

DEVELOPING EVALUATION CRITERIA FOR ASSESSING THE PERFORMANCE OF SMART RETROFITTING OF EXISTING BUILDINGS

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Abstract. The existing building sector is contributing to high energy consumption and CO₂ emissions worldwide. Therefore, building practitioners should commit to adopting energy-conserving practices and minimizing CO₂ emissions. Consequently, the adoption of smart retrofitting (SR) in existing buildings is one of the easiest and cheapest ways to achieve energy efficiency and reduce CO₂ emissions. In Sri Lanka, SR adaptation was at a low level. However, there is a shortage of research and studies concerning assessing the performance of the SR of existing buildings in Sri Lanka after its implementation. Therefore, the purpose of this research is to develop an assessment model to assess the performance of the SR of existing buildings for the post-installation phase in Sri Lanka. A qualitative research method was used in this research to identify factors to develop an SR performance assessment model for existing buildings. Semi-structured expert interviews were conducted to validate the identified factors and obtain additional information related to the SR assessment, and the data collected was analysed through manual content analysis. As a result, a total of 39 factors were identified, which fell into seven categories: technical adaptability, human comfort, economic adaptability, energy management, environmental sustainability, safety and security, and compliance. Finally, the SR performance assessment model is developed.

Keywords. Smart Retrofits, Existing Buildings, Assessment Model

1. Introduction

Global energy consumption has grown dramatically during the past few years, and the rate of global energy consumption is expected to increase by another 30% by 2040 (Dilogini et al., 2021). According to the European Union, the existing building in the EU accounts for 40% of the total energy consumption and 36% of the total CO₂ emissions worldwide (Balaras et al., 2023). Specifically, the construction and maintenance of conventional buildings consume about 30- 40% of energy consumption and are subject to releasing high levels of greenhouse gases (Ejidike & Mewomo, 2023). However, existing buildings should have to be modernized on a large scale to become decarbonization (Naimoli, 2020). Meanwhile, the existing buildings sector has reasonably high energy consumption compared with the new buildings in the built environment (Madushika et al., 2023). To this end, the EU has committed to reducing domestic greenhouse gas emissions and CO₂ emissions by 80% by 2050 to improve energy conservation (Aldakheel, 2021).

Due to these reasons, the retrofitting concept was introduced as the most suitable solution for achieving energy efficiency and reducing CO₂ emissions by remodeling buildings with the aim of sustainability (Gleeson et al., 2011). In recent years, the integration of smart features with retrofitting in existing buildings has been the subject of research in the current Industry 4.0 era (Newman et al., 2021). Similarly, the adoption of Smart Retrofitting (SR) in existing buildings is one of the easiest and cheapest ways to enhance and modernize building performance and attain sustainability (Farahani et al., 2019; Jayarathne & De Silva, 2022; Luddeni et al., 2018).

In this research, SR is described as the process of converting an existing building through the integration of new technologies, supporting the transition towards smart buildings to be able to sense, interpret, communicate, monitor and control building systems and actively respond to building and occupant needs to achieve energy saving, occupant comfort, safety and security, technical, economic and environmentally feasible.

On a similar note, it is observed that SR in building stock make a considerable contribution to the national CO₂ emission reduction, accounting for 61% of the total reduction (Hirvonen et al.,2021).As energy savings and carbon reduction are one of the main drivers of SR, SR reduces energy consumption while improving the building's smartness (Peiris et al., 2023). Out of these in the building sector, the SR concept creates a more comfortable, convenient, and flexible environment by reducing maintenance and operating expenditures, which enables organisations to boost their productivity and increase their marketability (Huseien & Shah, 2022).There are a variety of reasons that hinder SR implementation, such as risk associated with cyber-attacks in communication networks (Lawrence et al., 2016), lack of knowledge of new technologies, and specific legal obstacles (Aldakheel et al., 2020), lack of IOT experience between facility management (Pašek & Sojková, 2018). However, it is a known fact that a lack of knowledge and experience is a challenge that may hinder retrofitting (Aldakheel et al.,2020; Ibaseta et al., 2021).

