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SMART² INFORMATION MODEL FOR SRI THROUGH EPC DATA V1

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Abstract	Deliverable 2.1 aims to facilitate the issuance of an SRI (Smart Readiness Indicator) assessment by integrating it with the Energy Performance Certificate (EPC) calculation process. This involves enhancing the consideration of smart readiness aspects within the EPC framework, using building digitization tools. The methodology involves documenting the overlapping and missing information between SRI and EPCs, and the definition of a parallel layer of information necessary for calculating both EPC and SRI simultaneously. This additional information will be described using Industry Foundation Classes (IFC) literacy of Building Information Modelling.
Keywords	SRI, EPC, IFC,

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CO	Confidential, only for members of the consortium (including the Commission Services)	☐
CL	Classified, information as referred to in Commission Decision 2015/444/EC	☐

EXECUTIVE SUMMARY

This deliverable presents a comprehensive exploration of the Energy Performance Certificates (EPCs) and Smart Readiness Indicators (SRIs) in the context of building energy performance assessment. It addresses the need for alignment and integration between these two critical tools and identifies opportunities for enhancing their utilization in the building community.

The document begins with an introduction that establishes the background and objectives of Task 2.1, emphasizing the importance of bridging the gap between EPCs and SRIs.

Section 2 delves into the challenges and requirements associated with EPCs and SRIs. It highlights the potential benefits of integrating these tools, such as facilitating wider adoption, improving calculation methods, and fostering active engagement with national testing committees. The section also discusses the importance of data collection, standardizing audit processes, and aligning training for EPC and SRI assessors.

Furthermore, Section 2.2 provides a detailed comparison of the required input data for EPCs and SRIs. It outlines the specific information needed for each assessment, emphasizing the areas of overlap and identifying missing information that could enhance their compatibility.

In Section 3, the document explores the utilization of Industry Foundation Classes (IFC) attributes for calculating SRIs. It identifies gaps in ISO 16739-1:2018 and proposes further development fields to improve the integration of IFC attributes into SRI calculations.

Section 4 introduces the concept of a parallel layer of information and outlines its content and architecture within the energy module. It also discusses the development of an Application Programming Interface (API) to extract required attributes from an IFC document for SRI calculations.

Finally, the document concludes by summarizing key findings and recommendations for aligning EPCs and SRIs, ultimately transforming them into effective decision-making tools for building energy efficiency assessments.

The comprehensive insights provided in this deliverable contribute to the ongoing efforts to bridge the gap between EPCs and SRIs, fostering a more holistic approach to building energy performance assessment and promoting sustainability in the built environment.

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LIST OF ACRONYMS AND ABBREVIATIONS

Term	Description
API	Application Programming Interface
BACS	Building Automation and Control Systems
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
MVC	Model View Controller
MVD	Model View Definition
REST	Representational State Transfer
SOAP	Simple Object Access Protocol
SRI	Smart Readiness Indicator
U value	Thermal transmittance

1. Introduction

1.1 Background and context of Task 2.1

In the quest for more energy-efficient buildings, the construction industry has undergone significant transformation, with the advent of smart technologies, digital tools, and new approaches to energy performance. Key to this transformation is the establishment of indicators and certificates to monitor and evaluate the readiness of a building for such advances. Among these, the Smart Readiness Indicator (SRI) has emerged as a crucial measure to assess the readiness of a building to integrate and use smart technologies for enhanced energy performance. The SRI assesses a building's capability to adapt its operation to the needs of the occupant, thereby improving its energy efficiency and overall functionality.

However, despite the potential advantages of the SRI, its implementation has encountered challenges, particularly concerning data collection and integration with existing Energy Performance Certificate (EPC) calculation procedures. This is primarily because the information required for the issuance of an SRI certificate largely overlaps with the data collected for the EPC. Given this situation, there exists an opportunity to integrate the two procedures, thus streamlining the process.

Task 2.1, aims to capitalise on this opportunity by linking the SRI and EPC calculation procedures. The task is scheduled to be carried out in two phases: M4-M12 and M34-M36. This initiative is geared towards supporting the implementation of the SRI by enhancing the consideration of smart readiness aspects in the EPC context. The task also seeks to leverage building digitisation tools to achieve this goal.

The methodology that Task 2.1 follows is rooted in the detailed documentation of overlapping and missing information between SRI and EPCs. The goal is to create a parallel layer of information that is required, in addition to the data provided for the calculation of the energy efficiency of buildings. This parallel layer aims to enable the simultaneous calculation of both the EPC and the SRI.

1.2 Objectives of the Task

The objectives of Task 2.1 are the following:

1. Document Overlapping and Missing Information between SRI and EPCs, as well as identify the missing information in EPCs required for the issuance of the SRI.
2. Employ Industry Foundation Classes (IFC) literacy of Building Information Modelling (BIM) to identify and describe a layer of required attributes for the calculation of SRI in a standardised digital format.
3. Propose a parallel layer of information that will complement the data already available for the calculation of building energy efficiency. This layer will facilitate the simultaneous calculation of both the EPC and the SRI.
4. Development of the architecture of the energy module of the Smart² platform.
5. Assess the ISO 16739-1:2018, identify gaps and propose further development fields to improve data sharing for the implementation of the SRI.
6. Provide a roadmap for the integration of the SRI into the EPC schema.

