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Responsive Public Policies for Smart and Sustainable Buildings: An Experimental Application of the Smart Readiness Indicator

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Abstract: The digital transition and decarbonization are strategic European objectives, supported at different levels by the Green Deal, the Energy Performance Building Directive (EPBD), and policies and tools such as the Energy Performance Certificate (EPC) and the Smart Readiness Indicator (SRI). The SRI measures a building's ability to use intelligent technologies to reduce its consumption and increase the energy awareness of occupants for energy efficiency. Furthermore, today, it has a limited impact on national regulations and public decision-making. Its application presents challenges including those related to heritage conservation. This paper contributes to the Italian SRI framework through an experimental application in the renovation of a historic building in the metropolitan city of Reggio Calabria (Italy). The analysis evaluates the SRI's adaptability by comparing its pre-renovated state, current state, and pre-design plan. The SRI calculation integrates assessment tools with BIM models for a potential future digital twin approach. The study, part of a funded national research project, aims to enhance policies for digitalization in the green transition. The paper is organized into the Introduction; Materials and Methods, which contains the methodological approach; Results; and Discussion and Conclusions. Following the experimental application, the results show that standardizing the SRI approach could enhance energy efficiency and digitalization in buildings.

Keywords: EPBD; public policies; smart building; smart readiness indicator; building information modeling

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1. Introduction

The European decarbonization path identifies key enabling technologies (KETs) as one of the principal innovative and implementation factors in the digital transition (e.g., in energy, transport, and industry). European digital policies, particularly the Digital Decade [1–5], in parallel with Industry 4.0 and 5.0 [6,7], are directing the digital transition to achieve the carbon and climate neutrality goals for 2050 while enhancing human-centered processes from both a lifecycle and transition perspective [8].

The European Green Deal [9] addresses policies and strategies for climate change, recognizing digitalization and related technologies as a key factor in achieving the sustainability goals [3]. The construction industry plays a crucial role in environmental challenges, being responsible for 36% of greenhouse gas emissions in Europe. The Renovation Wave Strategies promote comprehensive and integrated renovation, leading to smart buildings and enabling the efficient multi-scale generation and use of renewable energy (home, district, or city) [10] while adopting circular economy principles. Digital building renovation based on circular principles can significantly contribute to the achievement of climate neutrality given that 20–25% of lifecycle emissions in current EU building stocks derive from building materials [11]. Using the principle of "energy efficiency first" [12], the renovation and the improvement of energy has become an important task for our generation [13].

In synergy with the Renovation Wave, the EU Energy Performance of Buildings Directive (EPBD) introduced the Energy Performance Certificate (EPC), regulating its evolution through updates.

The EPC is a specific policy instrument that certifies the energy efficiency of buildings, supporting decision-making processes and promoting the establishment of greener buildings.

In the EPBD [12], the EU Commission integrated the twin goals of accelerating the renovation of existing buildings by 2050 (Nearly Zero-Energy Building, nZEB; Zero-Emission Building, ZeMB) and supporting the modernization of buildings through smart technologies [14]. It introduced two new tools to evaluate and certify potential building sustainability: the Smart Readiness Indicator (SRI) and the Building Renovation Passport (BRP).

The Smart Readiness Indicator measures a building's ability to use smart technologies to reduce its energy consumption and increase the energy awareness of its occupants. Although the EU Commission frequently refers to these methods as necessary and effective measures to achieve the 2030 and 2050 goals, their integration into the EPC policy framework remains marginal. At a public administration (PA) level, a twin transition cannot be guaranteed due to difficulties in the management of data and new digital technologies [15].

Numerous public European authorities at different levels (national, regional, municipal) have implemented environmental action plans and adopted policies in favor of both sustainability and the efficient use of resources, including further requirements, protocols, and indicators to implement their application. The functionality of the SRI and, more generally, of the EPC are often not recognized. This results mainly from data management, with data being scarce, inaccurate, and difficult to access due to a lack of smart meters and BRPs [16].

In Italy, moreover, no official trial on the SRI has been launched, so there is currently no shared codification or calibration to specific national needs.

In this context, this paper aims to contribute to the implementation of the Italian technical framework of the SRI, applying it in various renovation phases of a historic building in the metropolitan city of Reggio Calabria.

The regulatory constraints imposed for the protection of heritage (such as National Superintendencies) often limit the possibility of renovation interventions, also affecting the application of the SRI.

The integration of smart sensors for lighting and heating or automated monitoring devices may be limited or prohibited to preserve the architectural features of historic buildings. For the same reason, it is not always possible to install photovoltaic or solar panels for sustainable energy supply, and this negatively affects the improvement of a building's energy performance. These conditions represent a significant challenge for the integration of SRI strategies. However, they also highlight the importance of testing SRI methodologies in historical contexts, both to understand their adaptability and to explore pathways towards a digital and energy transition respectful of cultural heritage.

This paper presents the current national research results of PRIN2022 BETTER POLICY: Building Environmental Tools To Empower Responsive Policies Outreaching LIfeCYcle, aimed at improving the effectiveness of policies in the field of digitization for green transition, using EU instruments and indicators. The developing studies contribute to the implementation of the SRI framework while considering national specificities and emphasizing the role of PA in accelerating SRI process application.

The paper is organized into Section 2—which contains the methodological approach; Sections 3 and 4..

2. Materials and Methods

Section 2 is structured into 3 subsections. It deals with the introduction of a critical and analytical framework, detailing the background and development of the SRI (Section 2.1), its tools and calculation (Section 2.2), and its experimental application on a historical building (Section 2.3).

2.1. The SRI's Background and Development in EU Polices and Strategies: A Critical Analisis

As part of the EU's policies and strategies to achieve its carbon and climate neutrality targets, as well as the EPBD objectives, this paper aims to support PA in implementing and applying Smart Readiness as an indicator of "green and digital" building potential.

This paragraph introduces a critical analysis concerning the definition and the development of the SRI concept and the method for its evaluation. Over the last decade, European policies and strategies for a global transition towards low-carbon economies and improved resilience to climate change have been reinforced through digitalization. Thus, smartness is essential for achieving energy efficiency in buildings (Nearly Zero-Energy Building (nZEB) and Zero-Emission Building (ZeMB)) [17].

