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Review

The Smart Buildings Revolution: A Comprehensive Review of the Smart Readiness Indicator Literature

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Abstract: The construction industry is embracing advanced digital technologies, such as the Internet of Things and automation systems, to enhance energy management and occupant comfort in smart buildings. Recognizing the need to assess the readiness of buildings to support energy-efficient and adaptive functionalities, the European Commission introduced the smart readiness indicator (SRI) in 2018. While the SRI provides a standardized framework, its adoption, limitations, and potential to drive the evolution of smart buildings remain underexplored. This study addresses these gaps through a systematic literature review, incorporating bibliometric and qualitative analyses to evaluate the state of research on the SRI. The bibliometric analysis reveals that research on smart readiness is growing rapidly, with a strong focus on energy efficiency and smart buildings. This literature primarily evaluates and promotes the adoption of the SRI within buildings, aligning with the need to explore the paths for the evolution of smart buildings. The qualitative review summarizes six understudied research topic required to drive the evolution of smart buildings in the literature: *The applicability of the SRI to different contexts, including various building types and climatic conditions*; *the subjectivity in the framework*; *the alignment with other certificates and standards*; *the SRI as a tool for smart retrofit*; *expansion to the neighborhood and district levels*; and *the score correlation with energy performance*. The findings show that, although the SRI was originally introduced for buildings, it has much wider applicability, at the more detailed building component level as well as at the broader neighborhood and district levels. Future research could focus on the role of the SRI in evaluating smart readiness at the neighborhood scale and determining the minimum acceptable SRI score.

Keywords: SRI; smart readiness indicator; smart buildings; energy efficiency; demand response

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1. Introduction

Buildings play a dual role throughout their entire life cycle, from construction to operation, demolition and end of life disposal, as energy consumers and carbon emitters [1]. The reliance on new construction alone poses a significant threat of exhausting the remaining carbon budgets [2]. The utilization of energy within buildings accounts for more than one-third of the total global primary energy consumption [3]. This is due to the incorporation of new appliances, rising comfort standards, and longer periods of indoor occupancy [4]. Reducing the environmental impact of buildings and improving their overall environmental performance are primary goals of sustainable development [5].

Buildings in Asia account for a quarter of the total energy consumption [6], while in the United States, this sector accounts for about 37% of the total energy consumption [7], in Africa for 34% [8] and in the European Union (EU) for 40% [9–11]. Furthermore, 75% of buildings in the EU exhibit inadequate energy performance, and 85% of buildings were constructed before 2000 [12].

Within the built environment, smart technologies are particularly effective in enhancing operational efficiency, energy flexibility, and occupant well-being [13]. Empirical studies confirm that digital technologies contribute to reducing operational emissions in buildings, particularly by optimizing energy use [14,15]. The European Commission (EC) has recognized the pivotal role of digitalization in boosting the sustainability transition of EU Member States [16]. One of the primary goals of the EC by 2050 is to achieve climate neutrality [17], and the building sector is instrumental in fulfilling the EU's environmental and energy targets.

To enhance building energy performance, tackle the existing building stock, and progress toward achieving decarbonized and highly energy-efficient buildings by 2050, the Energy Performance of Buildings Directive (EPBD), recast in 2024, was introduced [12]. Aligned with the EPBD's objective of expanding the transparency of individual buildings' energy performance [18], it is essential to strengthen the role of buildings in becoming both energy producers and providers of flexibility [19].

The EPBD has emphasized the significant potential for energy savings through efforts directed at enhancing building performance and associated energy efficiencies [20]. The EC has identified digitalization as a primary factor in enhancing the energy efficiency of EU Member States [16]. Moreover, the EPBD advocates for the integration of intelligence technologies and has introduced the smart readiness indicator (SRI) [10,21]. The initial reference to these measures can be traced back to the Clean Energy for All Europeans package [22].

The "smartness" of a building refers to its capability to utilize information and communication technologies effectively, which allows the building to dynamically address the demands of the grid and occupants, thus improving the overall building performance and energy efficiency [18]. The general framework for calculating the smartness indicator for buildings [23], as outlined in the proposal to amend the EPBD, focuses on the following key SRI functionalities: (i) the readiness of a building to interact in the demand response with the district infrastructure and the energy system, (ii) the building's technological readiness to adapt to user requirements, specifications and the energy environment; and (iii) the readiness of a building to operate more efficiently. The SRI raises awareness of the benefits of smart building technologies, including automation and electronic monitoring of building systems such as domestic hot water, heating, ventilation, electricity and lighting [23]. Implementing the SRI framework is expected to promote technological innovation in the construction sector and incentivize the integration of advanced smart technologies in buildings. Furthermore, the SRI should articulate and amplify the practical benefits of building smartness for building key functionality and smart service providers [24].

The EPBD recast proposal includes mandatory SRI applications for large non-residential buildings with high energy demands [25]. This initiative is part of broader efforts to integrate smart technologies into the building sector, promoting energy savings and creating more responsive and efficient buildings [26]. Today, the SRI is also being tested nationally by the EU Member States through official test phases and various LIFE Clean Energy Transition projects [27], which are providing valuable insights and supporting the broader implementation of the framework across Europe. In conjunction with the energy performance certificate, the implementation of the SRI has been estimated to potentially reduce the total energy consumption by up to 198 terawatt hours (TWh) by 2050, consequently averting approximately 32 million tons of greenhouse gas emissions annually [28,29]. The SRI is designed to enhance energy-saving policies and promote sustainable practices in buildings [22]. Thus, the SRI is recognized as a fundamental measure for evaluating buildings' capability to utilize electronic systems and information and communication technologies. This capacity enables buildings to adjust their operations dynamically to meet the needs of occupants and the grid, consequently improving the overall building performance [30].

The methodological framework of the SRI employs a multi-criteria assessment scheme, with methods that demand minimal input and present results in a way that is easily understandable for a nontechnical audience [10]. The proposed approach quantifies a building's or building unit's smart readiness score as a percentage, reflecting the relationship between its current smart readiness and its maximum potential readiness. The SRI framework encompasses a range of technical domains and impact criteria. Each domain includes different levels of smartness for various functionalities, typically ranging from two to five levels. During the audit, conducted by a third-party assessor, all the available services within the building are examined, and predefined weighting factors are applied to combine these services into a comprehensive parameter. These weighting factors are tailored to the specific case, considering factors such as the building type and climate zone. Two audit methodologies are proposed: a simplified approach and a detailed approach [31,32].

To pave the way for the future development of the SRI, it is crucial to gain a thorough understanding of its progress and evolution. This topic is particularly important as Member States are currently piloting the framework and preparing to make key decisions about its implementation and methodology. These decisions will be instrumental in shaping the SRI's effectiveness and its potential to promote smart, energy-efficient buildings. To guide this exploration, the following research questions (RQs) are posed:

- RQ1: What are the key topics and identified research gaps in the SRI literature?
- RQ2: How does the current research literature consider the paths for the evolution of smart buildings?

To answer the research questions, a comprehensive research study was conducted. The rest of this paper is organized into four sections. Section 2 introduces the methodology employed, while Section 3 describes the data employed for the quantitative analysis of the SRI-related literature through bibliometric and content analyses. In this section, the key contributors and keywords in the SRI field are also presented to further analyze the past and current research trends in the literature. Section 4 presents the results, introducing the six dominant themes that arose from the analysis as well as emerging topics and future research directions in the reviewed literature. Section 5 provides a conclusion and summarizes the research gaps in the SRI literature.

2. Methodology and Data

This study applied a comprehensive search of the literature, covering an overview of the SRI-related concepts, models, applications, trends, and challenges that can be encountered in relation to the framework's implementation. This section first introduces the research paper selection process that led to the number of papers included in the further review. Second, the bibliometric analysis conducted of the final number of papers is introduced in detail.

Research Paper Selection

The research process began by identifying the relevant research papers from the SRI-related literature. The research paper selection proceeded from the identification of papers to the screening and inclusion stages, following the PRISMA flow diagram [33,34]. The process encompassed all the studies conducted on the topic of the SRI from 2017 to January 2024. The review process began with a systematic literature search to gather relevant studies on the SRI and its role in buildings.

The identification of relevant journal articles began by applying a combination of the keywords "smart readiness indicator" and "building" in Scopus, Web of Science, ScienceDirect, and ProQuest. The identification process included the review of the articles (indexes, tables of content, and keywords) to exclude non-relevant research papers. After removing duplicates, the total number of journal papers was 219. The screening process following the paper identification was carried out in five phases. The phases included, first, the screening of titles; second, the screening of abstracts; third, the selection of only peer-reviewed journal articles; fourth, ensuring that the articles provided substantial insights into the SRI; and finally, a full-text review to assess their relevance to specific SRI domains. The criteria applied for excluding irrelevant research papers after each phase are outlined below:

- Screening the titles: Articles primarily focused on topics outside the scope of the SRI, such as sustainable buildings, artificial intelligence, digital twins, or other building certification systems, were excluded to ensure relevance to the study's objectives (Reason 1).
- Screening the abstracts: Articles that did not explicitly address the SRI, such as its interaction with occupants, integration with the energy grid, or impact on building performance, were excluded to maintain alignment with the primary focus of the review (Reason 2).
- Screening the journal articles: To ensure the reliability and academic rigor of the findings, only peer-reviewed journal articles were included; conference papers, book chapters, and other non-journal publications were excluded (Reason 3).
- Ensuring substantial insights: Articles that did not delve deeply into the SRI framework, its practical applications, or its complexities were excluded to prioritize studies that contribute meaningful, detailed perspectives, ensuring the inclusion of papers that explore the full scope of the SRI (Reason 4).
- Screening the content of the full paper: Articles that merely mentioned the SRI without providing a detailed analysis or substantial insights into its implementation, challenges, opportunities, or a specific domain of the SRI framework were excluded. Relevant studies were further classified based on their focus within the SRI framework, as outlined in Table A1 (Appendix A). This criterion ensures the inclusion of papers that offer a high level of relevance, depth, and focus on at least one critical domain of the SRI (Reason 5).