Being a developing country, the adoption of the smart building concept in Sri Lanka is still novel to industry experts and researchers due to a lag behind in the integration with new technologies (Dilogini et al., 2021; Waidyasekara & Madhusanka, 2019). Similarly, in Sri Lanka, several studies have been conducted related to smart buildings and service preferences (Weerawardhana et al., 2024); some studies consider focusing on green retrofits (Periyannan et al., 2023) or energy retrofits (Amjath et al., 2021). In addition, it is obvious that several studies concerning the developing criteria for selecting the best suitable smart retrofit option for buildings (Jayarathne & De Silva, 2022; Peiris et al., 2023).

Even though there are several studies on SR in the Sri Lankan context, there is a shortage of research and studies concerning assessing the performance of SR in the post-installation stage of existing buildings in Sri Lanka. Therefore, this research aims to develop an assessment model to assess the performance of the SR of existing buildings in Sri Lanka after its installation. The introduced model can be used by industry professionals to measure the effectiveness of SR projects in their buildings, while policymakers can use this model to select the most suitable SR methods for different types of buildings when implementing organisational and national-level energy policies.

2. Literature Review

2.1 EXISTING ASSESSMENT MODEL AND RATING SYSTEMS RELATED TO SMART BUILDINGS AND SMART RETROFITTING

Concerning assessing the performance of buildings, the focus of this work is to develop a performance assessment model by identifying a set of factors to assess the building performance in existing buildings. Accordingly, several building performance assessment schemes have contributed to assessing the Smart Buildings (SB) and SR performance as mentioned below.

According to Kelly et al. (2012), building performance is crucial for assessing and estimating energy efficiency, cost-saving enhancements, and quantifying the overall emissions in a built environment. Post occupancy assessment (POE), benchmarking, building in use (BIU), quality assessment, balanced scorecards, and facility performance measures are several building performance assessment schemes developed in literature studies. (Islam et al., 2019).

Accordingly, several smart building performance assessment schemes have been developed in the past few years (Apanaviciene et al., 2020). Kolokotsa et al. (2007) developed a matrix tool giving importance to 25 sub-performance indicators that were categorized into five key criteria: responsiveness, functionality, economic issues, suitability, and environment to assess the performance of intelligent buildings. Further study by Arditì et al. (2015) proposed a smartness index considering the issues related to smart buildings under three main categories: energy, economic, and occupant comfort issues to assess the smartness of the building. Gunatilaka et al. (2021) proposed several aspects that need to be included to assess the level of smartness in Commercial Buildings in Sri Lanka. The author developed a scoring system forming six main Assessment criteria (occupancy comfort, communication and data sharing, energy management, health, safety, building automation, and sustainability features) and 31 sub-criteria for assessing the level of smartness from a commercial building's perspective.

Extending the review further, MATOOL, developed by Building Research Establishment, BIQ (Building Intelligence Quotient), IBI (Intelligent Building Index) and TIBA (Taiwan Intelligent Building Association) are several frameworks which highly developed based on the application of smart building concepts (Affonso et al., 2024).

Within this reference, it can be revealed that some existing building assessment frameworks are mostly focused on sustainability approaches: mainly a 'three pillar' framework to assess the sustainable impact of smart buildings (Crespi,2018). In addition to that Green Building Assessment Tool (GBTool), Green Star, BREEAM (The Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design) in the USA, and CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), considered as mostly used environmental performance assessment schemes to assess the performance of buildings (Arditì et al., 2015; Gunatilaka et al., 2021). However, it is obvious that these tools are focused on specific areas: sustainable environmental aspects and do not prioritize occupant satisfaction in terms of assessing building performance (Das, 2012). Accordingly, Hassanain et al. (2022) conducted the POE process model to assess user satisfaction with smart buildings and found that user responsiveness is an essential feature of smart buildings.

Moreover, Aldakheel (2021) proposed key performance indicators (KPIS) to assess the SR in residential buildings under three main categories: energy performance, grid performance, and technological performance. In addition, Apostolopoulos et al. (2022) used the smart readiness indicator (SRI) to investigate the cost estimation and smartification of SR in typical residential buildings.