Industry 4.0 prior [6] and the subsequent Industry 5.0 [7] have clear visions, methods, and tools to make KETs fully operational and functional for decarbonization strategies. Industry 4.0 introduced competition and interconnection between the physical and digital dimensions. Industry 5.0 outlines a range of human–machine–environment iterations, using cloud platforms which control production services and optimize costs and the final product quality, while implementing resource-saving processes, waste reduction, and recycling. Industry 5.0 is part of the Digital Decade [18], a global framework steering actions towards digital transformation, ensuring that all aspects of technology and innovation are functional for people. The Digital Decade is also instrumental in achieving the climate neutrality goals set by the European Green Deal for 2050.

The growth strategy outlined by the European Green Deal "aims to transform the EU into a just and prosperous society, with a modern, resource-efficient and competitive economy that will generate no net greenhouse gas emissions in 2050 and where economic growth will be decoupled from the use of resources" [9]. The Renovation wave [13] is part of this strategy. It deals with the twin transition goals of the construction sector with an energy upgrading program to make buildings sustainable, smart, and renewable-energy-efficient. Europe's cultural specificity and history are expressed through its unique and deeply diverse building heritage; however, to reduce emissions by 55% by 2030 substantial widespread intervention is needed, including a 60% reduction in greenhouse gas emissions from buildings, a 14% reduction in final energy consumption, and an 18% reduction for heating and cooling [9].

The Renovation Wave prioritizes three areas: the decarbonization of heating and cooling systems; combating poverty and energy inefficiency; and finally the renovation of public buildings [13].

"Fit for 55" proposes common rules to reduce the EU's carbon footprint, which includes a reduction in energy consumption by using renewable energy sources to achieve zero carbon emissions [19].

The EPBD was also revised within "Fit for 55" to meet the objectives set out in the EU strategies. All directives in the different versions (2010/31; 2018/844; 2024/1275) promote the improvement of the energetic efficiency of buildings. Therefore, the member states are encouraged to implement these measures by establishing a minimum energy performance requirement for new or extensively renovated buildings. What follows is the mandatory certification of energy efficiency through the issuance of energy certificates.

This enables the periodic inspection of air-conditioning systems, and the provision of information to users on energy performance indicators [20]. The European Performance in Buildings Directive 2024/1275 amalgamates issues related to national renovation plans, energy performance, and building intelligence readiness. It introduces the Smart Readiness Indicator, which measures a building's ability to use smart technologies, which leads to decarbonization, and more comfortable and efficient living environments (Figure 1).

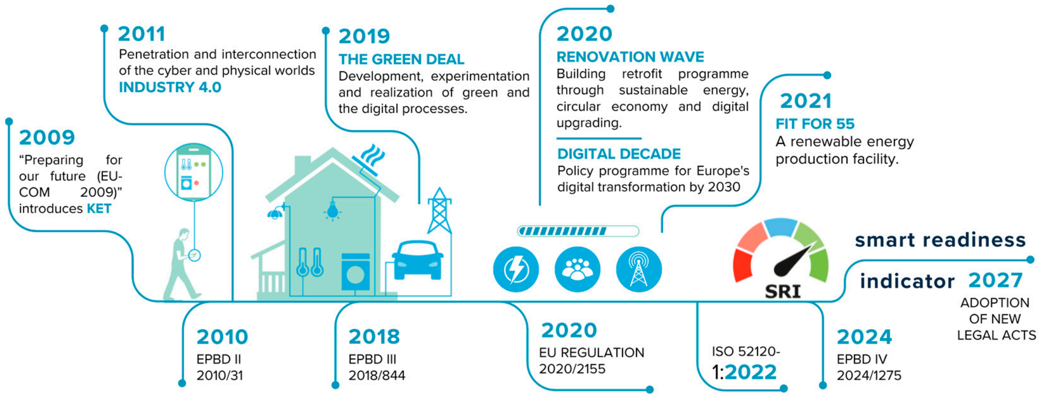

Figure 1. The SRI's evolution based on the cross-reading of the main European strategies and their related directives. Authors' elaboration on EU data source [17].

The application of the SRI considers the smartness of a building to be its ability to recognize and actively react to varying scenarios connected to the operation of technical building systems, the external environment, and the occupants' requirements. This is assessed through the evaluation of 3 key functionalities:

- Optimize in-use performance, which includes energy efficiency;
- Adapt operations to the occupants' needs;
- Respond and adapt to signals from the grid.

Implementing the SRI framework into the construction sector incentivizes the use of smart technologies in buildings, which integrate building automation and electronic monitoring, i.e., heating, hot water, ventilation, and lighting [17].

The common rating system was established by the Commission Delegated Regulation (EU) 2020/2155 and in the EPBD 2024/1275 to achieve the parallel goals of the renovation and smart modernization of existing buildings by 2050 [12,14].

The SRI is complementary to the EPC contained in the same directive. This indicator is designed to complement tools that examine both energy and sustainability performance (Figure 2).

The European Commission stated, in the first phase, that each member state is responsible for its own reference database to calculate the Smart Readiness Indicator. The database includes several interconnected banks: data on energy performance, inspections, and restructuring activities; these are used to issue a building passport, calculate smart readiness, and measure energy consumption. One of the most interesting aspects introduced by the SRI is building systems data management [20].

The EU defines the structure and the principles of the SRI calculation method, while the operational and technical aspects are provided by national authorities participating in the official EU test or in pilot activities conducted by LIFE Clean Energy Transition projects.

The technical framework deals with smart ready services, levels of functionality, and instrumental parameters. The official EU test of the indicator will enable the Commission to refine the procedures. In this initial phase the test is applied to non-residential buildings.

