tools based on climatic zoning and experts judgement using K-means clustering and fuzzy AHP. *Building and Environment,* 223**,** 109473.

Sadeghi, R. & Goerlandt, F. 2023. Validation of system safety hazard analysis in safety-critical industries: An interview study with industry practitioners. *Safety Science,* 161**,** 106084.

Salkind, N. 2010. *Encyclopedia of Research Design*, SAGE.

Salosin, A., Gamayunova, O. & Mottaeva, A. 2020. The effectiveness of the Smart Office system. *Journal of Physics: Conference Series,* 1614**,** 012028.

Santos, A., Liu, N. & Jradi, M. 2021. AUSTRET: An Automated Step Response Testing Tool for Building Automation and Control Systems. *Energies,* 14**,** 3972.

Sarkar, A. & Singh, J. 2010. Financing energy efficiency in developing countries—lessons learned and remaining challenges. *Energy Policy,* 38**,** 5560–5571.

Saunders, M. N. K., Lewis, P. & Thornhill, A. 2023. *Research methods for business students,* Harlow, England ;, Pearson.

Schäuble, D., Marian, A. & Cremonese, L. 2020. Conditions for a cost-effective application of smart thermostat systems in residential buildings. *Applied Energy,* 262**,** 114526.

Schneider Electric. 2025. *Retrofitting buildings for sustainability* [Online]. Available: https://www.se.com/hk/en/work/campaign/buildings-of-the-future/retrofitting-buildings-for-sustainability.jsp?utm [Accessed 22 April 2025].

Scorpio, M., Ciampi, G., Rosato, A., Maffei, L., Masullo, M., Almeida, M. & Sibilio, S. 2020. Electric-driven windows for historical buildings retrofit: Energy and visual sensitivity analysis for different control logics. *Journal of Building Engineering,* 31**,** 101398.

Seddiki, M., Anouche, K., Bennadji, A. & Boateng, P. 2016. A multi-criteria group decision-making method for the thermal renovation of masonry buildings: The case of Algeria. *Energy and Buildings,* 129**,** 471–483.

Sedighi, M. & Jalalimanesh, A. 2017. Mapping research trends in the field of knowledge management. *Malaysian Journal of Library & Information Science,* 19.

Shadman Roodposhti, M., Aryal, J., Shahabi, H. & Safarrad, T. 2016. Fuzzy Shannon Entropy: A Hybrid GIS-Based Landslide Susceptibility Mapping Method. *Entropy,* 18**,** 343.

Shahsavarani, A. M. & Azad Marz Abadi, E. 2015. The Bases, Principles, and Methods of Decision-Making: a review of literature. *International Journal of Medical Reviews,* 2**,** 214–225.

Shaik, S., Nundy, S., Maduru, V. R., Ghosh, A. & Afzal, A. 2022. Polymer dispersed liquid crystal retrofitted smart switchable glazing: Energy saving, diurnal illumination, and CO2 mitigation prospective. *Journal of Cleaner Production,* 350**,** 131444.

Shalal, A. 2025. IMF must be more active on debt restructurings, Georgieva says. *Reuters.*

Shannon, C. E. 1948. A mathematical theory of communication. *The Bell System Technical Journal,* 27**,** 379–423.

Shao, Q. G., Liou, J. J. H., Weng, S. S. & Chuang, Y. C. 2018. Improving the Green Building Evaluation System in China Based on the DANP Method. *Sustainability,* 10**,** 20.

Sheela, M. S., Gopalakrishnan, S., Begum, I. P., Hephzipah, J. J., Gopianand, M. & Harika, D. 2024. Enhancing Energy Efficiency With Smart Building Energy Management System Using Machine Learning and IOT. *Babylonian Journal of Machine Learning,* 2024**,** 80–88.

Shen, P. 2024. Building retrofit optimization considering future climate and decision-making under various mindsets. *Journal of Building Engineering,* 96**,** 110422.

Shen, W., Xue, H. H., Newsham, G. & Dikel, E. Smart building monitoring and ongoing commissioning: A case study with four canadian federal government office buildings. 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC), 5–8 Oct. 2017 2017. 176–181.

Si, J. & Marjanovic-Halburd, L. 2018. Criteria weighting for green technology selection as part of retrofit decision making process for existing non-domestic buildings. *Sustainable Cities and Society,* 41**,** 625–638.

Si, J., Marjanovic-Halburd, L., Nasiri, F. & Bell, S. 2016. Assessment of building-integrated green technologies: A review and case study on applications of Multi-Criteria Decision Making (MCDM) method. *Sustainable Cities and Society,* 27**,** 106–115.