2.2. PARAMETERS FOR ASSESSING SMART RETROFITTING OF BUILDINGS

The selection of smart retrofit measures for a particular building is a complex process. (Peiris et al., 2023). Further, the author developed decision-making criteria for making decisions on suitable smart retrofit measures. The author highlighted that when selecting various SR measures, the decision maker should consider financial, technical, environmental, legal, and human criteria to choose optimum SR solutions. Energy-saving, human comfort, and green attributes can be considered as SR performance benchmarks of buildings (Jayarathne & De Silva, 2022).

According to the literature findings, most of the authors and existing smart building assessment schemes identified the most frequently used factors: green, safety, energy, economic, occupant comfort, environment, technological, sustainability, automation, health and safety. In addition to that, papers on retrofit decision-making criteria focus on technical, financial, environmental, legal, human, energy saving, human comfort, and green attributes. Within the list of identified factors, the development of a new assessment model to assess the performance of SR in existing buildings is presented in Figure 1.

2.2.1 Technical Adaptability

The adoption of SB technologies has enabled us to control and inspect remotely and operate in a shared network when compared with traditional buildings, which operate independently (Froufe et al., 2020). According to the authors, building automation systems and their inherent components (actuators and sensors) monitor and control interconnected services, enable remote monitoring, and manage multiple building operations automatically (Baig et al., 2017; Gunatilaka et al., 2021). Moreover, a high degree of automation characteristic of SB technologies can facilitate predictive maintenance approaches of existing systems (Moretti et al., 2021).

Accordingly, the inclusion of technology and automation into a reality in a common building will result in improving the value and life span of the building with the help of real-time updates and maintenance approaches (Froufe et al., 2020). Under this category, the study identified six (6) factors that are essential in assessing the performance of SR, including system interoperability, integrating BMS with existing controls, maintenance fault prediction capabilities, real-time monitoring and control, compatibility with existing systems, and flexibility to adopt changes.

2.2.2 Energy Management

Energy management is a prominent factor in optimum energy efficiency due to the use of information communication technology and advanced computing (Aslam et al., 2017; Mir et al., 2021). The adoption of SR technologies is becoming progressively meaningful for buildings to consider that they could decrease their energy costs (Crespi, 2018). Examples include the use of smart metering with an energy management system (Mbungu et al., 2020), smart grid (Mbungu et al., 2020), and integration with machine learning technologies to detect and predict anomalies in power consumption (Eini et al., 2021) are considered. Through building intelligent controls and management features, the SB energy management system can make intelligent, real-time decisions and manage building energy consumption by exploiting the information from IOT sensors and smart grids

(Froufe et al., 2020). Under this category, the study identified (6) factors that are essential in assessing the performance of SR including intelligent controls and energy management capabilities, energy efficiency improvements and saving capabilities, demand management capabilities, prediction of energy consumption, onsite renewable energy generation capabilities, and accuracy of smart metering capturing and monitoring real-time energy consumption.

2.2.3 Human Comfort

Parkinson et al. (2023) mentioned that human comfort is a fundamental factor that needs to be considered in buildings. Further study pinpointed sources for customer dissatisfaction: acoustics, temperature, noise level, visual privacy and air quality. This evidence should motivate building owners to respond proactively by adopting SB technologies to prioritize a comfortable indoor environment for occupant satisfaction (Daissaoui et al., 2020) Examples include controlling temperature and ventilation based on implementing SB technologies in HVAC retrofits make user satisfaction while maintaining an acceptable indoor air quality with high ventilation rates (Rodriguez & Fumo, 2024; Sieber et al., 1996). However, SR measures lead to complying with health certifications and standards that promote the health and well-being of the occupants: ASHRAE standard 62.1 (Rodriguez & Fumo, 2024). Under this category, the study identified four (4) factors that are essential in assessing the performance of SR, including maintaining indoor air quality, the ability to optimize thermal comfort, the ability to optimize visual comfort, and effective space utilization.