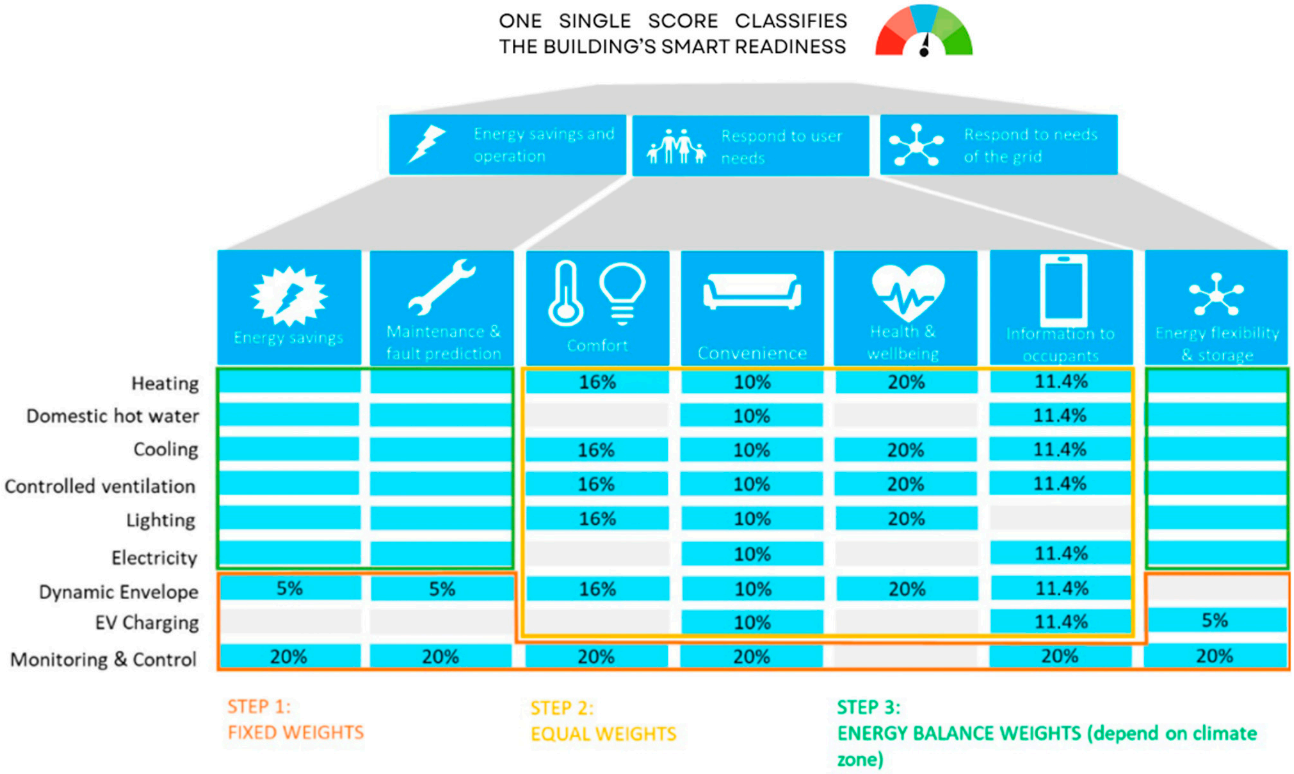

Figure 2. The functionalities, the domains, and the impacts of the SRI, and an overview of its weighting scheme. EU open access source [17].

The Green Building Council of Italy (GBC) is introducing a digital maturity assessment process, which refers to the SRI impact criteria [21]. The digital maturity assessment aims to improve operational efficiency, interoperability between stakeholders, data management, and sustainability. Furthermore, it aims to overcome the main gaps in the implementation of energy assessment systems to facilitate the SRI's application.

The SRI will be ratified by European nations from 2026 (Figure 3).

Figure 3. A timeline of the implementation of the SRI planned by the EU and the decarbonization targets of EPBD buildings. Authors' elaboration.

This current experimental phase will focus the EU's efforts in both defining technical and operational frameworks to standardize data collection and identify the main gaps to be addressed for the application of the Smart Readiness Indicator [22–24].

A critical analysis of a voluntary experiment on the SRI (tunES 2024) within the LIFE projects (SmarterEPC, SRI-ENACT, Smart Square) outlines a scenario of both awareness and adoption of the indicator by the main stakeholders in the construction chains. Certain projects also focus on the gap in the application of the indicator within public administration.

The gap that most affects the operational application of the SRI stems from three main causes: widespread lack of awareness about environmental sustainability; digital poverty and the digital divide; and PA's non-involvement in the SRI test phases.

To establish effective energy certification tools, a unified vision of sustainable strategies is required by member states to focus on national and European objectives. However, the negative perception of this application is generating certain difficulties common to several states [25]. It thus becomes more difficult to introduce, as a common practice, additional calculation systems based on data or on digitized dynamic forms of calculation. This remains a considerable obstacle to the widespread acceptance of SRI testing and implementation.

Quantitative and qualitative poverty in digital technologies is a common condition for most European PAs. The existing digital divide represents a systemic difficulty in digital transformation and in achieving the Green Deal goals. At an operational level, this also indicates the need for greater coordination, advanced cohesion, and efficiency between institutions and stakeholders (e.g., in the construction sector) [26].

Although the SRI is widely recognized as promising and advantageous, any assessment of environmental effectiveness still requires a systemic and holistic approach. This reduces the risks of over- or under-estimation when compared to traditional methods of assessing overall environmental balance.

All of these aspects have an indirect impact on the implementation of the SRI as they may affect the path towards the green digitization of PAs.

To date, the adoption of the SRI is perceived to be an additional bureaucratic burden due to the lack of practical and user-friendly tools. PAs do not have the internal capacity to manage data in a digital way or access specific software that allows faster consultation or comparability [27,28].

Moreover, there are limitations within guidelines and protocols that hinder the indicator's functionalities and effective use. Its application method lacks sufficient standardization. The reliability of current SRI calculation methodologies is considerably uncertain, and, despite the development of specific SRI calculation tools, they are either unknown or not considered sufficiently developed by the end users [16].

Given the current state of official European SRI testing, it is necessary to form as many cross-cutting work teams as possible. Furthermore, greater account must be taken of SRI testing to allow better diffusion of knowledge and the development of user strategies, given the potential of the instrument in a particular national context.

In Italy, the main actions are carried out by energy companies, universities, and research centers such as ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) [29], but no public administrations have taken part in the systematic testing of the indicator, nor has it been applied in the process of building stock renovation, according to the EPBD.