Sinaga, L., Husin, A. E., Kristiyanto, K., Arif, E. J. & Pinem, M. P. 2023. Blockchain-Building Information Modeling (BIM): Aplication in Cost Eficiency of Retrofitting Green Chemical Industrial Buildings. *Computational Engineering and Physical Modeling,* 6**,** 1–22.

Sing, M. C. P., Chan, V. W. C., Lai, J. H. K. & Matthews, J. 2021. Energy-efficient retrofitting of multi-storey residential buildings. *Facilities,* 39**,** 722–736.

Slovák, Ľ., Daněk, J. & Daněk, T. 2023. The use of focus groups in cultural ecosystem services research: a systematic review. *Humanities and Social Sciences Communications,* 10.

Smalheiser, N. R. 2017. Chapter 12 - Nonparametric Tests. *In:* SMALHEISER, N. R. (ed.) *Data Literacy.* Academic Press.

Snyder, H. 2019. Literature review as a research methodology: An overview and guidelines. *Journal of Business Research,* 104**,** 333–339.

Starbucks Corporation. 2018. *Starbucks Announces Global Greener Stores Commitment* [Online]. Available: https://stories.starbucks.com/press/2018/starbucks-announces-global-greener-stores-commitment/ [Accessed 22 April 2025].

Stemler, S. 2000. An overview of content analysis. *Practical assessment, research, and evaluation,* 7**,** 17.

Sun Hung Kai Properties Limited. 2023. *Our Sustainability Strategy* [Online]. Available: https://www.shkp.com/en-US/sustainable-development/our-sustainability-strategy [Accessed 22 April 2025].

Sun, X., Gou, Z. & Lau, S. S.-Y. 2018. Cost-effectiveness of active and passive design strategies for existing building retrofits in tropical climate: Case study of a zero energy building. *Journal of Cleaner Production,* 183**,** 35–45.

Swire Properties Limited. 2021. *Sustainable Development* [Online]. Available: https://www.swireproperties.com/en/sustainable-development/ [Accessed 22 April 2025].

Syed Ali, A., Riley, C., Acton, E., Ali, A., Heidarinejad, M. & Stephens, B. 2021. Development and evaluation of an automatic steam radiator control system for retrofitting legacy heating systems in existing buildings. *Energy and Buildings,* 251**,** 111344.

Taboada-Orozco, A., Yetongnon, K. & Nicolle, C. 2024. Smart Buildings: A Comprehensive Systematic Literature Review on Data-Driven Building Management Systems. *Sensors,* 24.

Taherdoost, H. & Madanchian, M. 2023. Multi-Criteria Decision Making (MCDM) Methods and Concepts. *Encyclopedia,* 3**,** 77–87.

Talon, C. & Goldstein, N. 2015. Smart offices: how intelligent building solutions are changing the occupant experience. *Navigant Research*.

Tan, Y., Liu, G., Zhang, Y., Shuai, C. & Shen, G. Q. 2018. Green retrofit of aged residential buildings in Hong Kong: A preliminary study. *Building and Environment,* 143**,** 89–98.

Tashakkori, A. & Creswell, J. W. 2007. *The new era of mixed methods*, Sage Publications.

Tavakol, M. & Dennick, R. 2011. Making sense of Cronbach's alpha. *Int J Med Educ,* 2**,** 53–55.

Teplow, D. B. 2018. *Progress in molecular biology and translational science*, Academic Press.

The Electrical And Mechanical Services Department Of Hong Kong SAR 2012. Buildings Energy Efficiency Ordinance (BEEO). Hong Kong SAR.

The World Bank Group 2021. World Development Report 2021: Data for Better Lives.

Tiwari, A., Lohani, Q. M. D., Muhuri, P. K. & IEEE. 2020. Interval-valued Intuitionistic Fuzzy TOPSIS method for Supplier Selection Problem. IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Jul 19–24 2020 Electr Network. NEW YORK: Ieee.

Todeschi, V., Mutani, G., Baima, L., Nigra, M. & Robiglio, M. 2020. Smart Solutions for Sustainable Cities—The Re-Coding Experience for Harnessing the Potential of Urban Rooftops. *Applied Sciences,* 10**,** 7112.

Tokede, O. O., Love, P. E. D. & Ahiaga-Dagbui, D. D. 2018. Life cycle option appraisal in retrofit buildings. *Energy and Buildings,* 178**,** 279–293.