Task 2.1 is a crucial step towards optimising the implementation of the Smart Readiness Indicator in the building energy performance context. By documenting overlapping and missing information, creating a parallel layer of information, and leveraging digital tools, the task aims to facilitate the simultaneous calculation of both the EPC and the SRI. This approach is expected to streamline the process and contribute to the wider adoption of smart technologies in the construction industry.
With Deliverable 2.1 (M12 version), the overlapping and missing information between SRI and EPC is included. The Deliverable also discusses on the IFC and its correlation with the SRI. The deliverable also proposes the layer or information required to complement the available dta in EPC. M36 version will cover

topics related to the architecture of the API, the gaps of the ISO 16739 as well as on the roadmap for the integration of the SRI into the EPC.

2. The context of the Energy Performance Certificates and overlapping input with the SRI

2.1 EPC and SRI Needs and Challenges

The Energy Performance Certificate (EPC) is a document that provides information about the energy efficiency of a building or property. While the European Union (EU) has implemented various regulations and directives related to energy performance in buildings, the specific requirements and details of EPCs can vary from one EU member state to another. EPCs are typically required when a building is constructed, sold, or rented out. They are intended to help property owners and tenants understand the energy efficiency of a building, as well as its potential energy costs. EPCs provide a rating or score that indicates how energy-efficient the building is, often using a scale from A (most efficient) to G (least efficient).

Key information included in an EPC may consist of:

- Energy Efficiency Rating: This is the main feature of the EPC and is usually presented graphically, with a rating from A (most energy-efficient) to G (least energy-efficient).
- Recommendations: EPCs often provide recommendations for improving the energy efficiency of the building, such as installing insulation, upgrading heating systems, or using energy-efficient lighting. These recommendations can help property owners make informed decisions to reduce energy consumption and lower energy bills.
- Energy Consumption: EPCs typically include an estimate of the building's annual energy consumption in kilowatt-hours per square meter (kWh/m^2).
- CO2 Emissions: The certificate may also provide information on the estimated carbon dioxide (CO2) emissions associated with the building's energy use.
- Assumptions: EPCs may list certain assumptions made during the assessment, such as occupancy patterns and standard usage, to provide context for the energy efficiency rating.
- Validity: EPCs are typically valid for a set period, and they may need to be renewed or updated if significant changes are made to the building's energy systems.

The EU has aimed to improve the energy efficiency of buildings as part of its broader efforts to reduce greenhouse gas emissions and combat climate change. The specific requirements for EPCs, including how they are calculated and displayed, have been established through EU directives and regulations. However, individual member states have some flexibility in implementing these requirements, so there can be variations in the exact format and content of EPCs across different EU countries. It's important to consult the relevant national or local authorities to get detailed information on EPC requirements and regulations in a specific EU member state. The EPBD (Energy Performance of Buildings Directive) is a key piece of EU legislation aimed at improving the energy efficiency of buildings across European Union member states. It sets out various provisions and requirements related to Energy Performance Certificates (EPCs) as part of its efforts to promote energy efficiency. The key provisions related to EPCs under the EPBD are the following:

1. Mandatory EPCs: The EPBD typically requires member states to establish a system for the mandatory issuance of EPCs for buildings. These certificates must be made available to buyers or tenants when a building is sold or rented.

2. Energy Performance Rating: EPCs are required to include an energy performance rating or indicator for the building, often displayed on a scale from A (most energy-efficient) to G (least energy-efficient). This rating provides information about the building's energy efficiency.

3. Validity Period: The directive specifies the validity period for EPCs. Typically, EPCs are valid for a certain number of years (e.g., 10 years), after which they may need to be updated or renewed.

4. Recommendations for Improvements: EPCs are required to include recommendations for cost-effective measures to improve the energy performance of the building. These recommendations are intended to help building owners and occupants make informed decisions about energy efficiency upgrades.

5. Display of EPC Information: Member states are often required to establish systems for the public display of EPC information, such as in property listings or advertisements. This is aimed at raising awareness of the energy efficiency of buildings among potential buyers or tenants.

6. Inspections and Audits: The EPBD may include provisions related to inspections and audits of heating and cooling systems in buildings to ensure they are functioning efficiently. These inspections may be required at regular intervals.

7. Minimum Energy Performance Requirements: The directive may establish minimum energy performance requirements for new and existing buildings, with the goal of promoting the use of energy-efficient technologies and materials in construction and renovation.

8. Public Buildings: The EPBD often includes specific requirements for public buildings, such as government offices and educational institutions, to lead by example in terms of energy efficiency and EPC compliance.