2.2. The SRI's Calculation and Active Tools

The EU has formalized the method of calculating the Smart Readiness Indicator by way of an Excel spreadsheet. This entails a check-list approach, which incorporates the 'smart ready services' that are present and/or planned in a building. The 'smart ready services' concern specific technologies and can be evaluated through two service catalogs (A—a detailed method and B—a simplified method). Each lists relevant services, the level of 'intelligence', the description of expected impacts on end-users, and the energy network. The evaluation of services is based on Smart Readiness scores, reflecting functionality levels in intelligent technology implementation. The impact scores are assigned to each functionality level and aggregated to calculate the building's Smart Readiness score as a percentage [18] (Figure 4).

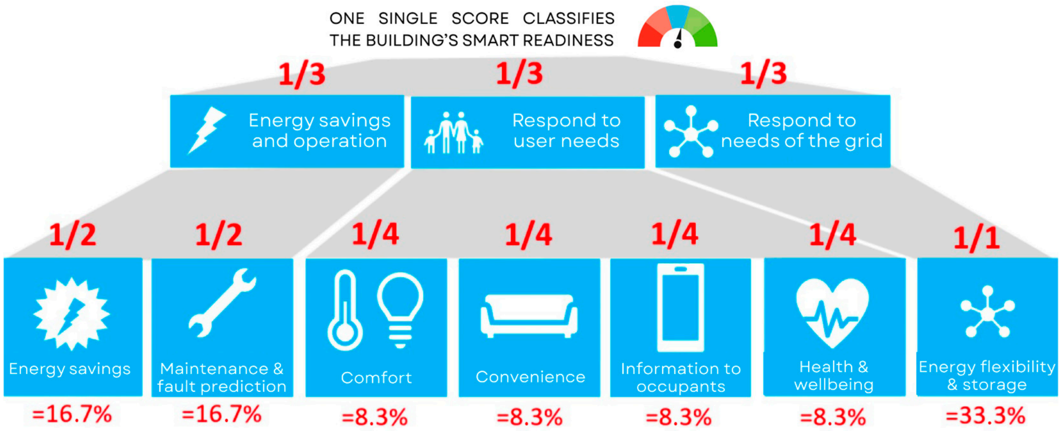

Figure 4. The functioning of the Smart Readiness Indicator: The aggregation of impact scores to three key functionalities or to a single score. EU open access source [17].

Within the LIFE projects the widest possible range of applications, assumed by the EU Commission, were explored. These included expanding the knowledge and functionality of the SRI; the development of operative tools; and collecting and improving the availability of data, highlighting the dissemination of the results linked to the EPC. Fourteen States participated in the formal testing phase [17] (Figure 5).

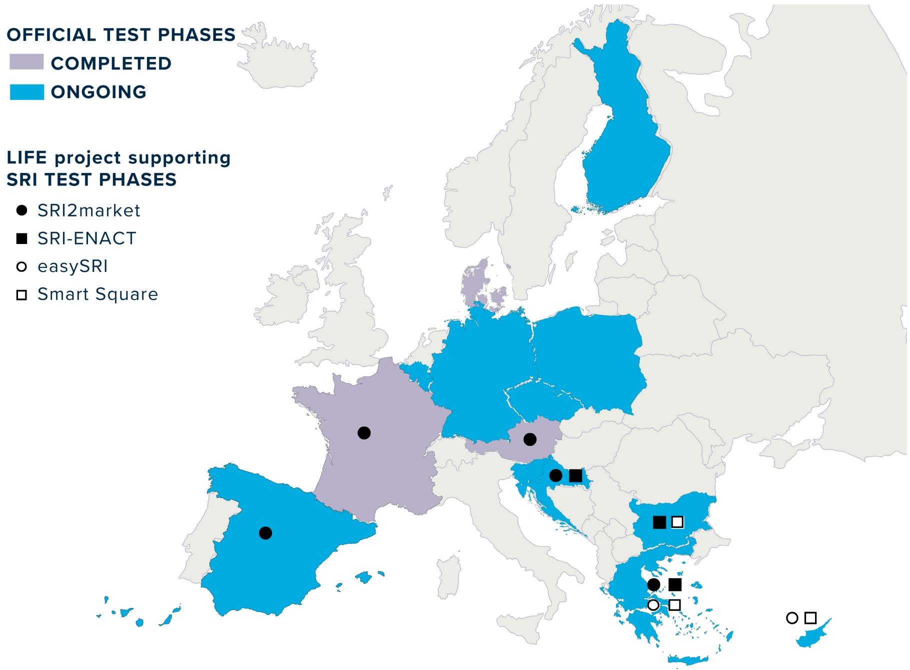

Figure 5. The States involved in the SRI trial and supporting the LIFE project, updated in September 2024. Authors' elaboration.

The table below shows a road map of the EU projects on the SRI, highlighting their objectives, the countries involved, and the possible tools for calculating the output. The results of each project are available on the related websites (Table 1).

At present, there are many online tools (see Table 1), which have different levels of availability, but are similarly applicable, supported by guidelines and video courses. Each tool simplifies SRI evaluation thanks to their immediate interfaces, their assisted calculation modes (see call-center mode), and the automatic setting of some parameters (e.g., reference values are set in relation to the geographical location of the building). They process and aggregate all information entered to provide benchmarks, such as the SRI level percentages of buildings and the most critical domains. Once the technical domain, single or multiple, is chosen and the service catalog is selected (A or B), the main characteristics are requested by means of drop-down menus. After successive evaluations, the tools allow access to the SRI's history. A simplified calculation mode, called "call-center", is also available in the form of an interview with multiple responses.

Table 1. The EU SRI projects under the LIFE program, as well as their member state partners and tools.