Figure 1 illustrates the selection process that led to the final number of journal articles included in the further analysis.

After the screening, the final set of research papers numbered 68. The full list of the articles included in the final review can be found in Appendix A. Next, the analysis of the final dataset is discussed.

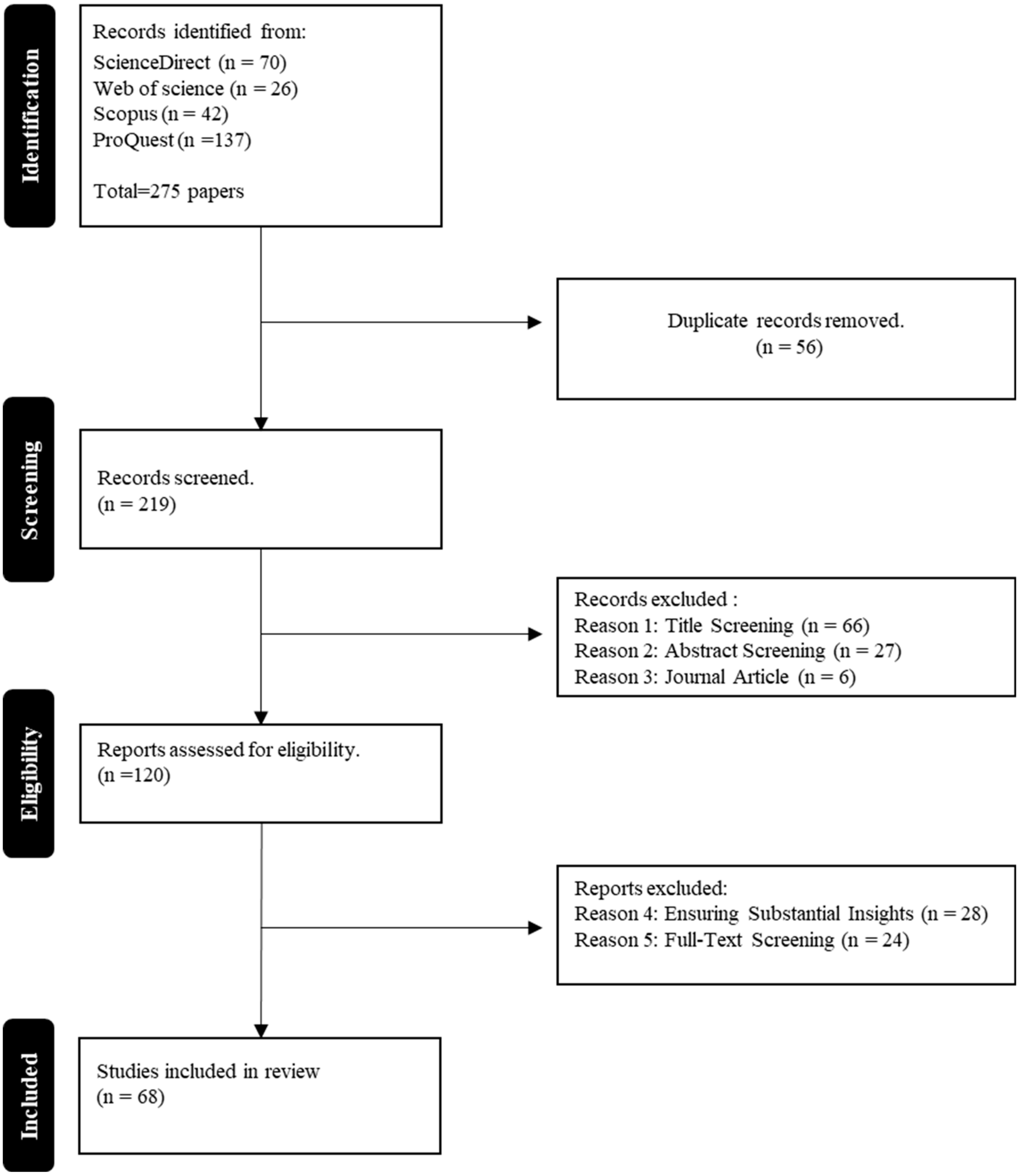


Figure 1. PRISMA flow diagram summarizing the literature review process.

3. Data Analysis and Visualization

This section presents a comprehensive bibliometric analysis of the dataset, focusing on the mapping of keywords, the distribution of journal articles, and the identification of key trends in the research landscape. The analysis examines the frequency and relevance of keywords across studies, using visualizations such as keyword co-occurrence networks and article publication trends to illustrate the evolution of the research focus over time. Additionally, the detailed bibliometric analysis of the final set of research papers includes the itemization of publishers and a breakdown of keywords to highlight dominant themes in the current SRI literature. A content analysis was conducted to assess how the existing literature aligns with the framework and to identify research gaps, providing deeper insights into the field's development.

3.1. Mapping of Keywords

The main characteristics that are common to the final dataset, consisting of 68 journal papers, were analyzed based on the keyword co-occurrence using VOSviewer software version 1.6.20 [35]. The counting method used in the software was full and the minimum number of occurrences of a term was two, resulting in 114 keywords. In order for two words to be classified as co-occurring, they must appear together in the title, abstract, or list of keywords within the same paper. The VOSviewer map visually represents each word with a circle, where the size indicates its frequency of occurrence, and the color signifies its cluster affiliation [36]. The proximity of circles on the map denotes the strength of the co-occurrence: closer circles indicate frequent co-occurrence, while greater distances indicate infrequent or non-existent co-occurrence. Figure 2 illustrates the keyword co-occurrence map for this research. Demand response, smart buildings and energy efficiency were found to be the predominant keywords in the SRI literature (green cluster).

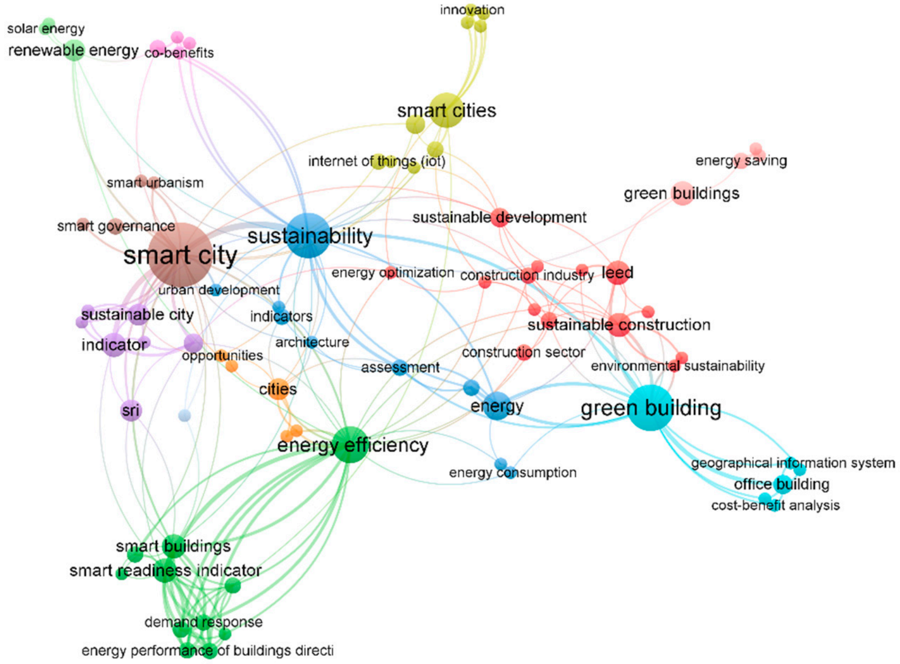


Figure 2. Keyword co-occurrence map.

3.2. Number of Journal Articles

The SRI concept has increasingly appeared in journal articles since its introduction in 2017, with references to the term significantly increasing each year. A great number of journal articles have referenced the SRI over the past three years alone; 50 of the 68 papers included in this study (73%) were published between 2021 and 2023. The number of journal articles published per year is presented in Figure 3.

As Figure 3 shows, the annual number of journal articles involving the SRI has been increasing since the introduction of the index. The main journals publishing SRI-related literature are in the fields of energies (11), energy and buildings (9), buildings (8), and sustainable cities and societies (6). The remaining articles are distributed across various journals, including the *Journal of Building Engineering*, *Journal of Cleaner Production*, and others.