9. Data Collection and Reporting: Member states may be required to collect and report data on building energy performance to the European Commission to monitor progress in improving energy efficiency.

Inevitably, EPCs and SRIs encounter many requirements and obstacles to becoming the primary instruments for assessing building energy efficiency and smartness. These primary requisites and challenges are detailed below:

2.1.1 Facilitating Wider Adoption of EPCs and SRIs

Despite being introduced in May 2018, the concept of SRI remains unfamiliar to most European citizens. Furthermore, EPC coverage has yet to attain the desired levels, even though EPC issuance has been mandatory for new buildings since the initial EPBD in 2002, primarily since more than 75% of European buildings were constructed before 1990. Achieving broader acceptance of EPCs and the SRI concept will hinge on creating awareness among stakeholders and the general public and launching initiatives that boost the visibility and trustworthiness of these assessment tools.

2.1.2 Exploring Integration Opportunities between EPCs and SRIs

There is no concrete evidence regarding integrating SRIs into EPC assessments, even though this integration is a crucial requirement of the EPBD recast. A critical need in this field is the development of simplified methods to jointly calculate the smartness assessment of buildings using data that aligns with EPC calculations. Additionally, establishing a unified visual identity for both instruments is crucial. Approaches to promote the adoption of technology bundles that combine energy efficiency enhancements with smart upgrades in building construction and renovation are still in their infancy. There is also a need to harmonise and present data from both instruments in a manner that best serves user requirements.

2.1.3 Enhanced Utilisation of Research-Developed Calculation Tools in the Building Community

Despite the substantial development of EPC and SRI tools through EU-funded research projects, leveraging the latest breakthroughs in asset and operational rating, as well as smartness assessment for buildings, these tools are underutilised once the projects conclude, often remaining dormant within research institutions and relevant stakeholders. A significant challenge lies in establishing a hub where the broader public can access the appropriate tools and services for EPCs and SRIs generated by research initiatives.

2.1.4 Active Engagement with the SRI Platform and National Testing Committees

The SRI platform, overseen by the Commission’s DG Energy, is pivotal in facilitating SRI testing and implementation, promoting the SRI and its associated best practices. It serves as a collaborative platform involving all stakeholders interested in the SRI, fostering forward-thinking discussions on technical, regulatory, and implementation aspects of the SRI. There is a pressing need to contribute to the SRI platform by identifying and nurturing synergies that can effectively drive SRI implementation, thereby catalysing the action of the Commission’s DG Energy in SRI implementation. Sharing experiences with Member States currently in the SRI implementation phase is also essential. [5]

2.1.5 Enhancing Data Collection, Aggregation, and Analysis for EPCs and SRIs in Anticipation of National Database Establishment

As stipulated in the forthcoming EPBD recast’s 19th Article, each Member State must establish a national database for building energy performance data. Consequently, developing tools and methods for efficient collection and post-processing of energy and smartness-related data from EPCs and SRIs is essential at national and regional levels. These efforts will also enrich the information in the EU Building Stock Observatory.

2.1.6 Standardising On-Site EPC and SRI Audit Processes

Despite clear indications in (EC) Regulation 2020/2156, Articles 3 and 5, regarding the necessity of an SRI certificate obtained through an audit, standardised processes for conducting such audits are currently absent. Furthermore, the final report on technical support for SRI development, particularly for the SRI expert method (Method B), addresses on-site SRI inspections. Therefore, enhancing synergies and connections between reviews and audits carried out for energy audits, EPCs, and SRIs to increase the cost-efficiency of these instruments is imperative.

2.1.7 Transforming EPCs and SRIs into Key Decision-Making Tools

Despite EPCs and SRIs potentially providing crucial information on operational building unit costs, real estate appraisal does not recognise them as pivotal decision-making tools. To bridge this gap, further advancements in EPCs and SRIs should incorporate real estate valuation, thus mitigating risks associated with financing energy efficiency projects and building renovations by merging lifecycle cost-oriented EPC and SRI recommendations.

2.1.8 Enhance and Align the Training of EPC and SRI Assessors

As outlined in the 22nd article of the EPBD, Member States are responsible for ensuring that the energy performance certification of buildings and smart readiness assessments are conducted independently by qualified and accredited experts. There is a pressing need to advance further and refine the creation of unified training and accreditation programs for auditors specialising in EPCs and SRIs. Notably, in the post-Covid era, remote learning and virtual training centers have become predominant, making it imperative to establish a virtual shared training hub for EPC and SRI assessors to uphold the requisite standards of assessment quality. [5]