Project	Partners	Tool
iEPB https://iepb-project.eu/ (accessed on 10 April 2025)	Austria Greece Netherlands Spain	
SmarterEPC https://lifeprojects.r2msolution.com/smarterepcthe-new-hub-for-bulding-evaluation/ (accessed on 10 April 2025)	Cyprus Finland France Greece Italy Netherlands Romania	
tunES https://empirica.com/tunes/ (accessed on 10 April 2025)	Austria Croatia Greece Hungary Italy Poland Slovenia	
SRI2market https://ieecp.org/projects/sri2market/ (accessed on 10 April 2025)	Austria Croatia Cyprus France Portugal Spain	SRI2market https://sri2market.eu/sri/proyecto/ (accessed on 10 April 2025)
Smart Square https://www.smartsquare-project.eu/ (accessed on 10 April 2025)	Belgium Bulgaria Cyprus Greece Ireland Italy Netherlands Romania	Smart-ready-GO! https://www.smart-ready-go.eu/ (accessed on 10 April 2025)
SRI-ENACT https://srienact.eu/ (accessed on 10 April 2025)	Austria Belgium Bulgaria Croatia Greece Latvia Czech Rep. Romania Spain	SRI toolkit https://www.srienact-tool.eu/login (accessed on 10 April 2025)

Table 1. *Cont.*

Project	Partners	Tool
easySRI https://www.easysri.eu/en (accessed on 10 April 2025)	Austria Cyprus Greece Ireland Italy Norway Spain	

The Life Projects are designed to address the gap related to the SRI's application, accessibility, and knowledge aspects. The number of trials within the projects does not involve all EU countries and is therefore insufficient to guarantee the quantity of data needed for the standardized evaluation method. Further trials are necessary through a single scheme to allow data comparison and the creation of a data system. Moreover, when compared to the current stage of development, the Life Projects results are severely limited by systemic shortcomings, the effects of which will become apparent over time.

Focusing on public buildings and public administrations necessitates consideration of the functionality of the SRI in achieving the aims of decarbonization.

2.3. The SRI's Experimental Application

This paper presents the results of the ongoing experimental application of the SRI on a historic public-owned building adopting the Excel spreadsheet provided by the European Union. The pilot building is part of a set of four that make up a single block located in the historic center of Reggio Calabria. The building, "Torre A", was planned and built between 1921 and 1928. A floor was added between 1952 and 1958. The pilot building consists of a single volumetric unit with three floors above ground and another underground, built around a central courtyard. It occupies an area of about 750 square meters (Figure 6).

It is currently owned by the metropolitan city of Reggio Calabria and hosts administrative activities. Its urban context is characterized by important historical and artistic sights: the Aragonese Castle, the Church of the Optimati, the Cathedral, and the Court. The area is of considerable public interest (L. 1497/39 art.136 of the D.Lgs. 42/0.) and is protected by the Archaeological Superintendence of the Calabrian Regional Government (Figure 7).

The building is now under a renovation pre-design plan.

The objective is to combine the building's original and historical features of architectural value with the creation of functional and modern spaces, highlighting its central role in the historic center of Reggio Calabria.

The pre-design plan proposes the following:

- The redefinition of common areas, the restoration of the internal courtyard, and the construction of a multi-purpose room.
- The functional reorganization of internal spaces and the re-design of offices.
- Seismic adaptation.
- The adoption of innovative technical solutions to improve the energy efficiency of the building and reduce its environmental impact.

Innovative technical solutions will be adopted to improve the energy efficiency of the building and reduce its environmental impact in line with EPBD energy efficiency priorities within existing buildings. When appropriately applied, the SRI optimizes the EPC and the energy performance of buildings [30].

Figure 6. "Torre A". Graphical representation. Authors' elaboration.

Furthermore, with reference to PRIN BETTER POLICY research, the experimental application of the SRI has value as an overall "green and digital" indicator.

The current state of the building was assessed by an on-site inspection and survey, after which the building was found to be energy-inefficient. Therefore, the renovation plan focuses on the following green and digital, energetic, and thermophysical aspects:

- Regulatory realignment according to the European Directives 2030–2050 for PA.
- The introduction of certain analysis criteria, evaluations, and energy intervention strategies for the building envelope and housing comfort requirements.
- Material choices to align with the Italian Green Public Procurement (PAN-GPP) guidelines, Minimum Environmental Criteria (MEC), and Criteri Ambientali Minimi (CAM) for Italian regulations [31].
- The proposal of criteria for automation, control, and monitoring systems to allow the optimal management of buildings and plants.

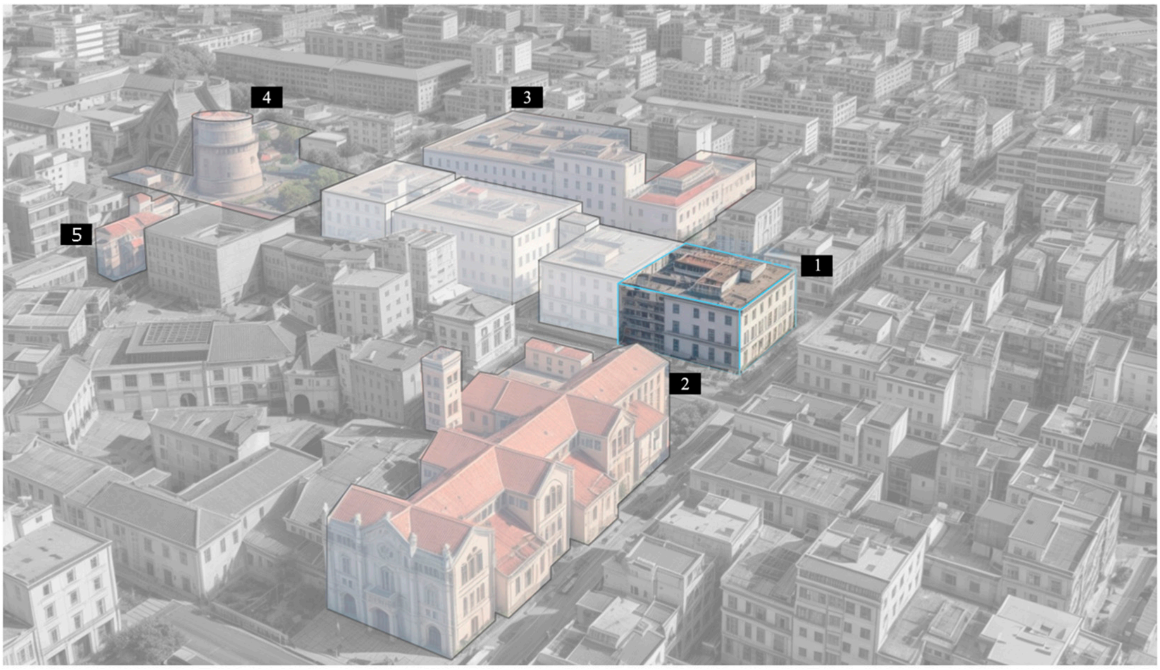

Figure 7. The urban context and the selected historic building (n 1). Authors' elaboration. Legend: ① "Torre A"; ② Cathedral; ③ Court; ④ Aragonese Castle; ⑤ Optimati Church.