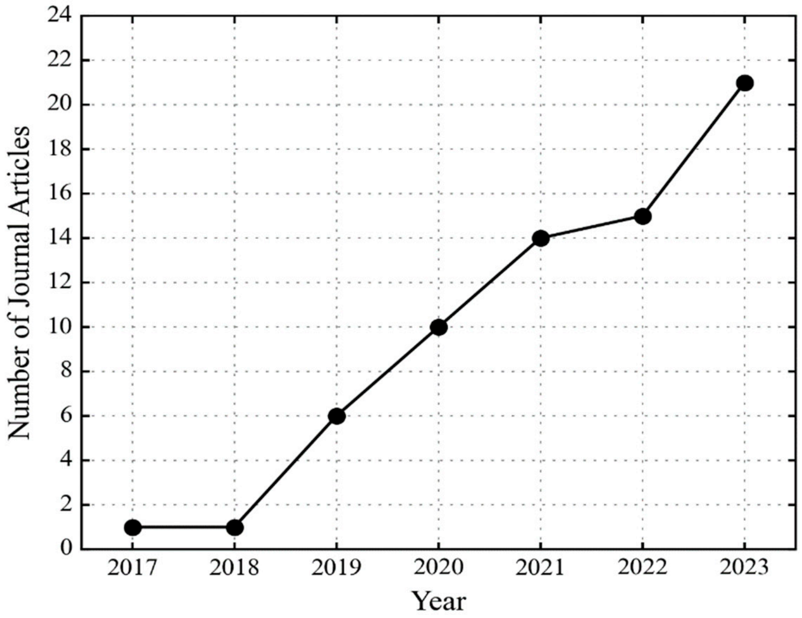


Figure 3. Number of journal articles per year.

3.3. Content Analysis

A comprehensive content analysis was conducted of the 68 journal articles identified as relevant to the research questions. The analysis followed a systematic three-phase approach. Initially, the articles were categorized based on their alignment with the three primary functionalities outlined in the SRI framework: interaction with occupants, interaction with grids, and optimization of the building's intrinsic performance (Appendix A).

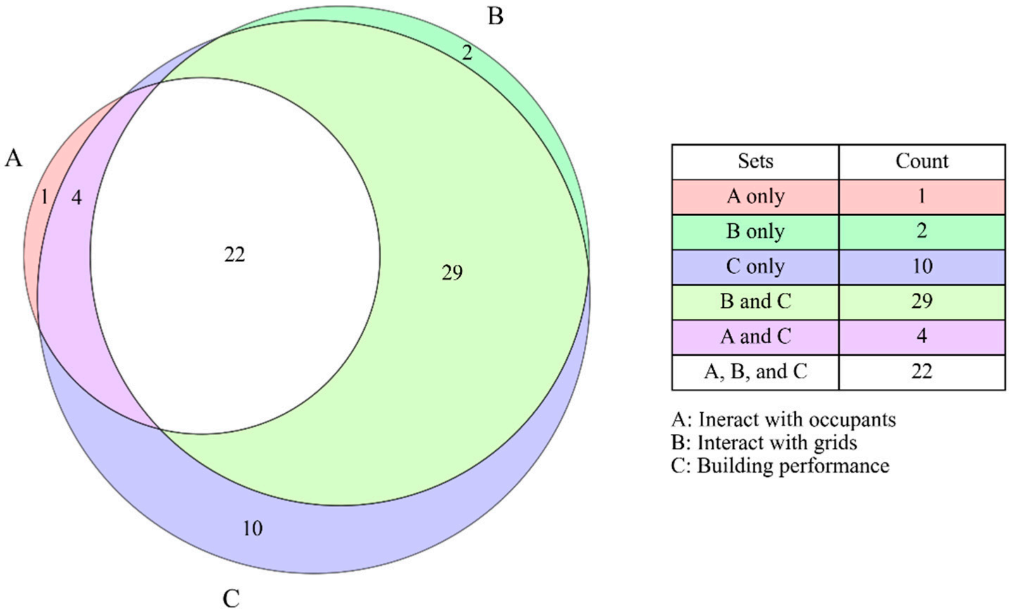
The second part of the content analysis comprised a systematic review of the research papers by making notes on all the key sections of a paper. Notes were made on the research methodology, research context and findings, future research directions, and conclusions and implications. These notes focused on identifying the main topics, aims, and scope of each article.

Finally, an analysis was conducted by making a detailed comparison and drawing distinctions in terms of the key themes. This step involved identifying emerging words and expressions from the notes, grouping them into clusters, and refining the clusters into final themes. This process was guided by the main topics and objectives covered in each article, ensuring that the themes accurately reflected the primary focus areas of the literature. Categorizing the articles into distinct themes posed challenges, particularly due to the overlapping content, with some papers contributing to multiple thematic areas. This complexity was addressed by prioritizing each paper's primary focus and carefully cross-referencing relevant themes. These steps ensured that the content analysis effectively captured the intricate relationships and contributions across various thematic dimensions, providing a comprehensive overview of the key areas in the SRI literature.

Key SRI Functionalities Addressed in the Literature

The majority of the reviewed journal articles concentrated on topics related to building performance, with 66 of the 68 selected articles addressing this domain. Of these, 54 articles specifically explored interactions with grids, while 27 focused on interactions with occupants. The relationships between the identified themes and the key functionalities outlined in the SRI framework are detailed in Table A1, Appendix A.

The following section discusses the key themes of the SRI in detail. The Venn diagram in Figure 4 illustrates the distribution of data across the SRI's key functionalities. The overlapping areas in the Venn diagram reveal that 29 articles addressed both building performance and grid interactions. A significant subset of 22 articles encompassed all three key functionalities, demonstrating an integrated approach employed by the research. These findings illustrate a comprehensive and holistic approach within the research community, with a significant number of articles examining the interconnectedness of building performance, grid interaction, and occupant interaction. This integrated perspective is crucial for advancing the development of smart, resilient, and sustainable building systems, aligning with the key functionalities of the SRI.



Sets	Count
A only	1
B only	2
C only	10
B and C	29
A and C	4
A, B, and C	22

A: Ineract with occupants
B: Interact with grids
C: Building performance

Figure 4. Venn diagram of the data distribution.

4. Results and Discussion

This research study aimed to identify and label the current dominant themes (RQ1) and summarize the identified gaps in the literature (RQ2). The following subsections present the results of the research study.

4.1. Dominant Themes in the Smart Readiness Literature

The content analysis revealed six dominant themes that consistently appeared across the reviewed literature on the SRI. These themes highlight the main areas of focus and emerging trends within the field.

The six themes were the applicability of the SRI in different contexts, the subjectivity in the SRI framework, the alignment between the SRI and other certifications or standards, the SRI as a tool for smart retrofitting, expansion of the SRI to neighborhoods and districts, and the correlation between the SRI scores and energy performance.

While each theme is distinct, they all fall under the broader scope of the SRI's main functions. However, many articles contributed to multiple themes, making it difficult at times to classify them into just one category. This highlights the overlapping and interconnected nature of the SRI literature. Table 1 presents a summary of the identified themes and provides a short description of the topics.

These themes are separated by a narrow line, reflecting the multifaceted nature of smart readiness and the need for a holistic approach to understanding and implementing the SRI in various contexts. The following subsections provide more detailed discussions of each theme identified in the SRI literature.

Table 1. Categorization of the dominant themes and insights from the publications.

Themes	Description of the Themes	Insights from the Publications	List of Journal Articles
Applicability of the SRI to Different Contexts	Exploring how the SRI can be adapted to various environments, emphasizing the need for flexibility in addressing the unique characteristics and requirements of different building types and geographic locations.	The articles highlight the versatility of the SRI in accommodating diverse contexts, from single detached buildings to urban high-rises all the way to rural developments.	[4,16,37–48]
Subjectivity in the SRI Framework	Addressing the subjectivity in the SRI assessments, which can lead to inconsistencies and biases.	The articles delve into the challenges of maintaining objectivity and propose potential measures to enhance the reliability and fairness of the SRI evaluations.	[1,20,22,32,38,44,48–56]
SRI's Alignment with Other Certificates and Standards	Examining the importance of integrating the SRI with existing building certifications and standards.	The articles highlight the benefits of such alignments, including enhanced credibility and streamlined processes.	[3,13,14,18,21,43,44,51–60]
SRI as a Tool for Smart Retrofitting	Illustrating the practical application of the SRI in retrofitting existing buildings to improve their smart readiness.	The articles include case studies and showcase examples that demonstrate how SRIs can guide the upgrading process, leading to enhanced building intelligence, efficiency, and overall performance.	[18,46,61–63]
SRI's Expansion to Neighborhoods and Districts	Exploring the potential for expanding the application of SRIs beyond buildings to larger urban areas, such as neighborhoods, campuses, and districts.	The articles discuss the benefits and challenges of implementing SRIs at a community level, promoting smart urban development, and fostering interconnected, sustainable environments.	[16,31,51,53,64–67]
SRI Score and Energy Performance	Addressing the relationship between the SRI scores and actual energy performance.	The articles investigate the reasons why the SRI scores do not always correlate with energy efficiency.	[10,32,49,50,56,65,68,69]

4.1.1. The Applicability of the SRI to Different Contexts

The SRI is a versatile tool that can serve in various contexts, such as climate, energy, and economic performance. Climate plays a significant role in determining a building's flexibility performance, with approximately five main global climate types impacting building operations [37]. While the SRI methodology successfully identifies the general characteristics of sample buildings, it necessitates further refinement to effectively account for the distinct attributes of buildings in different climates, such as Mediterranean climates [9], which often exhibit unique energy and thermal behavior patterns [38].