2.2 SRI vs EPCs: Overlapping and missing information

Energy Performance Certificates (EPC) represent one of the core elements of the EU policy on the energy efficiency of buildings, as expressed by the Energy Performance of Buildings Directive (EPBD). EPCs mission is to present the building's energy performance transparently and to define cost-optimal improvements in the energy efficiency of building units. Regardless of how significant EPCs are for the valorisation of the energy performance of buildings, considerable deficits and gaps are revealed. As of 2022, the coverage of EPCs is still relatively low. In addition, EPCs are not viewed to be adequately advertised. Utilising various scales and formats hinders the comparability between different national schemes. EPC assessors are, in many cases, not trained under agreed, high-quality standards. Identifying these gaps, the EPBD recast, planned to be used by the initial stage of 2023, introduces additional provisions intending to regulate many of these issues. EPBD recast also aims to promote further different tools that have been recently developed and which aim to improve the energy, sustainability, and smartness performance of buildings. The 2018 recast 2018/844/EC introduced the Smart Readiness Indicator (SRI), an optional scheme for rating the smart readiness of buildings, targeting the promotion of smart building technologies. The SRI aims to enlighten property owners about the benefits of incorporating building automation and electronic monitoring into their technical systems. These advancements improve a building's resilience to climate change and contribute to energy efficiency, accessibility, and occupant well-being and comfort. Additionally, they provide tangible evidence of savings, boosting the confidence of those who reside or work in these enhanced spaces.

Significant advancements are unfolding in energy and intelligence appraisal of buildings.

- The emergence of the Smart Readiness Indicator (SRI) system, aimed at evaluating the intelligent features of building units, is ushering in fresh prospects in building energy assessment. However, viewing the SRI system in conjunction with the EPC is crucial, as they are meant to complement each other. Many building occupants have yet to grasp the essence of EPCs fully. Hence, a cautious approach is advisable in promoting and establishing SRIs. It's beneficial to heed the insights gained from the rollout and acceptance of the EPC framework within EU Member States to avoid repeating past errors and ensure a consistent calculation methodology between the SRI and EPC. There's an evident necessity for a unified offering of these two tools to the building users. Concurrently, there's a chance to amalgamate processes, datasets, and tools already associated with EPC issuance to streamline and expedite the SRI certification process. This collaborative strategy could be broadened to various sectors, like employing these tools for real estate valuation.
- Harmonizing the certification issuance process for both, through the adoption of analogous tools inspection protocols and engaging experts and auditors to evaluate both the energy and intelligence aspects of buildings, is feasible. Now, more than ever, enhancing educational programs and quality control measures across both certifications is crucial. Implementing joint schemes and procedures will not only solidify SRIs as robust and thorough tools for appraising building intelligence but will also bolster the prominence of EPCs to the anticipated level. [1][2]
- Examining EPCs alongside SRIs unveils numerous discrepancies and absent information that could hinder a thorough appraisal of a building's functionality. Their evaluation scopes differ significantly. EPCs are primarily directed towards understanding a building's energy dynamics, offering a glimpse into energy thriftiness and financially prudent enhancements. They are pivotal in accurately depicting a building's energy consumption patterns and potential zones for betterment.

Conversely, SRIs delve into the amalgamation of advanced tech solutions and building automation to ascertain a building's readiness for the modern era. The approaches adopted in these evaluations vary, mirroring how data is collected, scrutinised, and disseminated. This variance can pose challenges in juxtaposing and amalgamating the findings, affecting the broader understanding and standardisation of building functionality across different locales.[3]

- A critical issue is harmonising the education and certification requirements for assessors performing EPC and SRI assessments. Due to different training standards, the existing environment indicates a potential discrepancy in the validity and reliability of assessments. Lack of commitment to established, high-quality training requirements may frequently result in uneven evaluations and recommendations, especially for EPC assessors. This contradiction not only calls into question the validity of the assessments but also presents a problem for building owners looking for trustworthy advice on enhancing energy efficiency. The root of the problem is the variation in assessment quality caused by the lack of a standardised training and qualification structure for assessors. This mismatch consequently impacts the reliability and effectiveness of recommendations given to building owners. A comprehensive and precise building performance assessment is still challenging without a standardised approach to assessor training and qualification. The effects go beyond individual reviews, affecting the general goal of improving energy efficiency and intelligent preparedness throughout the building industry.[3]
- EPCs and SRIs use different scales and data formats to compare and aggregate data across various national schemes, which is a significant challenge. This discrepancy not only affects the creation of a uniform database or a platform necessary for monitoring and evaluating building performance across areas, but it also makes it difficult for stakeholders to understand the assessment's findings. Collecting practical insights from the assessments may be challenging if there is a lack of uniformity in data formats and scales for building owners, decision-makers, and other stakeholders. Understanding building performance measures may result from this variation in data format, which could also impact the decision-making process. A standardised approach in data structuring and scaling is essential to provide a comprehensive and consistent understanding of assessment results, which is crucial to moving closer to the larger energy efficiency goals.
- The EPBD recast indicates that EPCs and SRIs will be developed and utilised concurrently shortly to enhance energy efficiency and innovative building capabilities. Various aspects of the EPBD, which previously focused solely on EPCs, have now been expanded to encompass SRIs. For example, independent control systems are being revised to include SRIs alongside EPCs and a common approach is expected to be applied to both assessment instruments. Databases for tracking energy performance will consist of EPCs and SRIs. The directive's fifth annex requires EPCs to indicate whether a smart readiness assessment has been conducted for the building and provide the assessment's value. Considering that the SRI is a relatively new assessment scheme and EPC coverage in existing buildings has not reached the required levels, efforts are anticipated shortly to promote the concurrent adoption of both assessment tools and leverage their synergies.