An experiment was conducted to assess the value of the SRI in three different scenarios: the pre-renovated state, the current state, and the ongoing pre-design plan.

After the survey and the data analysis within the pre-design plan, 5 of the 9 SRI domains were selected and investigated, as shown in Table 2:

- Heating (H);
- Domestic hot water (DHW);
- Cooling (C);
- Lighting (L);
- Electricity (E).

To ensure the scientific nature of the SRI calculation, as well as the consistency and comparability of the data, simulations were conducted using the EU Excel spreadsheet.

The results were interpreted and processed according to the EU case study form.

The semi-underground level was not considered in the evaluations due to inaccessibility, and because it contains no equipment and is not under intervention.

In its pre-renovated state, the building was equipped with an air-conditioning system with external units in line with the provisions laid down by the Superintendence for Cultural Artefacts. Each room was furnished with one or two indoor units with individual control over the temperature. The lighting system was controlled manually (on/off), both in common areas and in individual rooms. There were no renewable electricity generation systems or cogeneration.

Table 2. The characteristics of the domains that were present in the pilot building in its pre-renovated state and current state and in the pre-design plan.

Domain	Pre-Renovated State	Current State	Pre-Design Plan
H—Heating	Individual room control	Individual room control with communication between controllers and BACS	Individual room control with communication between controllers and BACS
	Constant temperature control	Demand-based control of air flow	Demand-based control of air flow
		Variable speed pump control	Variable speed pump control
		Variable control of heat generator capacity (inverter frequency control)	Variable control of heat generator capacity (inverter frequency control)
		Control according to dynamic priority list	Control according to dynamic priority list
	No report information	Central or remote reporting of current KPIs	Central or remote reporting of current KPIs and historical data
DHW—Domestic Hot Water	Automatic control (on/off)	Automatic control (on/off)	Automatic control (on/off)
			Automatic control of solar storage charge
	No report information	Indication of actual values	Indication of actual values
C—Cooling	Individual room control	Individual room control with communication between controllers and BACS	Advanced central automatic control with intermittent operation and/or room temperature feedback control
		Variable speed pump control (external demand signal)	Variable speed pump control (external demand signal)
	No interlocking (avoiding simultaneous heating and cooling in the same room)	Total interlocking	Total interlocking
		Variable control of cooling production capacity depending on the load or demand (inverter frequency control)	Variable control of cooling production capacity depending on the load or demand (inverter frequency control)
		Load prediction-based sequencing	Load prediction-based sequencing
	No report information	Central or remote reporting of current KPIs	Central or remote reporting of current KPIs
L—Lighting	Manual on/off switch control	Manual on/off switch control	Manual on/off switch + additional sweeping extinction signal

Table 2. *Cont.*

Domain	Pre-Renovated State	Current State	Pre-Design Plan
E—Electricity system	Report on current electricity consumption on building level	Report on current electricity consumption on building level	Performance evaluation including forecasting and/or benchmarking Current state of charge (SOC) data available Real-time feedback or benchmarking on appliance level Automated management of local electricity consumption based on current renewable energy availability Automated management of (building-level) electricity consumption and electricity supply to neighboring buildings (microgrid) or grid

The current state of the building is the result of a recent renovation. A lot of work has been carried out on the heating/cooling and lighting systems. The individual air-conditioning units have been replaced by reversible multi-split heat pumps with soft-touch wire panels. On each floor an electric water heater has been added for the production of domestic hot water. The lighting system has been completely replaced with the latest generation of energy-saving LED lamps, which are manually controlled in every room and public area.

The pre-design plan includes a photovoltaic panel system to fulfill the building's energy requirements. The modification directly affects the SRI, with the major impact criteria related to energy efficiency and improving the performance of the building, with regard to the heating and cooling domains. Therefore, they are considered priority areas for action. Moreover, the current available technologies permit definite and tangible improvements in a short time at low cost. While proportionally fewer, some benefits were also found in the SRI impact criteria relating to the well-being of occupants.

The pre-desgn plan is based on BIM model management, from the perspective of associating it with a digital twin of the building, making the SRI part of the digital model.

3. Results

The building's SRI score in the pre-renovated state is 8.9% (G class). In the current state the score rises to 39.5% (E class). The forecast of actions in the pre-design plan leads to a total score of 52.9%, moving to the D class (Figures 8–10).

Figures 8–10 show the three SRI assessment scenarios, while the technical characteristics are broken down in Table 2.

Figure 8 shows the initial scenario in the pre-renovated state of the building (SRI class G). The aggregate scores for the key functionalities, impact criteria, and individual domains are also reported. The building has low scores in most domains, particularly in the heating, cooling and domestic hot water systems, which are at level 0. This first configuration reflects the common limitations found in historical buildings, where technological integration is minimal. The figure provides a reference point for evaluating the impact of the simulated interventions in the subsequent scenarios.

Figure 8. Report on SRI application with reference to the pre-renovated state of the building. It shows the total and partial results by functionality, impact criterion, and domain.

Figure 9 shows the SRI assessment after renovation. The SRI of the renovated building increased to Class E. The intervention consisted of the replacement of the internal conditioning and ventilation systems. The use of more efficient technologies exponentially increased the aggregate scores. As in the previous state, the heating, cooling, and hot water system domains, not present in the building and not mandatory, remain at level zero.

Figure 9. Report on the SRI application with reference to the current state of the building. It shows the total and partial results by functionality, impact criterion, and domain.

Figure 10 shows the results for the pre-design plan scenario. Photovoltaic panels, intelligent monitoring systems, and sensor-based controls will be integrated into the building for smart heating, cooling, and lighting systems. From this data management and monitoring perspective, Building Informative Modeling was applied.