Pereira and Ramos introduced a rigorous methodology to analyze occupant behavior, which has a critical impact on the SRI key performance [39]. Through a comprehensive year-long case study, the researchers identified significant seasonal variations in occupant behavior, such as the operation of windows and roller shutters, driven by environmental parameters and room-specific conditions. These findings highlight the importance of incorporating occupant behavioral insights into the development of smart management in buildings.

From an energy perspective, the SRI plays a vital role in assessing both energy efficiency and flexibility. It enables buildings to minimize energy consumption while optimizing their interactions with the grid, thereby supporting the shift toward a more sustainable and resilient energy infrastructure. Energy flexibility can directly influence the daily lives and economic outcomes of various stakeholders, including users, owners, caretakers, and facility managers, while the successful implementation and effectiveness of energy flexibility strategies largely depend on the acceptance and motivation of these stakeholders [40]. The SRI functions as a metric for the smartness of building systems, and its promotion is expected to significantly enhance energy efficiency within the building sector, leading to substantial energy savings. Achieving a 100% SRI score is difficult, because such buildings would have very sophisticated intelligence systems, which can be expensive and sometimes even be non-user-friendly [41].

Plienaitis et al. [16] evaluated the SRI for educational buildings and found that, despite improvements in controlling the building heating systems and automation, the achieved maximum SRI values exhibited notable differences, indicating differing levels of smart functionality within the systems. The study underscored the importance of integrating assessments of building smartness alongside energy performance evaluations.

Majdalani et al. [42] assessed the energy flexibility of space cooling and heating across various geographical regions in Portugal. Using a genetic algorithm to optimize the thermostat settings, the approach aimed to reduce the operational costs or grid interaction. The results revealed that the energy flexibility indicator effectively measured the potential flexibility influenced by factors such as the thermal inertia of the household, time-of-use electricity tariffs, user comfort boundaries, and geographical location.

Attia et al. [43] explored the fundamental concept and definition of resilient cooling for buildings, noting that the SRI could be used to measure the resilience of the cooling of buildings. Furthermore, Ramezani et al. [38] noted that although the SRI methodology successfully identified the general characteristics of sample buildings, there is still a need for some adjustments to accurately reflect the unique characteristics of non-residential buildings in Mediterranean climates. Also, Al-Obaidi [44] investigated the utilization of the Internet of Things (IoT) for enhancing energy efficiency in buildings, highlighting that the current SRI is primarily used to raise awareness among building owners and occupants, as well as to evaluate IoT services and functionalities.

The SRI plays a role in economic assessments by evaluating the financial viability of smart building technologies. Although the initial investment can be substantial, the SRI helps demonstrate long-term savings and returns, making it a valuable tool for decision-makers looking to balance environmental and economic goals.

Investing in a progressive smart building system has proved to be economically viable, yielding a return-on-investment of over 10% and increasing property value by over EUR 10 million [45]. Despite the initially high investment required for smart technologies, their costs could potentially be recouped within approximately three years of operation [46]. Janhunen et al. [45] evaluated the SRI metrics to assess the economic viability of implementing a feasible smart energy system in a building. The researchers did not explicitly establish a direct link between SRI performance and building performance, as smartness reflected operational savings in their analysis, not only energy performance.

The SRI can be applied to measure social impacts, promoting user engagement with energy-saving initiatives and enhancing the overall quality of life in smart buildings. From an economic efficiency standpoint, the substantial investment costs associated with energy efficiency programs aimed at enhancing the energy index in smart residential buildings pose a significant challenge [4]. Aagaard [47] assessed the social and environmental impact of smart home technology, focusing on how the concept of convenience has influenced technological development. They found that the pursuit of convenience often leads to user passivity and disengagement from energy-saving efforts. Moseley [48] discussed Horizon 2020 projects that explore smart buildings within the context of the SRI and highlighted that, while many projects focus on user interaction and self-management, fewer investigate topics such as smart charging, electro-mobility, artificial intelligence, and domestic appliances. These gaps indicate potential areas for future research and development in smart building technologies.

4.1.2. The Subjectivity of SRI Assessments

The SRI stands apart from traditional rating systems by prioritizing the automation level of building services and their associated impact, with a particular emphasis on the digital readiness of buildings. Unlike conventional frameworks, the SRI aims to assess the technological sophistication and flexibility of buildings in adapting to smart solutions. However, several studies have raised concerns regarding the inherent subjectivity of the SRI due to its reliance on a checklist-based assessment approach [20,22,38,49,50,55–57]. The SRI's checklist-based assessment and the absence of clear guidelines introduce subjectivity into the evaluation process, leading to inconsistent certification.

Dakheel et al. [50] have highlighted shortcomings of the SRI methodology and emphasized the need for a more quantitative approach to effectively assess the performance and advancement of smart technologies for buildings. In addition, the study by Martinez et al. [70] emphasized how the revised audit process of the SRI evaluates both energy efficiency and the readiness of buildings to integrate smart technologies.

Vigna et al. [54] assessed office buildings in Italy with two panels of experts, revealing that the accuracy of evaluations significantly depends on the data source. Their findings highlighted that the intricate characteristics of the building, encompassing diverse equipment, the involvement of multiple stakeholders in the management and design, a wide range of functions, and various technical building systems, led to the lack of a single reference individual for streamlined data collection for the SRI assessment. Martínez et al. [32] emphasized the importance of converting measured data into actionable insights and quantifying critical efficiency indicators such as the SRI to facilitate informed decision-making.

Some studies have also focused on the qualitative aspects of the current SRI framework [20,52,53]. These studies have introduced methods for adding quantitative features to the SRI to improve the transparency of the method. A quantitative and standardized evaluation of smart readiness could facilitate the exchange of smart technologies and best practices across different building types and countries.

Märzinger and Österreicher [51] investigated the potential for load-shifting and the dynamic interaction between buildings and the grid. The initial attempt to automate the SRI calculation showed promise, achieving a success rate of 73.61%. Likewise, Siddique et al. [20] sought to enrich the SRI framework. The integration of these quantitative elements represents a crucial step toward enhancing the effectiveness of the SRI framework. To assess the impact of these enhancements, a theoretical application was examined, and the outcomes were compared against those of the framework. Their findings reveal a notable increase in the SRI score following the inclusion of quantitative elements, thus underscoring the potential of these enhancements to bolster the framework's utility and reliability.

Despite its strengths, the SRI's application to emerging technologies such as electromobility, smart charging, and self-learning systems remains limited. These underexplored areas highlight gaps in the current framework, which could hinder its ability to fully capture the potential of advanced smart technologies [48].

By integrating quantitative elements, such as IoT monitoring and building information modeling (BIM), the SRI can offer a more standardized evaluation that supports informed decision-making, improves building energy efficiency, and facilitates the exchange of smart technologies across different contexts. Automating the SRI assessment process is crucial for efficiently evaluating building readiness [59].

Integrating BIM data with SRI information allows for informed decision-making regarding building energy efficiency enhancements [55,71]. The assessment could be executed during the design phase or in the current context, in any form, such as the available BIM or EnergyPlus modeling [44,56]. Siddique et al. [55] proposed an algorithm utilizing BIM data and SRI to recommend enhancements in building energy efficiency, demonstrating the potential for coupling SRI and BIM data. This illustrates the potential for advancing automated pipelines within BIM frameworks to enhance the efficiency and precision of SRI assessments.

Monge et al. [1] also, highlighted that IoT monitoring is crucial for enhancing building energy efficiency. They argued that to further advance energy efficiency and deepen understanding of buildings' energy efficiency, it is essential to complement simulation studies with quantitative real-world measurements in operational buildings.

Additionally, Vigna et al. [54] and Märzinger and Österreicher [51] have noted that utilizing a qualitative manual assessment approach restricts the exploration of smartness in relation to performance-based and quantifiable indicators. Integrating a quantitative indicator alongside the qualitative evaluation is crucial, representing a key consideration in enhancing the efficacy of the assessment process [54].

Automating the SRI assessment process and refining its methodology could help address current limitations and enhance the framework's credibility and effectiveness in evaluating smart building readiness.

4.1.3. SRI's Alignment with Other Certificates and Standards

A multitude of sustainability rating systems have emerged with the objective of evaluating the performance of buildings. Sustainability rating systems, such as the Digital Building Logbook (DBL) and the SRI, play a crucial role in evaluating building performance.

The DBL was introduced by the EC as a repository of all the pertinent data on a building [17,57,58]. The SRI has significant potential to enrich the DBL by enabling the collection of real-time building data [57,58]. Integration of the DBL with other data sources, such as the SRI and energy performance certificates (EPCs), developing an interoperable, uniform, and cohesive national database on energy efficiency, is crucial [17]. The SRI supports energy efficiency and circularity in buildings [57]. As outlined by Gomez Gil et al. [57], the absence of a centralized database to store the assessment reports at present prevents the SRI from being regarded as an interoperable data source compatible with the DBL.