2.2.1 Required Information for the Calculation of an EPC

An EPC indicates how well a building behaves in terms of its energy consumption in the following energy consumption categories: heating, cooling, ventilation, lighting, and domestic hot water. There are various methodologies employed to evaluate the energy performance of a building. One common approach is to assess based on the actual energy consumption, known as the operational rating, which is a practice seen in not more than 11 EU MS. Another prevalent method is to evaluate based on energy efficiency calculations, termed the asset rating, and this is observed in all EU MS.

When it comes to the calculation aspect, several factors and pieces of information are taken into consideration to ensure an accurate assessment. Initially, general information about the building and details regarding the assessor are collected. An in-depth analysis of the building envelope and geometry is conducted to understand the structure better. The assessment also examines the building services provided, significantly impacting energy performance. Moreover, the activity within different building zones is analyzed, and this data is often sourced from a dedicated database. Lastly, weather data, which is also typically retrieved from a database, is factored into the assessment as it plays a crucial role in determining the energy efficiency of the building. The following table (Table 1) illustrates the structure and detailed requirements for calculating an EPC in Cyprus. [4]

Table 1: *Structure and requirements for calculation of an EPC: Example from Cyprus*

Building Envelope	Building Geometry	Building Services
Vertical elements (U and Cm values) - walls - columns/beams	- zones - orientation	**Heating - Cooling system** - type - source of heat/fuel - efficiency
Horizontal elements (U and Cm values) - roof - floor - mezzanine - ceiling - exposed floors	**Building envelope data** - walls - columns/beams - roof, floor - exposed floors - mezzanine, ceiling - doors, glazing	**Domestic Hot Water** - Type - Source of heat/fuel - Storage capacity - efficiency **Lighting system** - technology - efficiency
Frames (U values, T-L solar) - doors - glazing	**Shading systems** - cantilever - movable shading	**Renewable energy sources** - technology - orientation - area

The calculation of an Energy Performance Certificate (EPC) using the asset method typically requires specific input data related to the building's construction, insulation, heating, cooling, ventilation systems, and other relevant features. The asset method is one of the approaches used to assess the energy performance of a building, and it focuses on the building's design and specifications rather than its actual energy consumption. Here are the required inputs for the asset-based calculation of an EPC:

1. Building Geometry and Envelope:

- Building envelope geometry
- Building orientation (e.g., north, south, east, west).
- Wall construction details, including insulation materials and thickness.
- Roof construction details, including insulation materials and thickness.
- Window and door specifications, including frame materials, glazing type, and U-values (thermal transmittance).

2. Heating and Cooling Systems:

- Type of heating system (e.g., gas boiler, electric heating).
- Heating system efficiency or performance parameters.
- Type of cooling system (if applicable).
- Cooling system efficiency or performance parameters.
- Ventilation system details, including heat recovery (if applicable).

3. Hot Water Systems:

- Type of hot water production (e.g., electric water heater, solar thermal).
- Hot water system efficiency or performance parameters.

4. Lighting:

- Type of lighting fixtures (e.g., incandescent, LED).
- Lighting control systems and efficiency measures (e.g., occupancy sensors, daylight sensors).

5. Renewable Energy Sources:

- Details of any renewable energy sources integrated into the building's design (e.g., solar panels, wind turbines).

6. Occupancy and Usage:

- Number of occupants or building users.
- Operating hours (for commercial buildings).
- Specific usage patterns or requirements (if applicable).

7. Climate Data:

- Local climate data, including temperature, humidity, and heating/cooling degree days, to account for the impact of external conditions on energy use. This data is typically based on historical weather information for the building's location.

The asset method uses this input data to create a model of the building's expected energy performance, taking into account factors like heat loss, heat gain, and energy demand. The calculated results are used to generate the Energy Performance Certificate, which provides information on the building's estimated energy efficiency.

2.2.2 Required Information for the Calculation of an SRI

The Smart Readiness Indicator (SRI) for buildings was a relatively new concept and regulation within the European Union (EU). The key aspects that typically influence the calculation of the SRI for a building:

1. Smart Systems and Technologies:

- Identification and assessment of the smart systems and technologies installed in the building, such as smart thermostats, lighting control systems, energy management systems, home automation devices, sensors, and building management systems.

2. Functionality and Integration:

- Evaluation of the functionality and integration capabilities of smart building automation and control systems (BACS). This may include assessing how these systems communicate with each other and with the building's infrastructure.

3. Climate Data:

- Climatic zone of the building for definition of weighting factors.