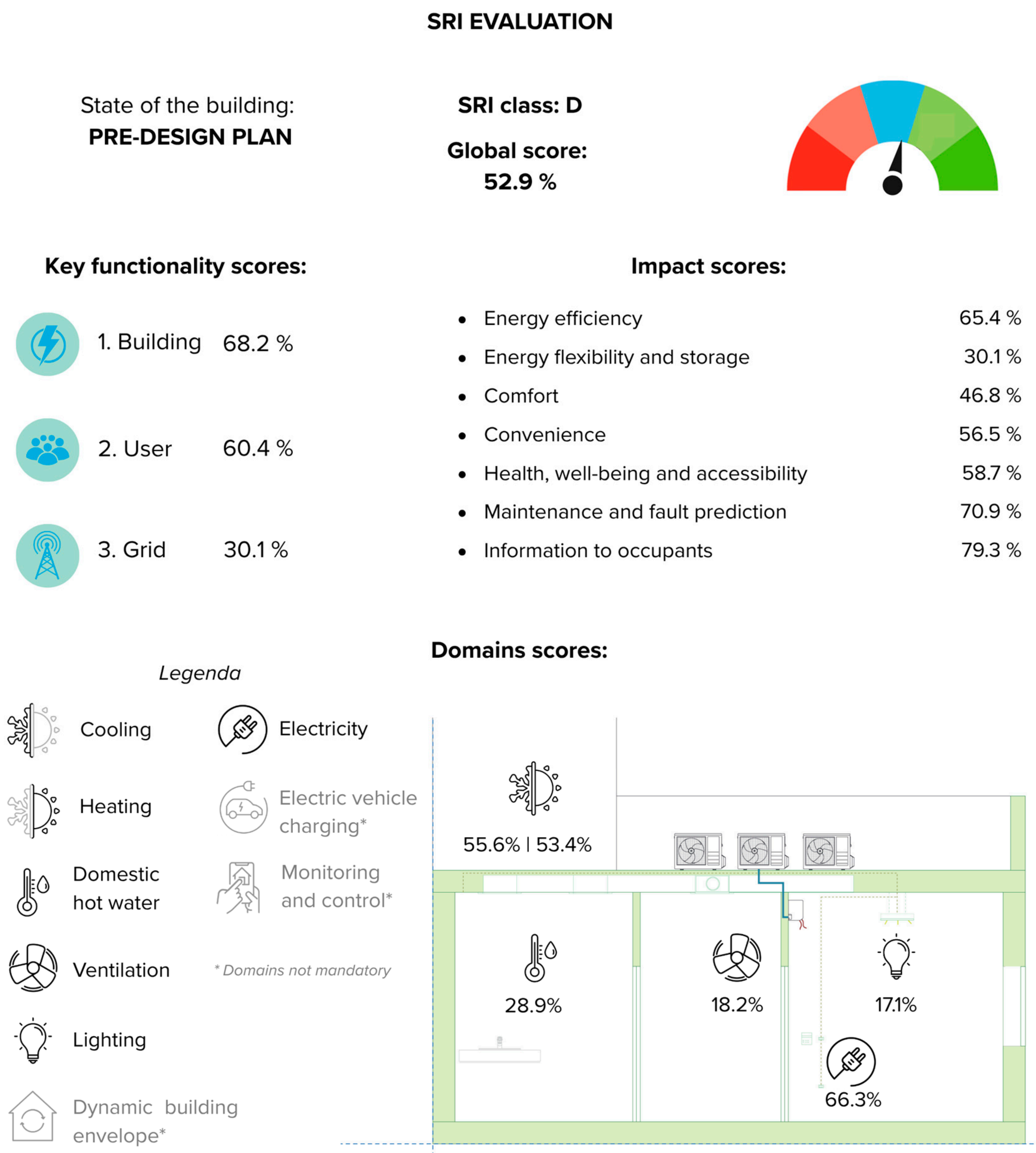

Figure 10. Report on SRI application with reference to the pre-design plan of the building. It shows the total and partial results by functionality, impact criterion, and domain.

The following graphs compare the scores obtained from the three SRI assessment scenarios (Figure 11).

Figure 11. Comparison of the three simulations scores: pre-renovated state, current state, and pre-design plan. Authors' elaboration.

4. Discussion and Conclusions

This study contributes to the progress of the national technical framework on the SRI in an effective way, adopting a BIM model at the pre-design plan stage.

The results demonstrate the usefulness of the indicator by highlighting the critical points related to the technical domains and determining the priorities for intervention.

The trials demonstrate that improvement intervention in one of the nine domains has positive effects on all three key functionalities of the indicator.

More specifically, the replacement of obsolete heating and cooling systems with high-efficiency systems that have intelligent control capabilities enables a switch from functionality level 0 to 3. This leads to an improvement in energy efficiency (key functionality 1), directly linked to the issue of decarbonization. Moreover, the high adaptability of the indicator leads to user satisfaction and improved well-being (key functionality 2). On the contrary, there is no benefit to key functionality 3, due to the lack of energy integration with smart grids, which is common in historic buildings.

The comparison of the results obtained in the three simulations demonstrate that the best SRI results are achieved when all three key functionalities exploit and employ sensor technology and system monitoring. The experimental application highlights the challenge of linking the SRI calculation to the BIM model.

Although direct and automated integration between Building Information Modeling (BIM) and the Smart Readiness Indicator (SRI) was not envisaged in this experimental application, a manual link was introduced, integrating the SRI Evaluation Sheets into the BIM model. This approach allowed the first step to be taken towards conceptual interoperability development, highlighting the potential for more structured integration between the two tools through dedicated interfaces (Figure 12).

This paper is part of the research project PRIN2022 BETTER POLICY, which deals with the potential semantic and informative integration between digital models (BIM) and energy evaluation processes while recognizing the lack of interoperability and standardization as critical issues [32,33].

This addresses the digitization path introduced by the Public Procurement Code (Decree of 31 March 2023 n. 36). Moreover, the introduction of the BIM methodology, as a mandatory tool, in all phases of the building lifecycle, from design to operation and maintenance, is linked to improved energy performance, as outlined by the GPP and the CAM [32] (Figure 13).