Additionally, frameworks assessing sustainability performance, such as key performance indicators (KPIs), are increasingly important for transitioning buildings to zero-carbon and resource-efficient structures. Märzinger and Österreicher [51] and Li et al. [3] proposed a repository of key performance indicators (KPIs) designed to assess the sustainability performance of buildings. This repository is particularly useful in the context of transitioning buildings to zero-carbon, resource-efficient, and resilient structures. The SRI comprehensively evaluates both internal factors, such as building characteristics and occupancy, and external conditions, such as weather and renewable energy generation [3]. Popa et al. [60] proposed a method to decrease the primary energy demand (including domestic hot water, heating, and electricity consumption) by suggesting a self-assessment tool for building occupants that would provide an estimate of the EPC rating of a residence.

Research on the KPIs for assessing the sustainability performance of buildings transitioning to resource-efficient, resilient structures, and zero-carbon has gained traction [3,24,59]. Al Dakheel et al. [50] highlighted limitations in the proposed methodology for the SRI. They argued that the methodology should be more quantitative to effectively test the performance and progress of smart technologies in buildings. Therefore, the EPBD should consider advancing the current SRI methodology, along with the concepts of smart buildings (SBs) and smart readiness (SR). Consequently, the set of KPIs developed requires further testing to accurately evaluate the performance of smart retrofitted buildings.

The SRI can contribute to and play a role in the development and assessment of KPIs for sustainability in buildings by evaluating factors such as energy efficiency [24,59].

Several studies have explored frameworks for assessing the smartness and sustainability of buildings. Morkunaite et al. [61] suggested a framework for evaluating the levels of building smartness through automation and control. Their framework can determine the minimum requirements for achieving SRI levels in a cost-effective manner. They also noted that six of the nine service domains included in the SRI framework are also included in the ISO 52120 standard [72], indicating potential alignment between the two frameworks.

Zuhaib et al. [18] explored the perspectives of end-users regarding the future development of EPCs to support EPC schemes in the EU. The findings underscore that features are perceived most favorably when tenants or homeowners prioritize energy conservation and consider energy performance a significant factor in property purchase or rental decisions.

The European Building Automation and Controls Association (eu.bac) system certification scheme evaluates building automation and control systems (BACSs) with the objective of ensuring long-term sustainable operations and improving energy efficiency based on the EN 15232 standard [21,73,74]. Building automation and control systems offer substantial capabilities for optimizing the energy performance of various systems [49,68,75,76]. Consequently, it is imperative for planners and building owners to identify potential areas for improvement and evaluate the status of their BACS. A common aspect between the eu.bac platform and the SRI assessment methodology is that each is based on the guidelines and calculation principles of the EN 15232 standard. Compared to the eu.bac, the SRI provides a more holistic analysis that incorporates more dimensions of a building, encompasses a wider range of criteria and impacts, including building flexibility and maintenance levels, occupant information, and comfort [21,73,77], and can encourage the adoption of advanced systems in buildings [21].

4.1.4. The SRI as a Tool for Smart Retrofitting

The SRI provides a practical measure of the technical smartness of building systems, highlighting the environmental and sustainability benefits of increasing building intelligence [18].

Apostolopoulos et al. [62] examined the retrofitting costs associated with enhancing building smartness and improving SRI scores by evaluating various residential building renovation scenarios across five EU countries. They found that retrofitting older buildings, which typically fall into the lowest SRI class (0–20%), can improve the scores to 65–80%

by enhancing automation and control, particularly in areas like comfort and well-being. Retrofitting strategies focusing on automation and control can raise these buildings to higher SRI classes (SRI score of 65–80%) [62].

The majority of homeowners and tenants prioritize energy efficiency, heating sources, and comfort when purchasing or renting property. Additionally, smart technology is deemed important by 34% of homeowners and tenants [18]. Smart technologies present an ideal solution for retrofitting existing buildings [46].

Similarly, Canale et al. [63] analyzed eight smart building typologies representing the Italian residential building stock. The SRI was calculated for each typology using three scenarios, focusing on energy retrofitting. From a smart perspective, the analysis revealed national average SRI values of 5.0%, 15.7%, and 27.5%. In the "energy" scenario, which reflects the current trend of retrofitting existing buildings, the SRI was relatively low, ranging from 15% to 23%. This is primarily attributed to the limited level of automation and control in the systems commonly employed for retrofitting existing residential buildings. Notably, the installation of highly energy-efficient systems or renewable energy production systems does not impact the SRI; rather, it is the degree of automation and control that influences the indicator.

Morkunaite et al. [61] evaluated the energy savings resulting from adjustments made to regulate the operational parameters of heating system components in buildings. Their study provides valuable insights into establishing minimum requirements for the SRI. Notably, their analysis covers six of the nine service domains outlined in the ISO 52120 standard.

As smart technologies gain prominence, they offer an effective path for retrofitting existing buildings to align with modern energy and comfort demands.

4.1.5. SRI's Expansion to Neighborhoods and Districts

The expansion of the SRI to neighborhoods and districts is vital for achieving broader energy conservation goals, recognizing the interconnectedness of urban systems. To truly achieve energy conservation, it is imperative to incorporate intelligent neighborhood elements, recognizing their profound interconnections, rather than only concentrating on individual building energy components [64]. The current SRI framework predominantly focuses on assessing the resilience and energy efficiency of individual buildings, while the SRI could also be a valuable tool for the management of building utilities at an urban level [16].

Plienaitis et al. [16] analyzed the SRI for educational buildings and observed that the SRI score is influenced by the level of control of services and automation, particularly those managed at the city level, such as district heating systems. They observed that central management of these systems can limit a building's potential to attain the highest level of smartness. Their study emphasized the significance of city-level services in realizing optimal smartness levels at the building unit level.

To improve the SRI for complex residential settings, Adegov et al. [65] proposed adding a questionnaire to the SRI assessment for complex residential buildings, including detailed questions on electricity consumption, such as specifying the volume and capacity of boilers. In addition, for hot water supply systems and heating, it is recommended to delineate each category of energy consumption. Furthermore, it is essential to document the orientation of windows, their size, and whether they are equipped with other shading devices or protective layers.

Märzinger and Österreicher [51] extended the application of the SRI and introduced a weighting factor for the SRI districts to ensure that areas with diverse attributes in terms of the size, type, and quality can be comparably assessed.

Samancioglu and Nuere [66] investigated the development of smart campuses by categorizing their essential services according to the smart buildings, scope, and technologies. They introduced the Smart Availability Scale to assess campus system outputs using multi-criteria decision-making methods and newly created index parameters using the SRI criteria.

Galal and Elariane [53] applied checklists to assess the smart readiness of buildings and cities, drawing inspiration from the SRI. Their checklists would serve as comprehensive tools for evaluating the readiness of structures or urban areas to incorporate smart technologies effectively.

Kourgiozou et al. [31] employed the SRI calculation to university campuses, focusing on large stocks and energy hubs, recognizing that aggregating the building SRI scores into a campus-wide score does not fully capture the potential interactions between assessed buildings. This limitation stems from the inherent calculation of the SRI, as it primarily investigates on-site electricity generation and storage within building boundaries, while harmonization with the grid is taken into account.

Le Dréau et al. [67] conducted a study on building energy flexibility at an aggregated level, identifying several barriers and research gaps. These include challenges related to market and policy frameworks, early planning and design, and operation phases. Despite the legal frameworks, limited financing deters private investment. Planners face interoperability challenges and lack tools for effective demand response programs. Operational challenges include complexity, communication, privacy, and acceptability issues.

4.1.6. SRI Scores and Energy Performance

Improving energy efficiency and increasing smartness levels are crucial determinants shaping contemporary trends in building. The implementation of the SRI by Becciho et al. [56] at the energy center building of Turin used EnergyPlus modeling (version 9.2.0) and different scenarios of control and energy management to assess their impact on the overall SRI evaluation. Their research revealed a disconnection between energy performance and smart readiness, indicating that reductions in energy needs resulting from dynamic simulations do not consistently translate into improvements in SRI scores. Moreover, when comparing various shading systems, they observed that the SRI failed to adequately account for the performance variations resulting from the installation of different devices, such as blinds with distinct materials and characteristics. Instead, the SRI primarily focuses on the control and management strategies of these systems, irrespective of their energy characteristics.

Adegov et al. [65] conducted a case study assessing the SRI's application to a complex multi-family building. The study emphasizes the need for detailed characterization of each energy type consumed, particularly hot water supply systems and heating. In addition, the documentation of the window orientation and the presence and size of shading devices or protective layers is crucial. These factors play a significant role in accurately evaluating a building's energy performance and the effectiveness of the SRI in such complex settings.

Garzia et al. [68] chose a methodology aligned with the SRI assessment framework to evaluate user needs in terms of control systems and building automation. In their study, they added a fourth area, "Monitoring, Control, and Supervision", to the three primary impact areas of the SRI introduced by Al Dakheel et al. [50]. They noted that enhanced control and user awareness contribute to greater satisfaction rates, whereas completely automated control systems often tend to cause lower levels of satisfaction.