2.2.3 Overlap between SRI and EPC input

Table 2 highlights the differences between EPCs and SRIs regarding the parameters they assess in a building. While both EPC and SRI require general building and assessor information, their focus diverges from there. EPCs delve into the physical and operational aspects of a building, examining factors like the building envelope, geometry, services, zone activity, and weather data. These factors, along with information on the overall yearly primary energy consumption, the use of renewable energy sources, the consumption of conventional energy sources, and the carbon dioxide emissions indicator, are essential for comprehending a building’s energy performance. Using these indicators, EPCs offer a thorough Building Energy Rating that indicates a building’s energy effectiveness and environmental impact.

On the other hand, SRIs focus on a more technologically driven assessment, focusing on the smart readiness of a building. The triage process is employed to sift through and identify relevant smart-ready services within the building. The functioning levels of building systems are also defined in SRIs, essential for comprehending how technologically and architecturally sophisticated a building is. The smart-ready services assessment results are aggregated into an overall SRI score, which expresses how close the building is to maximum smart readiness.

Table 2 illustrates the gaps and overlaps between the SRI and the EPC assessment scheme.

Table 2: *Overlaps and gaps between information required for EPC and SRI assessment*

Information	EPC	SRI
Building Geometry and Envelope	Building envelope geometry Building orientation (e.g., north, south, east, west). Wall construction details, including insulation materials and thickness. Roof construction details, including insulation materials and thickness. Window and door specifications, including frame materials, glazing type, and U-values (thermal transmittance).	Not required
Heating and Cooling Systems	Type of heating system (e.g., gas boiler, electric heating). Heating system efficiency or performance parameters. Type of cooling system (if applicable). Cooling system efficiency or performance parameters. Ventilation system details, including heat recovery (if applicable).	Evaluation of the functionality and integration capabilities of the building automation and control technologies.
Hot Water Systems	Type of hot water production (e.g., electric water heater, solar thermal). Hot water system efficiency or performance parameters.	Evaluation of the functionality and integration capabilities of the building automation and control technologies.
Lighting	Type of lighting fixtures (e.g., incandescent, LED). Lighting control systems and efficiency measures (e.g., occupancy sensors, daylight sensors).	Evaluation of the functionality and integration capabilities of the building automation and control technologies.
Renewable Energy Sources	Details of any renewable energy sources integrated into the building's design and its contribution to buildings energy balance	Evaluation of the functionality and integration capabilities of the building automation and control technologies.
Occupancy and Usage	Number of occupants or building users. Operating hours (for commercial buildings). Specific usage patterns or requirements (if applicable).	Not required

Climate Data	Local climate data, including temperature, humidity, and heating/cooling degree days, to account for the impact of external conditions on energy use. This data is typically based on historical weather information for the building's location	Climatic zone of the building for definition of weighting factors (choice between 6 climatic regions)

From Table 2 it is obvious that while both the EPC and the SRI assessment require data on the building technical systems, the EPC focus on the efficiency of the systems, towards converting the required energy to delivered energy, while the SRI focuses merely on the BACS installed.

The content of the Standard EN 15232:2017 and its successor ISO 52120:2021 plays a crucial role in evaluating the impact of building automation and control systems on the energy efficiency of buildings. These standards provide valuable guidelines for assessing the energy performance of buildings by taking into account the functionality and integration of advanced building technologies. However, it is essential to recognize that the methodologies used for calculating Energy Performance Certificates (EPCs) for buildings have not fully adopted the principles and criteria outlined in these standards. This disparity results in a significant gap between the input data required for the calculation of EPCs and the Smart Readiness Indicators (SRIs). EN 15232 and ISO 52120 emphasize the importance of building automation and control systems in optimizing energy use, enhancing occupant comfort, and reducing environmental impact. They advocate for the assessment of various parameters related to building systems, including heating, cooling, lighting, and ventilation, all of which are integral to a building's energy efficiency. However, EPC methodologies, while effective in evaluating a building's overall energy performance, do not delve into the intricate details of these advanced control systems.

The primary focus of EPC calculations remains on aspects such as building geometry, insulation, heating and cooling systems, and renewable energy sources. These inputs are crucial for estimating a building's energy consumption based on its design and specifications. In contrast, SRIs are designed to evaluate a building's readiness to leverage smart technologies, including automation and control systems. The data required for SRIs encompass assessments of the functionality, integration, and potential benefits of these technologies, which are not fully integrated into EPC calculations.

Consequently, a substantial gap exists between the input data required for EPCs and SRIs. While EPCs provide valuable insights into a building's energy efficiency potential, they may not fully capture the benefits of advanced automation and control systems. As we move toward more sustainable and technologically advanced buildings, there is a growing need to bridge this gap. Integrating the principles outlined in EN 15232 and ISO 52120 into EPC methodologies would allow for a more comprehensive assessment of a building's energy performance, accounting for the increasingly vital role of building automation and control systems in achieving energy efficiency and sustainability goals. Closing this gap is essential for accurately reflecting the true potential of modern buildings to operate efficiently and adapt to evolving smart technologies.