Although the experiment was conducted with a robust methodology, it is useful to point out certain limitations within this study:

- The experiment is currently based on a pilot which, although typologically and structurally representative of many historic buildings at the national and European levels, cannot be extended to other case studies.
- The specific characteristics of historic buildings, such as their original materials and architectural constraints, may limit the use of smart technologies.
- The regulatory constraints imposed for the protection of heritage (such as National Superintendencies) often limit the possibility of renovation interventions, further affecting the application of the SRI.
- The availability of data and simulations in the pre-design phase may affect the accuracy of the results.

Moreover, based on the results, it is possible to highlight some lines of future research to strengthen the application of the SRI:

- Promote awareness campaigns to overcome “digital poverty” and gaps, providing specific programs for the adoption of the SRI into the PA policies [16,23,26].

- Integrate national technical policies with respect to the CAM and the GPP with digital technologies and application of the SRI [10,16,22,26].
- Promote training programs for PA technical staff [25,26].
- Encourage pilot projects involving users for experimental applications of the SRI in public procurement, particularly for energy retrofit projects in the field of built heritage, with awards linked to the adoption of intelligent technologies and monitoring systems [23–25].
- Integrate systematic trials at the national level that bring together data, the SRI, and BIM models to promote greater interoperability of building performance data [29,33].
- Integrate, from the perspective of a digital twin approach, real-time data from sensors, smart meters, and other sources, providing a holistic view of a building's performance [10,26].

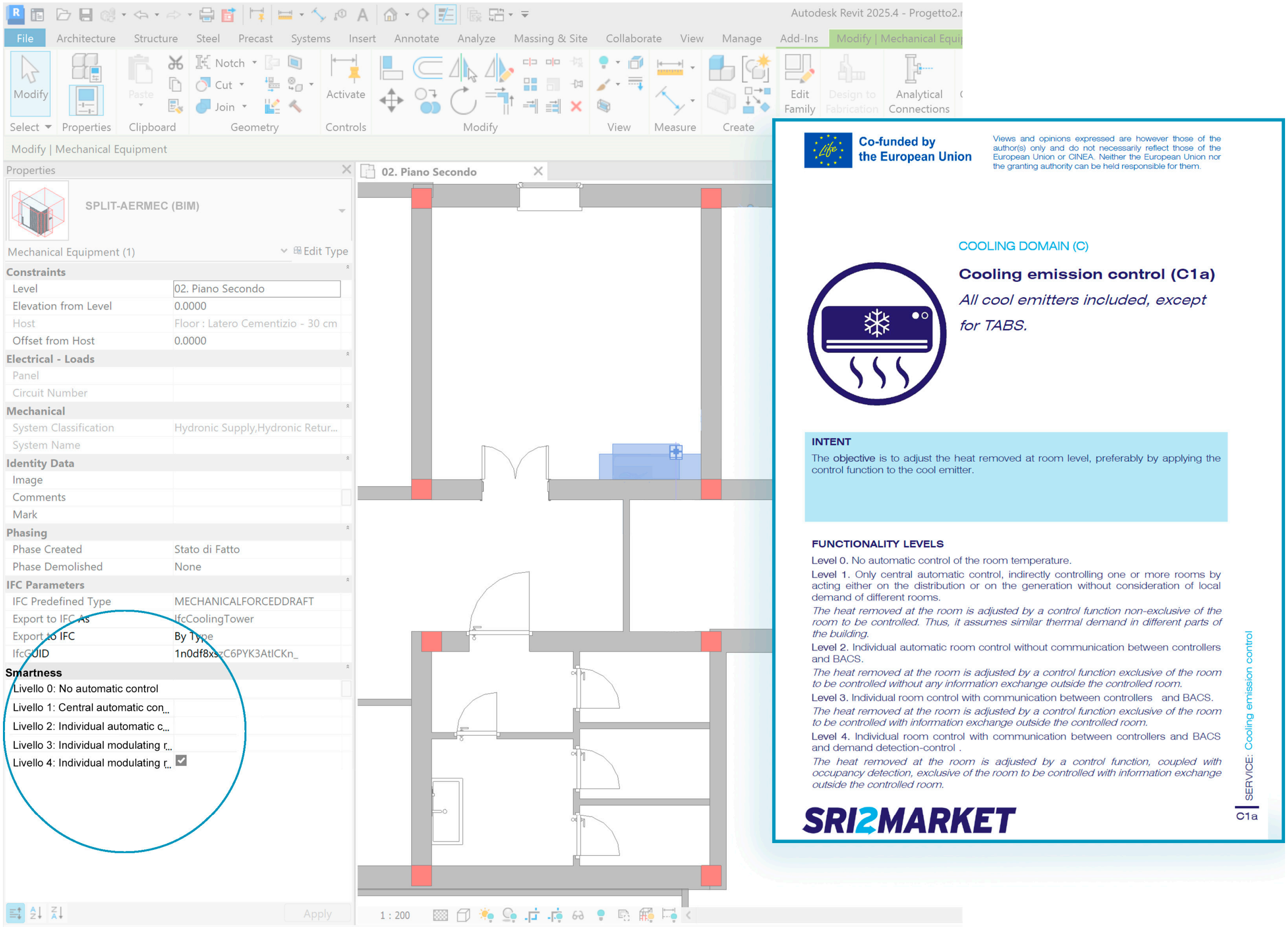

Figure 12. Proposal of visual integration of SRI in BIM (Autodesk Revit 2025.4). Authors' elaboration.

Figure 13. Relationships between SRI, digitalization, and environmental sustainability in the Code of Procurement and in the PAN GPP. Authors' elaboration.

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Abbreviations

The following abbreviations are used in this manuscript:

EPC	Energetic Performance Certificate
SRI	Smart Readiness Indicator
BIM	Building Information Modeling
PRIN	Progetti di Ricerca di Rilevante Interesse Nazionale
EU	European Union
KET	Key Enabling Technologies
EPBD	Energy Performance of Building Directive
nZEB	Nearly Zero-Energy Building
ZeMB	Zero-Emission Building
BRP	Building Renovation Passport
PA	Public Administration
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
L.	Legge
art.	Articolo
D.Lgs	Decreto legislativo
PAN-GPP	Piano d'Azione Nazionale—Green Public Procurement
MEC	Minimum Environmental Criteria
CAM	Criteri Ambientali Minimi
H	Heating
DHW	Domestic Hot Water
C	Cooling
L	Lighting
E	Electricity

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