2.2.4 Safety and Security

Studies indicate that incorporation of SB technology and systems that are interconnected can provide a dual benefit, ensuring data security and privacy, ensure data security and privacy (Peiris et al., 2023). Security and access control have become critical functions in modern buildings, with the combination of sensors and other control devices to control and monitor the building's indoor and outdoor environment (Bhatt & Verma, 2015). These techniques include smart access control, CCTV, intrusion detection devices, and audio surveillance to enhance the safety and security of the buildings (Ciholas et al., 2019). Furthermore, through their smart safety and security systems SR contributes to building cybersecurity through the integration of IOT (Peiris et al., 2023), providing faster evacuation in an emergency by integration of a sensor-based emergency alert system (Costa et al., 2019), and integration of fire monitoring system provide accurate detection of potential fire incidents at early stage increasing occupant safety and resilience (Baek et al., 2021). Under this category, the study identified four (4) factors that are essential in assessing the performance of SR, including cyber-physical systems, emergency response with BMS capabilities, smart access control and surveillance capabilities and fire detection and response capabilities.

2.2.5 Environmental Adaptability

Over the past decades, most countries and organizations have been concerned with approaches and guidelines to minimize building energy consumption and achieve environmental sustainability goals (Periyannan et al., 2023). Furthermore, buildings that contribute to producing considerable amounts of greenhouse gas emissions have become a global issue (Chen & Ng, 2016; Truong et al., 2016). Respectively,

SR has been identified as an alternative solution in building sustainability to minimize energy consumption and prevent greenhouse gas emissions (Haidar et al., 2018). Moreover, the attainment of sustainable certifications such as the Building Research Establishment Environmental Assessment Method (BREEAM) and Energy and Environmental Design (LEED) can be identified as a crucial criterion for assessing the SR in buildings (Fasna & Gunatilake, 2019). Under this category, the study identified two (2) factors that are essential in assessing the performance of SR, including water conservation and decarbonizing. Figure 1 shows the summary of the literature findings.

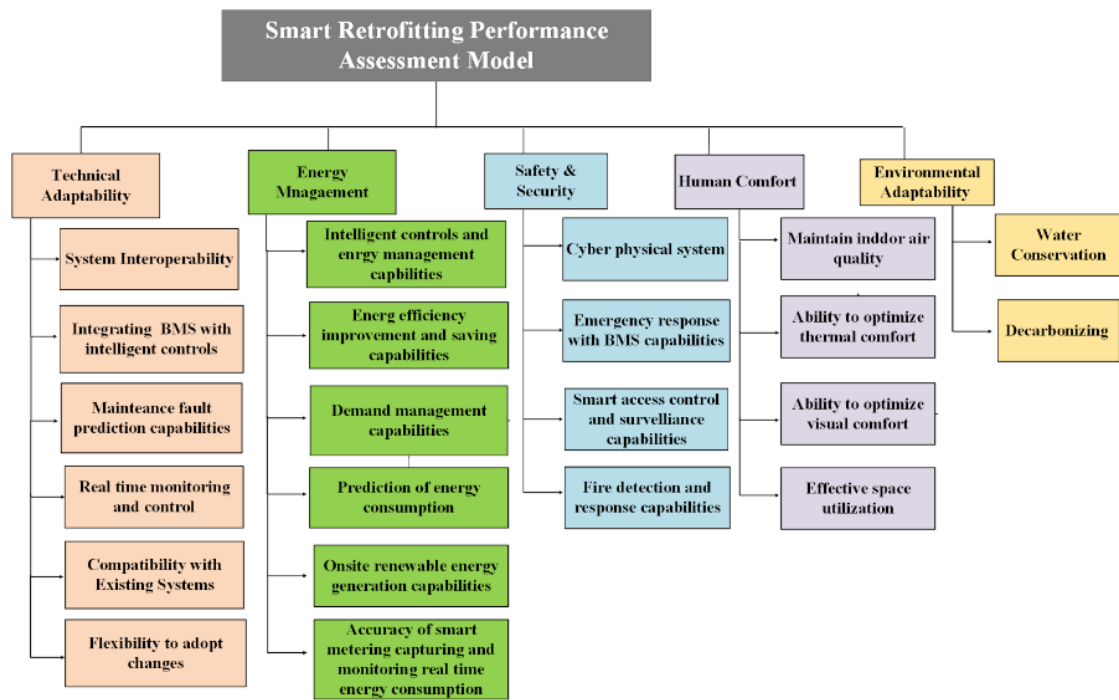


Figure 1: Developed SR performance assessment model from literature

According to the findings of the literature review, the existing SR performance assessment models focus on selecting suitable SR methods. This model provides several factors to be considered for the assessment of post post-implementation stage of SR in conventional buildings in Sri Lanka. It helps to measure the effectiveness of the implemented SR measures and to make informed decisions on the continuation of those measures. To make the assessment process easier, all factors have been divided into 7 categories.