Topaloğlu, F. 2025. Analytic network process (ANP) based decision support tool for nuclear power plant location and reactor type selection. *Nuclear Engineering and Technology,* 57**,** 103228.

Tranfield, D., Denyer, D. & Smart, P. 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management,* 14**,** 207–222.

Tseng, M. L. 2009. Application of ANP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila. *Environmental Monitoring and Assessment,* 156**,** 181–197.

Tsoumanis, G., Formiga, J., Bilo, N., Tsarchopoulos, P., Ioannidis, D. & Tzovaras, D. 2021. The Smart Evolution of Historical Cities: Integrated Innovative Solutions Supporting the Energy Transition while Respecting Cultural Heritage. *Sustainability,* 13**,** 9358.

UL Solutions. 2022. *SPIRE Smart Building Program™* [Online]. Available: https://spiresmartbuildings.ul.com/ [Accessed 22 April 2025].

United Nations 2015. Sustainable Development Goals. *Take Action for the Sustainable Development Goals.*

Van Eck, N. J. & Waltman, L. 2013. VOSviewer manual.

Verbeke, D. A. S., Rynders, G., Ma, Y. & Waide, P. 2019. The 2nd Technical Support Study on the Smart Readiness Indicator for Buildings.

Vergara, R., Castillo, T. & Herrera, R. F. 2025. Performance Evaluation System for Design Phase of High-Rise Building Projects: Development and Validation Through Expert Feedback and Simulation. *Buildings* [Online], 15.

Villalba, P., Sanchez-Garrido, A. J. & Yepes, V. 2024. A Review Of Multi-Criteria Decision-Making Methods For Building Assessment, Selection, And Retrofit. *Journal of civil engineering and management,* 30**,** 465.

Wang, A., An, Y. & Yu, S. 2023. Research on the Evaluation of Green Technology Renovation Measurement for Multi-Storey Houses in Severe Cold Regions Based on Entropy-Weight-TOPSIS. *Sustainability,* 15**,** 9815.

Wang, B. & Xia, X. 2015. Optimal maintenance planning for building energy efficiency retrofitting from optimization and control system perspectives. *Energy and Buildings,* 96**,** 299–308.

Wang, Z. 2008. Smart spaces: creating new instructional space with smart classroom technology. *New Library World,* 109**,** 150–165.

Weerasinghe, L. N. K., Darko, A., Chan, A. P. C., Blay, K. B. & Edwards, D. J. 2024. Measures, benefits, and challenges to retrofitting existing buildings to net zero carbon: A comprehensive review. *Journal of Building Engineering,* 94**,** 109998.

Wen, S., You, R. & Chen, Q. 2025. Implementing building retrofitting strategies to halve campus office building carbon emissions by 2035: A case study in Hong Kong with techno-economic analysis. *Energy and Buildings,* 338**,** 115705.

Wendzel, S. 2016. How to increase the security of smart buildings? *Communications of the ACM,* 59**,** 47–49.

Widiastuti, T., Al-Shami, S. A., Mawardi, I., Zulaikha, S., Haron, R., Kasri, R. A., Mustofa, M. U. A. & Dewi, E. P. 2024. Capturing the barriers and strategic solutions for women empowerment: Delphy analytical network process. *Journal of Open Innovation: Technology, Market, and Complexity,* 10**,** 100345.

Wiley, J. A., Benefield, J. D. & Johnson, K. H. 2010. Green Design and the Market for Commercial Office Space. *The Journal of Real Estate Finance and Economics,* 41**,** 228–243.

Wilkinson, S. J. & Reed, R. G. 2006. Office building characteristics and the links with carbon emissions. *Structural Survey,* 24**,** 240–251.

Wong, J., Li, H. & Lai, J. 2008a. Evaluating the system intelligence of the intelligent building systems. *Automation in Construction,* 17**,** 284–302.

Wong, J., Li, H. & Lai, J. 2008b. Evaluating the system intelligence of the intelligent building systems: Part 2: Construction and validation of analytical models. *Automation in Construction,* 17**,** 303–321.

Wong, J. K. W. & Li, H. 2008. Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Building and Environment,* 43**,** 108–125.

Wong, J. K. W., Li, H. & Wang, S. W. 2005. Intelligent building research: a review. *Automation in Construction,* 14**,** 143–159.

Woo, J.-H. & Menassa, C. 2014. Virtual Retrofit Model for aging commercial buildings in a smart grid environment. *Energy and Buildings,* 80**,** 424–435.