3. Industry Foundation Classes (IFC) attributes for the calculation of SRI

3.1 Introduction

Building Information Modelling (BIM) is a design approach in the construction sector adopted in numerous countries in recent years. The Industry Foundation Classes (IFCs), endorsed by the ISO and established as an international standard ISO 16739, are often associated with building information modelling. IFC is an open BIM standard, encompassing details like geometry, material, and cost. This standard utilizes an object-based file format and a data model to enhance interoperability within architecture, engineering, and construction and is a prevalent choice in projects employing BIM.

The IFC governs BIM data exchange and sharing between software programs used by the many construction or facility management industrial sector actors. It contains definitions that address the information needed for structures throughout their lifespan. The scope is expanded with this and forthcoming releases to provide data definitions for infrastructure assets across their life cycles.

IFC literacy entails a comprehensive understanding of BIM's schema, naming conventions, data structure, and data exchange principles. The IFC standard is maintained by buildingSMART International, which provides the necessary framework and guidelines for implementing IFC in BIM software applications. The existing IFC workflow presents challenges when facilitating smooth data exchange; it doesn't permit a modelling process initiated in one software environment to be seamlessly continued in another following an IFC export. A depiction of a typical IFC workflow is provided in Figure 1. [7]

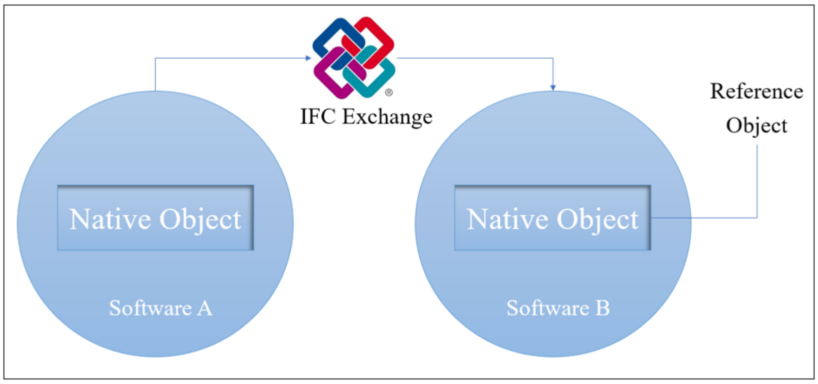

***Figure 1**: IFC workflow*

The schema specification can specify the design, construction, and operation of a facility or installation. Buildings, manufactured goods, mechanical and electrical systems, more abstract structure analysis models, energy analysis models, cost breakdowns, work plans, and many other things can all have physical components defined using IFC.

IFC schema is a standardised data model that codifies logically:

- the identity and semantics (name, machine-readable unique identifier, object type or function)
- the characteristics or attributes (such as material, colour, and thermal properties),
- relationships (including locations, connections, and ownership),
- objects (like columns or slabs),
- abstract concepts (performance, costing),
- processes (installation, operations), and

- people (owners, designers, contractors, suppliers, etc.).

The Industry Foundation Classes describe an exchange file format structure and a data schema. The data structure is specified in:

- EXPRESS data specification language, defined in ISO 10303-11,
- XML Schema definition language (XSD), defined in XML Schema W3C Recommendation.

The XML schema is created from the EXPRESS schema while maintaining the mapping standards outlined in ISO 10303-28.

A Model View Definition (MVD) is a subset of the referenced data and the data structure. In the construction and facility management industrial sector, a specific MVD is defined to serve one or more established workflows. Each workflow specifies the need for data exchange between software programs. Software programs that conform must identify the model view definition to which they adhere. [8]

Nonetheless, there are shortcomings in the existing standard. For example, while CODview2 aids in disseminating geometric characteristics, it doesn't cater to the geometric depiction of architectural elements. It also offers an opportunity for improvement, paving the way for intricate geometric portrayals of building components. Moreover, the ISO standard tends to focus on the data interchange format, overlooking directives for data handling. In subsequent versions, rectifying these shortcomings might result in a more robust and versatile ISO 16739-1 standard.

Understanding the schema is fundamental in BIM as the IFC schema serves as the core of data representation, delineating the arrangement and relationships of various elements and attributes. This schema encompasses data models articulated through an EXPRESS or XML Schema specification. Regarding naming conventions, IFC employs a particular system to maintain uniformity and clarity in representing data. For example, the names for types, entities, rules, and functions commence with the prefix "Ifc", followed by English words adhering to the CamelCase naming convention, such as IfcWall or IfcDoor. Delving into the data structure, IFC is structured into four conceptual layers, each allocated to a distinct schema, promoting a modular and scalable methodology for managing data. Grasping this data structure is pivotal for precisely identifying and describing attributes in BIM.