3. Research Methodology

In the first stage of research, a comprehensive literature review was carried out to identify the factors that affect assessing SR in existing buildings through journals, books, and conference proceedings. Subsequently, a qualitative approach was carried out to collect in-depth information and learn about respondents' thoughts and opinions based on their experience and opinions involved in integrating SR. Interviews have been identified as one of the best options for data collection to carry out an in-depth inquiry regarding the survey findings, and they mainly fall within the qualitative research (De La Croix et al., 2018). Further expert interviews are best suited to gather the data by investigating the experience and perspectives of the interviewees (Döringer, 2020). Therefore, expert interviews were carried out

to validate the data generated through the literature. Apart from verifying the relevance of the proposed SR assessment model identified through the literature, respondents were invited to make changes and modifications to the developed SR performance assessment model. The semi-structured interviews are the most widely used qualitative research data collection method in which predefined guidelines are used, but they allow the researcher to explore the issue or response with diversity (Islam & Aldaihani, 2022). Therefore, semi-structured interviews were carried out to extract relevant information from the experts. Manual content analysis was used for interpreting and analyzing the details from the semi-structured interviews. Table 1 illustrates the profile of the respondents for semi-structured interviews.

Table 1: Profile of the respondents

| Expert Code | Designation | Years of experience in the built environment |
|-------------|---|---|
| E1 | Head of Facilities Management | 12 years of working experience in leading commercial sector buildings |
| E2 | Ph.D. Candidate | 5 years of working experience in SR in office buildings |
| E3 | Building Automation Engineer | 10 years of working experience in building automation projects |
| E4 | Manager Engineering | 11 years of working experience in commercial and office buildings |
| E5 | MEP and Facility consultant | 16 years of working experience in commercial and office buildings |
| E6 | Engineer in Facility Management and commissioning | 10 years of working experience in building automation projects |

According to Table 1, the experts who were chosen by purposive sampling and further evaluated using several other additional factors, including possessing a degree in facilities management (FM)/engineering field, possessing a professional qualification in the facilities management/engineering field, possessing theoretical knowledge about new technology and in SR. Further, it is mandatory to have a minimum of 4 years of experience in SR practice or research and at least 5 years of experience in FM practice or research. Due to the lack of more experienced experts in the field of smart SR, the sample was limited to 6.

4. Findings and Data Analysis

Expert interviews were conducted to confirm the accuracy of the information obtained from the literature. With the help of additional information obtained through the expert interviews, the objectives of the study, which had been partially outlined by the literature review, were strengthened and completed. This phase involved six experts in total. In addition, experts interpreted factors and additional main criteria for the SR performance assessment of existing buildings.

All the experts confirmed all the factors mentioned in the technical adoption performance assessment through the literature review findings. In addition, the experts advised that the phrase 'Automated maintenance prediction capabilities' needs to be changed to 'Automated maintenance management' because the SB system supports not only predictive maintenance, but also corrective maintenance, and preventive maintenance activities point out that "trends, multi-trends supported for predictive and preventive maintenance, while real-time monitoring and alarming support corrective maintenance". The experts also highlight the need for real-time monitoring and controlling, which ensures the successful implementation of the SR project. On the other hand, experts emphasized the importance of IoT integration as a performance assessment criterion in the post-performance stage, enabling SB operation to sense, communicate, exchange data, and analyze data in real-time. Another technical assessment criterion for SR is integration with AI applications to enhance building performance through predictive fault detection using real-time data from IOT sensors. Experts further stated that successful SR projects are dependent on the user-friendliness of humans and their willingness to adopt new technologies.