Vigna et al. [10] developed a methodology to quantify the practical assessment of building energy flexibility performance. They demonstrated that activating building energy flexibility, despite its simplified implementation, leads to significant savings in terms of CO_2 emissions and residual energy. Improvements can be achieved through the implementation of more effective control strategies compared to conventional operations, without necessitating substantial renovations and advanced technologies.

Ożadowicz [49] proposed a hybrid approach to the technical structuring and design of field-level BACS networks, considering the SRI assessment method, and discussed the SRI assessment methodology and the EN 15232 standard guidelines to evaluate their impact on buildings' energy efficiency and develop technical guidelines for the design of BACS functions.

O'Connell et al. [78] evaluated the quality of demand response services by analyzing the flexible energy sources in buildings and their impact on occupant comfort. Their study introduced the "quality of flexibility" and examined air handling unit fans, heat pumps, and battery storage. Their results indicate that fan data exhibit low uncertainty, which is suitable for ancillary services, while heat pumps exhibit higher volatility but remain suitable for energy services.

As a benchmark for energy efficiency, the "act and measure-analyze-decide and act" methodology was employed to measure the SRI for university buildings by Martínez et al. [32]. Two conceptual spaces (digital and physical) within two dimensions (infrastructures and users) were designated using a three-level IoT model. They emphasized the importance of measuring data to convert it into actionable insights and quantifying critical efficiency indicators such as the SRI to facilitate informed decision-making.

To effectively develop the SRI, it is crucial to define smart services that leverage advanced technologies to optimize energy management and engage with building occupants' behaviors to meet their comfort requirement. Introducing the concept of "functionality levels" allows for the assessment of the degree of smartness of service implementation, extending from fundamental functionality to comprehensive smart solutions [69].

4.2. Research Gaps and Future Directions in the SRI's Dominant Themes

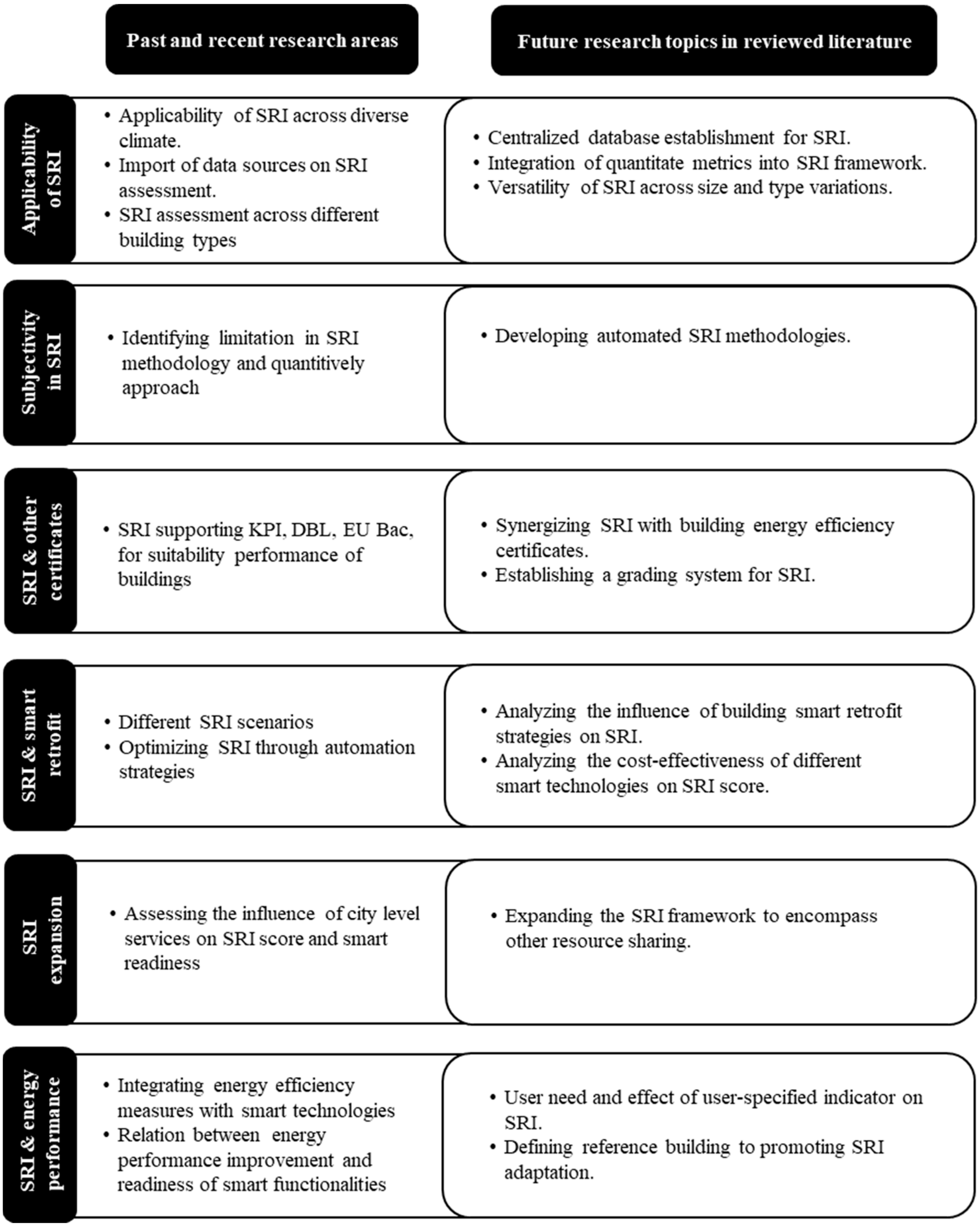
The present study examined the existing SRI literature and identified the dominant themes in a dataset of 68 journal articles (Table A1 in Appendix A). In addition, we highlighted the future research directions as proposed by the reviewed authors to address the research gaps in the literature. To answer the research questions, this study developed a framework to show the current and proposed future research areas in the existing SRI literature.

Figure 5 introduces the highlighted research gaps and emphasizes the future research directions suggested in the articles.

4.2.1. Research Gap in Applicability of the SRI to Different Contexts

Further development and refinement of the SRI methodology are necessary to adapt the measure to various types of buildings and environments. Plienaitis et al. [16] suggested exploring different metrics or indicators to accurately measure buildings' smartness levels across diverse contexts.

Vigna et al. [54] proposed broadening the detailed calculations to include a wider range of buildings of various types and sizes to validate the SRI methodology. Siddique et al. [55] recommended enhancing the algorithmic outcomes for residential systems (RSs) by incorporating cost considerations. For instance, in the thermal envelope RS, including the cost of insulating materials would enable users to align suggestions with their financial limitations. In addition, establishing a central database at the national level to streamline the collection of SRI data for future researchers in the field would also address the subjectivity of the SRI framework by including quantitative elements [55]. Ożadowicz [49] noted that for case studies, conducting supplementary cost analyses is necessary to illustrate the actual level of savings in relation to the required investments.



	Past and recent research areas	Future research topics in reviewed literature
Applicability of SRI	• Applicability of SRI across diverse climate. • Import of data sources on SRI assessment. • SRI assessment across different building types	• Centralized database establishment for SRI. • Integration of quantitate metrics into SRI framework. • Versatility of SRI across size and type variations.
Subjectivity in SRI	• Identifying limitation in SRI methodology and quantitively approach	• Developing automated SRI methodologies.
SRI & other certificates	• SRI supporting KPI, DBL, EU Bac, for suitability performance of buildings	• Synergizing SRI with building energy efficiency certificates. • Establishing a grading system for SRI.
SRI & smart retrofit	• Different SRI scenarios • Optimizing SRI through automation strategies	• Analyzing the influence of building smart retrofit strategies on SRI. • Analyzing the cost-effectiveness of different smart technologies on SRI score.
SRI expansion	• Assessing the influence of city level services on SRI score and smart readiness	• Expanding the SRI framework to encompass other resource sharing.
SRI & energy performance	• Integrating energy efficiency measures with smart technologies • Relation between energy performance improvement and readiness of smart functionalities	• User need and effect of user-specified indicator on SRI. • Defining reference building to promoting SRI adaptation.

Figure 5. Current and future research areas in the SRI literature categorized according to the dominant themes.

Future studies could explore the potential expansion of the SRI framework to other resource-sharing dimensions beyond energy, such as building facilities and spaces. Research could investigate how the SRI framework can be adapted to address challenges related to resource sharing, climate conditions, and flexible energy resource sharing to include aspects such as the utilization of building facilities [38,45,79,80].

4.2.2. Research Gap in Subjectivity of the SRI Framework

Future work on the SRI framework should aim to enhance its objectivity. A mathematical model could effectively fulfill the key functionality of the SRI, “Respond to the needs of the grid”, with the goal of making it more objective and quantitative. Siddique et al. [20,55] highlighted that the advanced framework would incorporate both qualitative and quantitative methods to generate more comparable SRI scores.

Regarding the further development and testing of the methodology for evaluating the energy performance of buildings, it is crucial to align the SRI framework with standardized energy performance metrics to ensure consistency and reliability. This includes refining the assessment criteria to better account for diverse building types and their unique operational contexts [22,54].