World Green Building Council. 2025. *Bringing embodied carbon upfront* [Online]. Available: https://worldgbc.org/climate-action/embodied-carbon/#:~:text=Buildings%20are%20currently%20responsible%20for,11%25%20from%20materials%20and%20construction. [Accessed 22/4 2025].

Xu, P. & Chan, E. H. W. 2013. ANP model for sustainable Building Energy Efficiency Retrofit (BEER) using Energy Performance Contracting (EPC) for hotel buildings in China. *Habitat International,* 37**,** 104–112.

Xu, P., Chan, E. H. W., Visscher, H. J., Zhang, X. & Wu, Z. 2015. Sustainable building energy efficiency retrofit for hotel buildings using EPC mechanism in China: analytic Network Process (ANP) approach. *Journal of Cleaner Production,* 107**,** 378–388.

Yang, A., Han, M., Zeng, Q. & Sun, Y. 2021. Adopting Building Information Modeling (BIM) for the Development of Smart Buildings: A Review of Enabling Applications and Challenges. *Advances in Civil Engineering,* 2021**,** 1–26.

Yang, C.-H., Lee, K.-C. & Li, S.-E. 2020. A mixed activity-based costing and resource constraint optimal decision model for IoT-oriented intelligent building management system portfolios. *Sustainable Cities and Society,* 60**,** 102142.

Yang, F. 2023. How to be smart about building cybersecurity. *Property Journal (RICS)*.

Yang, J. & Peng, H. 2001. Decision support to the application of intelligent building technologies. *Renewable Energy,* 22**,** 67–77.

Yang, X., Sayono, J., Xu, J., Li, J. N., Hester, J. & Zhang, Y. MiniKers: Interaction-Powered Smart Environment Automation. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2022. 1–22.

Yilmaz, K. 2013. Comparison of quantitative and qualitative research traditions: Epistemological, theoretical, and methodological differences. *European journal of education,* 48**,** 311–325.

Yin, R. K. 2009. *Case study research: Design and methods*, sage.

Yitmen, I., Al-Musaed, A. & Yücelgazi, F. 2022. ANP model for evaluating the performance of adaptive façade systems in complex commercial buildings. *Engineering, Construction and Architectural Management,* 29**,** 431–455.

Yoon, K. 1987. A Reconciliation Among Discrete Compromise Solutions. *Journal of the Operational Research Society,* 38**,** 277–286.

Yousif, C., Gatt, D. & Caruana, C. 2020. Building Energy Renovation and Smart Integration of Renewables in a Social Housing Block Toward Nearly-Zero Energy Status. *Frontiers in Energy Research,* 8.

Zanakis, S. H., Solomon, A., Wishart, N. & Dublish, S. 1998. Multi-attribute decision making: A simulation comparison of select methods. *European Journal of Operational Research,* 107**,** 507–529.

Zavadskas, E. K., Mardani, A., Turskis, Z., Jusoh, A. & Nor, K. M. D. 2016. Development of TOPSIS Method to Solve Complicated Decision-Making Problems: An Overview on Developments from 2000 to 2015. *International Journal of Information Technology & Decision Making,* 15**,** 645–682.

Zavadskas, E. K., Turskis, Z. & Kildienė, S. 2014. State of Art Surveys of Overviews on MCDM/MADM Methods. *Technological and Economic Development of Economy,* 20**,** 165–179.

Zhai, J., Nicole, L. & And Bendewald, M. 2011. Deep energy retrofit of commercial buildings: a key pathway toward low-carbon cities. *Carbon Management,* 2**,** 425–430.

Zhang, X. Q. 2016. The trends, promises and challenges of urbanisation in the world. *Habitat International,* 54**,** 241–252.

Zhao, X., Tan, Y. T., Shen, L. Y., Zhang, G. M. & Wang, J. H. 2019. Case-based reasoning approach for supporting building green retrofit decisions. *Building and Environment,* 160**,** 10.

Zhao, Y. & Taib, N. 2022. Cloud-based Building Information Modelling (Cloud-BIM): Systematic literature review and Bibliometric-qualitative Analysis. *Automation in Construction,* 142**,** 104468.

Zhou, L., An, C., Shi, J., Lv, Z. & Liang, H. Design and Construction Integration Technology Based on Digital Twin. 2021 Power System and Green Energy Conference (PSGEC), 2021. 7–11.

Zolfani, S. H. & Hasheminasab, H. 2020. *MCDM App* [Online]. Available: https://www.mcdm.app/ [Accessed 22 April 2025].

Zou, Z.-H., Yun, Y. & Sun, J.-N. 2006. Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment. *Journal of Environmental Sciences,* 18**,** 1020–1023.