All six experts confirmed the energy management criteria in the assessment of SR, as identified by the literature findings. The experts commented that the SR concept is progressively adopted by existing buildings due to the Energy efficiency improvements. In addition, E3 revealed that the "ability to facilitate onsite renewable energy generation has limitations because the criteria rely on the renewable energy generation connected to the smart energy management systems, BMS system or integrated into the smart grid". E1, E4, and E5 experts revealed that the 'prediction of energy consumption' phrase needs to be changed to 'Prediction of Energy Consumption and variations' to strengthen the meaning of the criteria. Two primary factors are disclosed by experts to assess the assessment of SR practices including 'System accuracy for optimized saving' as a new energy management criterion to ensure systems function accurately and maximize energy efficiency and 'energy benchmarking' as part of the criteria as it helps determine if SR implementation results in significant savings, energy goals are achieved as they expected. Experts agree that SR is a sustainable approach to decarbonization and water conservation, which is identified in the literature. In addition to that, E5 proposed Material conservation as a new criterion for sustainability performance by stating, "Some countries utilized recycled materials in electrical components". Although the experts revealed that the 'environmental adaptability' criteria need to be changed to 'environmental sustainability' to strengthen the meaning of the criteria

All experts agreed with the criteria for comfort, health and well-being that are found in the literature. Experts agreed on the importance of maintaining indoor air quality, optimising thermal comfort, and optimising visual comfort. They also highlighted that occupancy sensors are crucial for efficient space management and minimizing occupancy complaints. Other than that, experts revealed the need to address occupant satisfaction and enhance indoor air quality and temperature controls for increased productivity. In addition to these factors, experts emphasized that occupant satisfaction is a crucial factor of smart retrofits that should be considered when assessing performance. Under this occupant experience about their convenience, timesaving after the SR implementation needs to be addressed. The

literature review identified four functions for assessing performance, safety and security in retrofit buildings that are agreed upon by all the experts. Cybersecurity is becoming increasingly important for enhancing privacy and data security. Factors such as fault detection accuracy, response time, smart access control, and fire detection and response capabilities are crucial for assessing SR performance.

Nevertheless, experts commented that regulatory compliance was noted to assess the performance of SR implementation. These included guidelines established by professional organizations, such as achieving environmental sustainability certification, supporting human health certification, achieving operations standards and certifications (ISO), and complying with government codes and regulations, are the crucial factors that need to be considered to assess the performance.

In addition to these criteria, all the experts revealed economic adaptability as a new criterion for assessing the performance of SR. Most of the research has demonstrated that the payback period and return on investment of retrofits are more important to assess economic viability. Another economically sustainable criterion to assess SR is the operation cost by disclosing as lower operating costs are anticipated by building owners with the highest quality level in their retrofit projects. In addition to that, experts emphasize the importance of SR implementation for operational efficiency, cost savings, and asset value enhancement. Besides that, experts emphasized the importance of increasing asset value and brand image as a performance assessment criterion in the post-performance stage. Thus, it improves occupancy rates and tenant retention, enhancing market competitiveness.

5. Developed Assessment Model

The SR Assessment model is developed by considering the literature and experts' opinions to assess the performance of SRs. According to literature findings and based on the experts' opinions, 39 SR performance Assessment criteria were identified; and these fall under six main categories, such as technical adaptability, human comfort, health and well-being, economic adaptability, environmental sustainability, safety and security, and compliance. Figure 2 illustrates the developed Assessment model. When assessing the effectiveness of SR, industry practitioners can use the criteria in this model.