Janhunen et al. and Ożadowicz [45,49] highlighted the need for more investigation into the financial advantages of complete smart energy systems. This endeavor aims to strengthen the practicality of adopting such systems as a pathway toward a renewable and sustainable energy model.

Vigna et al. [54] suggested that research should focus on applying the detailed SRI calculation methodology to a broader and more diverse sample of buildings, encompassing various sizes and typologies. This approach would help to thoroughly test the robustness of the SRI framework and enhance its applicability across different contexts. Furthermore, validating the integration of SRI assessments with quantitative indicators for evaluating energy flexibility and operational performance is essential.

4.2.3. Research Gap in SRI’s Alignment with Other Certificates and Standards

The EPCs, integral to the EPBD, are recognized for their key role in reshaping the building market [46]. Plienaitis et al. [16] recommended that future research should focus on the integration of the SRI into assessments of energy efficiency. This could involve examining how the SRI scores can complement existing energy performance certificates and inform decision-makers related to building energy efficiency. Continued research should also focus on practical implementation experiences and lessons learned from EU countries that have voluntarily launched a test phase or implemented the SRI [16].

Becchio et al. [56] outlined the need to develop more precise indicators to effectively express and communicate the energy behavior of buildings, particularly to non-specialist audiences. This entails exploring methods to enrich indicators by integrating other tools, such as simulation models and real data, taking advantage of the growing accessibility of digital resources.

Fokaides et al. [22] emphasized the importance of integrating the SRI into building energy performance evaluations. They suggested improvements such as integrating the SRI into existing energy assessment processes, considering different building types, and setting minimum requirements.

Despite being in the early stages, the SRI is seen as a promising tool for assessing building intelligence [22]. Popa et al. [60] mentioned future research areas in this context, including the integration of semantic models for EPCs with semantic tools, aiming to reconcile and align them with cross-domain semantic models, facilitating reasoning on EPC data.

Siddique et al. [20] noted that there is potential to develop a more detailed scoring system. Instead of attributing a fixed value of one to buildings that meet certain standards, a grading system could be implemented. This grading system would allow for a range of scores (less than one) to be assigned based on diverse readings collected from the building across different impact criteria. This approach would provide a more nuanced assessment of building smartness and its impact on various factors.

Regarding the DBL, Gómez-Gil et al. highlighted the need to redefine key indicators, incorporating insights from the literature and emerging methodologies [57]. Al-Obaidi et al. [44] also recommended reassessing the DBL metrics, proposing the inclusion of new parameters such as tracking the reduction of carbon emissions. This would involve assessing decarbonization progress, identifying data needs for renovation roadmaps, and analyzing issues impeding IoT adoption, such as interoperability issues and unclear implementation strategies among industry professionals. The SRI is considered a valuable framework for enhancing the DBL framework, particularly in addressing interoperability challenges. Al Dakheel et al. [50] suggested that there is a need for a more quantitative approach to adequately assess the performance and advancement of smart technologies in buildings. Consequently, the EPBD should refine the current SRI methodology, along with the concepts of SBs and SR. They proposed a set of KPIs and acknowledged the need for further testing to evaluate their effectiveness in assessing the performance of smart retrofitted buildings.

4.2.4. Research Gap in The SRI as a Tool for Smart Retrofitting

Future research on the SRI highlights the need to refine its methodology, incorporating multi-objective optimization to balance energy efficiency, cost, and comfort in retrofitting. Ramezani et al. [38] proposed several future research directions for enhancing the SRI. First, there is a need for further development and studies to comprehensively consider all the pertinent aspects and address challenges associated with the SRI. Second, future research could explore integrating SRI improvement as one of the retrofitting objectives in multi-objective optimization studies, alongside factors such as thermal comfort, energy saving, cost, and environmental impacts. This involves formulating a multi-objective selection strategy, where retrofit measures are selected based on their efficacy in improving the SRI. Therefore, future research efforts could focus on refining the methodological framework of the SRI and incorporating it into multi-objective optimization studies to optimize building retrofit strategies effectively.

Canale et al. [63] provided further research directions to improve the SRI methodology, including analyzing prevalent automation systems, defining reference buildings, updating domains, and promoting SRI adoption. They also recommended evaluating national SRI implementation and conducting feasibility studies for smart refurbishment interventions.

The future research directions highlighted by Apostolopoulos et al. [62] focus on the need for research to investigate the cost-effectiveness of different smart technologies in retrofitting buildings, taking into account factors such as the building typology and year of construction. Second, further studies should explore how user-specified indicator weights affect the SRI, considering the operational characteristics and technical aspects of buildings.

Continuous research and development are essential to enhance the efficacy of emerging and sustainable technologies and their performance, ensuring their maximum potential in practical applications. Ma et al. [29] noted that it is essential to consider the affordability and scalability of technologies to make them accessible across various building types and global climatic conditions. Buildings can achieve grid responsiveness, net-zero energy, and energy-efficient by integrating these technologies into their design and operation.

To support the integration of smart solutions between buildings and neighborhoods, Ferrari et al. [64] collected smart solutions presented in articles. They claimed that a significant obstacle to adopting the SRI is the absence of practical or illustrative examples that demonstrate the potential percentage reduction in energy consumption achievable through implementation of the automation checklist. The absence of a measurable assessment of the energy performance in smart buildings can lead to confusion and discouragement among stakeholders. Additionally, while the SRI emphasizes building-scale initiatives, there exist a wide array of smart solutions at larger scales that could enhance energy efficiency, integrate renewable energy, and address community needs. However, there is currently no technical benchmark akin to the SRI that effectively supports these intelligent initiatives at the community level in practical application [64].

4.2.5. Research Gap in SRI's Expansion to Neighborhoods and Districts

Expanding the SRI to neighborhoods and districts offers an opportunity to scale its impact from individual buildings to larger urban environments, fostering more sustainable and energy-efficient communities. Ferrari et al. [64] recommended that future research should prioritize the development of a comprehensive reporting framework, mirroring the levels specified for building sustainability. This framework should specifically focus on implementing smart solutions for energy conservation within neighborhood building stocks.

Janhunen and Junnila investigated the relationship between SRI scores and carbon emissions in the Nordic context to understand why the highest level of smartness does not always lead to reduced carbon emissions [13]. Despite Nordic countries demonstrating a strong commitment to climate change mitigation, their lifestyle-based carbon footprints and consumption are among the highest globally [81].

Märzinger and Österreicher [51] suggested several avenues for advancing the assessment of the load-shifting potential in smart districts. First, further refinement and validation of the proposed quantitative methodology and SRI models through empirical studies in diverse settings are needed. Second, research should enhance the accuracy and timeliness of building and energy data inputs to improve the assessment reliability. Third, integrating emerging technologies into the SRI framework could better align it with evolving energy systems. Additionally, studies should examine the socio-economic and policy impacts of load-shifting strategies, including cost-effectiveness, stakeholder acceptance, and regulatory considerations. Finally, efforts should focus on creating decision-support tools and guidelines to help policymakers, stakeholders, and urban planners optimize energy management and foster sustainable development in smart districts.

Cano Suñén et al. [82] proposed future directions for the demand response, emphasizing the incorporation of additional variables such as indoor activities, outdoor weather conditions, window openings, and wind incidence. Additionally, integrating various building systems, including lighting, climate regulation, mobility, and security, is vital for a more comprehensive understanding of the complexity of the built environment in the context of the demand response.

4.2.6. Research Gap in SRI Score and Energy Performance

The SRI represents a pivotal tool in advancing the energy efficiency and sustainability of buildings by assessing their readiness for smart technologies. Its potential to integrate with other frameworks, such as BIM, IoT, and energy performance certifications, underscores its versatility in promoting data-driven decision-making and holistic building management.

Apostolopoulos et al. [62] proposed that future research should concentrate on refining the SRI methodology to provide more accurate assessments of smart readiness and energy efficiency in buildings across different contexts. Furthermore, research should investigate the impact of user-defined indicator weights on the SRI, considering operational building characteristics and technical aspects, and define the final weighting factors based on the implementation process.

Siddique et al. [55] suggested the possibility of integrating the developed algorithms with existing BIM software packages, such as Revit (version 2025.3), to enhance the energy efficiency suggestions in building models with increased personalization options. Research should address the practical challenges, such as standardizing weight factors, incorporating energy flexibility metrics, and ensuring interoperability with national and international frameworks. By addressing these areas, the SRI can evolve into a robust tool that not only improves energy performance but also contributes to the global transition toward sustainable, resource-efficient, and low-carbon building practices [55].

However, the current methodology has limitations, including the subjectivity in its evaluation and challenges in aligning with diverse operational contexts. Future advancements must focus on refining the SRI framework through enhanced quantitative measures, personalization, and integration with emerging technologies. Apostolopoulos et al. [62] proposed that future research should concentrate on refining the SRI methodology to provide more accurate assessments of smart readiness and energy efficiency in buildings across different contexts. Furthermore, research should investigate the impact of user-defined indicator weights on the SRI, considering operational building characteristics and technical aspects, and define the final weighting factors based on the implementation process.

Similarly, according to Al-Obaidi et al. [44], the incorporation of the IoT into smart buildings should prioritize energy-efficient design processes across four essential tiers. These divisions include minimizing energy loss, integrating renewable energy systems, monitoring indoor environments, and managing building systems. Such a strategic approach should aim to optimize the utilization of IoT technologies within the built environment, thereby enhancing the overall efficiency and sustainability.