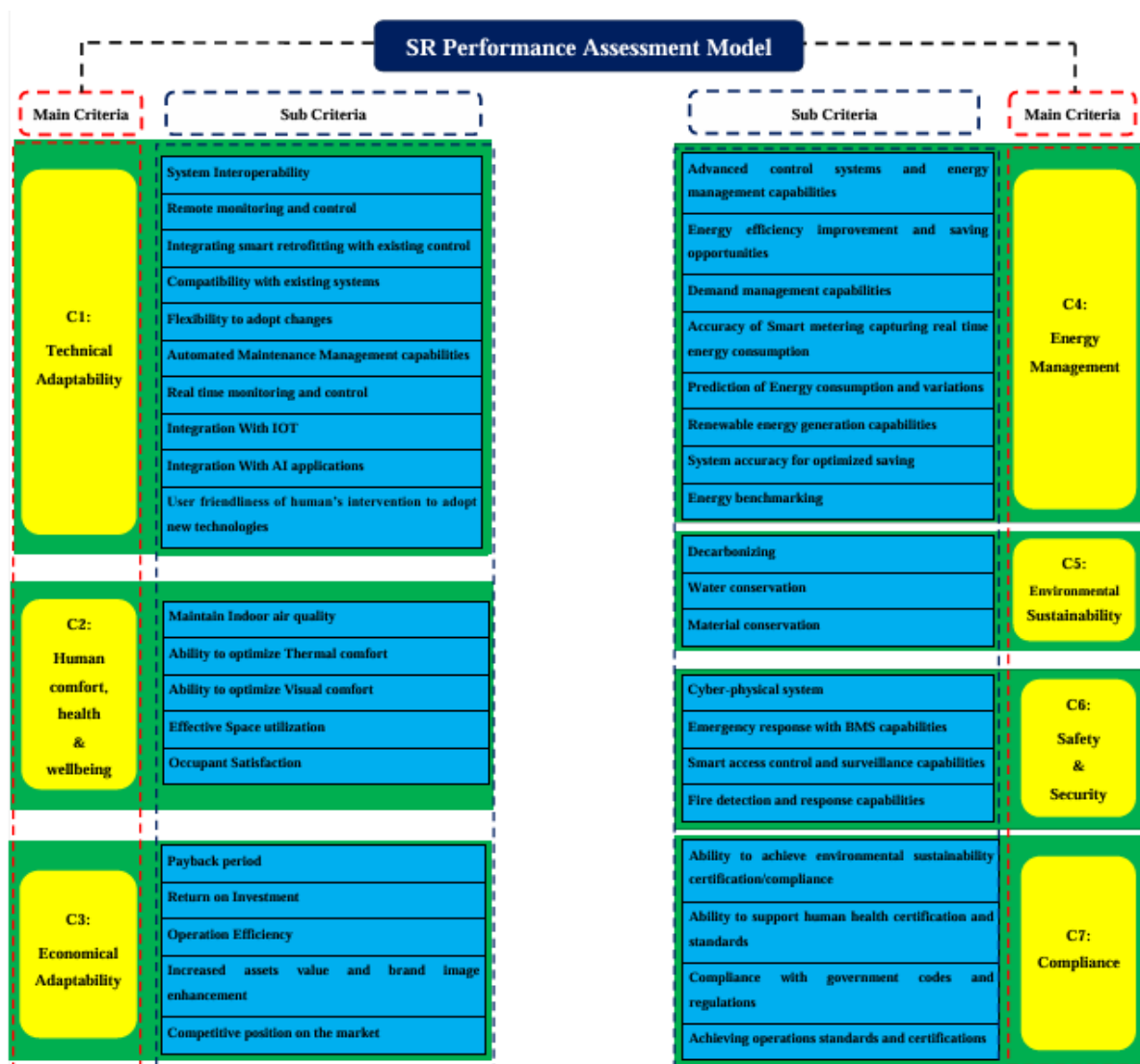


Figure 2: Developed SR performance assessment model

6. Conclusion

This study aims to assess the performance of implementing the SR concept in existing buildings. Initially, an in-depth literature review was carried out to identify the factors for assessing the performance of the SR concept, highlighting a focus on technical adaptability, energy management, human comfort, safety and security, environmental sustainability, economic adaptability, and compliance. According to literature findings and based on the experts' opinions, 39 SR performance Assessment criteria were identified, and these fall under seven main categories. Finally, a framework was developed that supports building practitioners in assessing the performance of their SR implementation.

Prior studies have focused on SR decision-making to select an appropriate smart retrofit option. However, it is difficult to assess the level of SR performance in existing buildings in Sri Lanka without a robust SR assessment model due to the lack of SR performance assessment models and the lack of SR-experienced building practitioners. In Sri Lanka adoption of SR is very rare. Hence, the developed model provides an assessment criterion to assess the performance of

SR in existing buildings after its implementation stage from a Sri Lankan point of view. The developed model will enable building practitioners to systematically assess the performance of their smart retrofit outcomes in terms of technical adaptability, energy management, human comfort, safety and security, environmental sustainability, economic adaptability, and compliance. Also, the outcome of this study serves as a benchmarking and KPIs evaluation tool, which can help facilities managers in making informed decisions regarding SR techniques that have been implemented.

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