Vigna et al. [69] emphasized the importance of continued research to refine the indicators for quantifying energy flexibility. This includes considering aspects such as thermal and electric features, cost, smart readiness, and cluster composition. Furthermore, they emphasized the need for future studies to focus on evaluating the effectiveness of strategies in enhancing building readiness for the demand response and smart technologies.

Overall, future research should aim to enhance the usability and effectiveness of the SRI methodology in promoting sustainable and comfortable built environments, while also addressing the practical challenges associated with its implementation and integration into existing frameworks.

5. Conclusions

This study aimed to examine the predominant themes in the current literature on the SRI and identify research gaps that are critical for advancing the evolution of smart buildings. To achieve this, and to address the research questions, we conducted a systematic literature review to understand the evolution of smart buildings and the status of the SRI. The findings show that the SRI literature predominantly focuses on the two main SRI domains, that is, the energy performance of buildings and the demand response, but lacks almost all the occupant-focused domains (see Figure 3). Similarly, the literature focuses on the extensions of the SRI rather than studying how the SRI can drive the evolution of smart buildings in the building stock. The findings demonstrate several significant research gaps. Despite the original introduction of the SRI for buildings, its potential extends much further. There is a need for more studies on the applicability of the SRI across different building types and climatic conditions, the challenges of subjectivity within the SRI framework, its alignment with other certifications and standards, its use as a tool for smart retrofitting, its expansion to the neighborhood and district levels, and the correlation of SRI scores with energy performance. Our content analysis identified six dominant themes with substantial research gaps in the literature:

1. The applicability of the SRI to different contexts
2. The subjectivity of the SRI framework
3. Alignment of the SRI with other certifications and standards
4. The SRI as a tool for smart retrofitting
5. Expansion of the SRI to neighborhoods and districts
6. SRI scores and energy performance.

These findings suggest that while the current literature focuses on the technical aspects of the SRI framework, there is a lack of emphasis on its role in driving the evolution of smart buildings. Most studies prioritize improvements in the technical implementation of the SRI, such as refining its methodology, broadening its scope, or enhancing its audit procedures, rather than exploring how these efforts can catalyze a broader transformation in the building sector.

The literature review emphasizes the role of the SRI as a versatile framework for assessing buildings' readiness to adapt to developing energy systems and occupant requirements. However, several challenges remain. There is a need for more practical examples that illustrate the potential energy reduction percentages, ensuring that the SRI indicators translate into tangible performance improvements. Addressing the limitations in applying the SRI to diverse geographical contexts is also crucial. This study developed a framework that integrates past and recent research, outlining key areas for future study, as illustrated in Figure 5.

Despite the promising insights uncovered in this review, there are several limitations. The review was limited to studies published in English and indexed in specific academic databases, potentially excluding significant contributions from non-English language publications or non-indexed sources. Moreover, the subjectivity in interpreting diverse research findings could have introduced bias into the synthesis process. Additionally, while Figure 5 outlines the relationship between the research gaps and the future research directions, this study does not include an expert validation process to assess the practical applicability of the future research.

Future research should focus on addressing the broader applicability of the SRI beyond individual buildings, particularly in terms of its use for assessing neighborhood-level or district-scale smart readiness. Additionally, research should aim to establish standardized minimum SRI scores for buildings, ensuring consistency and clarity in assessments. Integrating the SRI with existing certification systems would enhance its reliability and effectiveness as a tool for fostering sustainable, energy efficient buildings.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The relations between the SRI domains and the journal articles.

				SRI Domains		
Number	**Author**	**Location**	**Type of Building in Research Involving Case Studies**	**A: Interact with Occupants**	**B: Interact with Grids**	**C: Building Performance, Energy Efficiency**
1	Vigna et al. [54]	Italy	Office buildings	✓	✓	✓
2	Angelakoglou et al. [59]	-	-	✓	✓	✓
3	Ferrari et al. [64]	-	-	-	-	✓
4	Siddique et al. [55]	-	-	-	-	✓
5	Siddique et al. [20]	-	-	✓	-	✓
6	Ye et al. [52]	Ireland, Greece. Sweden and Spain	Different building features	✓	✓	✓
7	Plienaitis et al. [16]	Lithuania	Educational buildings	✓	✓	✓
8	Pereira and Ramos [39]	-	-	-	✓	✓
9	Gómez-Gil et al. [57]	-	-	-	✓	✓
10	Al-Obaidi et al. [44]	-	-	-	✓	✓
11	Adegov et al. [66]	Ukraine	A complex of multi-family buildings (consisting of five multi-family residential buildings)	✓	✓	✓
12	Ożadowicz [49]	-	-	-	✓	✓
13	Becchio et al. [56]	Northwest of Italy	An office building	✓	✓	✓
14	Ramezani [38]	Portugal	Two non-residential buildings	✓	✓	✓
15	Canale et al. [63]	Italy	Eight residential buildings	✓	✓	✓
16	Martínez et al. [32]	Spain	University of Zaragoza, three buildings	✓	✓	✓
17	Fokaides et al. [22]	Cyprus	The main wing of Frederick University	✓	✓	✓
18	Janhunen et al. [45]	Southern Finland	A shopping center	✓	✓	✓
19	Janhunen et al. [13]	Finland	Three different buildings	✓	✓	✓
20	Vigna et al. [67]	-	Educational building and a traditional office building	-	✓	✓
21	Apostolopoulos et al. [62]	Five EU countries (Denmark, Czech Republic, Greece, Bulgaria, Austria)	Ten residential buildings	✓	✓	✓
22	Galal and Elariane [53]	-	-	-	-	✓
23	Märzinger and Österreicher [51]	-	Different building features	-	✓	✓
24	Kourgiozou et al. [31]	UK urban university campuses	98 buildings, university campuses, Mediterranean non-residential buildings	✓	✓	✓
25	Jensen et al. [40]			✓	✓	✓
26	Al Dakheel et al. [50]	-	-	✓	✓	✓
27	Tzani et al. [83]			✓	✓	✓
28	Dell'Isola et al. [84]	Italy	Case study building	✓	✓	✓
29	Aagaard [47]			✓	-	-
30	Cano Suñén et al. [82]	Spain	University building	-	✓	✓
31	Salom et al. [24]	-	-	-	✓	✓
32	Santos et al. [75]	-	-	-	✓	-
33	Garlik [76]	-	-	-	✓	✓
34	Samancioglu and Nuere [71]	-	-	-	✓	✓
35	Azouz and Elariane [46]	Egypt	-	-	✓	✓
36	Broday and Gameiro da Silva [85]	-	-	-	-	✓
37	Ma et al. [29]	-	-	✓	✓	✓
38	Garzia et al. [68]	-	-	✓	-	✓
39	Morkunaite et al. [61]	-	-	-	-	✓
40	Popa et al. [60]	-	-	✓	-	✓
41	Ala-Juusela et al. [41]	-	-	-	✓	✓
42	Moseley [48]	-	-	✓	✓	✓
43	Alonso et al. [58]	-	-	-	-	✓
44	Arteconi et al. [37]	-	-	-	✓	✓
45	Attia et al. [43]	-	-	-	-	✓
46	Beccali et al. [80]	Victoria	Educational office	-	✓	✓

Table A1. *Cont.*

				SRI Domains		
Number	**Author**	**Location**	**Type of Building in Research Involving Case Studies**	**A: Interact with Occupants**	**B: Interact with Grids**	**C: Building Performance, Energy Efficiency**
47	Bonomolo et al. [86]	-	-	-	✓	✓
48	Chantzis et al. [87]	-	-	-	✓	-
49	Czétány et al. [88]	-	-	-	✓	✓
50	D'Ettorre et al. [79]	-	-	-	✓	✓
51	Engelsgaard et al. [73]	-	-	-	✓	✓
52	Engvang and Jradi [77]	Denmark	Office building	-	✓	✓
53	Fan and Song [89]	Spain	Domestic building	-	✓	✓
54	García-Monge et al. [1]	Spain	Campus building (three buildings of the Río Ebro campus)	✓	✓	✓
55	Gómez-Gil et al. [17]	Spain and Italy (Aragon and Lombardy regions)	-	-	-	✓
56	Janhunen et al. [19]	Helsinki	-	-	✓	✓
57	Kourgiozou et al. [90]	-	-	-	✓	✓
58	Le Dréau et al. [65]	-	-	-	✓	✓
59	Li et al. [3]	-	-	-	✓	✓
60	Li et al. [28]	-	-	-	✓	✓
61	López-Ochoa et al. [9]	Spain	Residential sector	-	-	✓
62	Majdalani et al. [42]	Portugal	Residential buildings	-	✓	✓
63	Medved et al. [91]	-	-	-	✓	✓
64	O'Connell et al. [78]	UK	Commercial buildings	✓	✓	✓
65	Oskouei et al. [4]	-	-	-	-	✓
66	Van Thillo et al. [21]	-	-	-	✓	✓
67	Vigna et al. [10]	-	-	-	✓	✓
68	Zuhaib et al. [18]	Five EU countries (Denmark, Greece, Portugal, Poland, and Romania)		✓	-	✓

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