The utility of BIM transcends the design and construction stages of a project, extending into post-construction phases for building lifecycle management, playing a crucial role in smart buildings. These advanced buildings are often outfitted with sensors to oversee and manage structures in real-time through intelligent, networked processes. The venture into delineating monitoring-related information using IFC within a BIM framework is relatively nascent, with a scant number of studies exploring the interrelation of physical objects, schedules, and quality management information concerning inspection and real-time monitoring processes. [7][8]

3.2 Identification and proposal of gaps and further development fields of ISO 16739-1:2018

This task aims to structure an approach towards identifying potential gaps and proposing further development fields for ISO 16739-1:2018, especially in enhancing data sharing for SRI implementation. The tables created as part of this document clearly overview the current framework by outlining factors, including the name and description of the indicator, calculation method, and required status. It is noted that all attribute values are integers.

This organized explanation provides a foundation for identifying the parts of the standard that need to be improved and expanded to increase data exchange considerably. The potential to support the efficient implementation of the SRI is highlighted by addressing these identified gaps and considering the suggested areas for further development.

Table 3 summarises all the available IFC entities with the relevant IFC schema for the SRI implementation. [7]

Table 3: *Summary table of available IFC entities and relevant IFC schema*

IFC entity	IFC schema
IfcDistributionElement	5.4.3.8
IfcSpatialZone	5.4.3.60
IfcShadingDevice	6.1.3.36
IfcWindow	6.1.3.50
IfcFlowController	6.2.3.12
IfcActuator	7.2.3.1
IfcController	7.2.3.5
IfcSensorType	7.2.3.9
IfcUnitaryControlElement	7.2.3.11
IfcElectricFlowStorageDevice	7.4.3.17
IfcElectricGenerator	7.4.3.19
IfcElectricMotor	7.4.3.21
IfcElectricTimeControl	7.4.3.23
IfcSolarDevice	7.4.3.39
IfcSwitchingDevice	7.4.3.41
IfcUnitaryEquipmentType	7.5.2.31
IfcAirToAirHeatRecovery	7.5.3.5
IfcFanType	7.5.3.38
IfcPump	7.5.3.53
IfcPumpType	7.5.3.54
IfcUnitaryEquipment	7.5.3.61
IfcUnitaryEquipmentType	7.5.3.62
IfcValve	7.5.3.63

In the following table the existing IFC schemas for the different functionality levels of the SRI are defined.

Table 4: *Heating system*

Indicator name	Description of indicator	Functionality level	IFC schema
Heating-1a	Heat Emission Control	**Level 0** No automatic control	6.2.3.12 7.4.3.41
		Level 1 Central automatic control (e.g. central thermostat)	7.2.3.11
		Level 2 Individual room control (e.g. thermostatic valves or electronic controller)	7.2.3.1
		Level 3 Individual room control with communication between controllers and BACS	6.2.3.12 7.2.3.5
		Level 4 Individual room control with communication and occupancy detection	7.2.3.9
Heating- 1b		**Level 0** No automatic control	6.2.3.12

	Emission control for TABS (heating mode)		7.4.3.41
		Level 1 Central automatic control	7.2.3.11
		Level 2 Advanced central automatic control	7.2.3.9
		Level 3 Advanced central automatic control with intermittent operation and/or room temperature feedback control	7.5.3.63
Heating-1c	Control of distribution fluid temperature (supply or return air flow or water flow)-Similar function can be applied to the control of direct electric heating networks	**Level 0** No automatic control	7.5.3.61
		Level 1 Outside temperature compensated control	7.2.3.9
		Level 2 Demand-based control	6.2.3.12
Heating-1d	Control of distribution pumps in networks	**Level 0** No automatic control	7.5.3.54
		Level 1 On off control	7.2.3.9
		Level 2 Multi-Stage control	-
		Level 3 Variable speed pump control (pump unit (internal) estimations)	-
		Level 4 Variable speed pump control (external demand signal)	-
Heating-1f	Thermal Energy Storage (TES) for building heating (excluding TABS)	**Level 0** Continuous storage operation	-
		Level 1 Time-scheduled storage operation	-
		Level 2 Load prediction-based storage operation	-
		Level 3 Heat storage capable of flexible control through grid signals (e.g. DSM).	-
Heating-2a	Heat generator control (all except heat pumps)	**Level 0** Constant temperature control	7.2.3.9
		Level 1 Variable temperature control depending on outdoor temperature	-
		Level 2 Variable temperature control depending on the load (e.g. depending on supply water temperature set point)	-
Heating-2b	Heat generator control (for heat pumps)	**Level 0** On/Off-control of heat generator	7.5.3.62
		Level 1 Multi-stage control of heat generator capacity depending on the load or demand (e.g. on/off of several compressors)	-
		Level 2 Variable control of heat generator capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	-
		Level 3 Variable control of heat generator capacity depending on the load AND external signals from grid	6.2.3.12

Heating-2d	Sequencing in case of different heat generators	**Level 0** Priorities only based on running time	-
		Level 1 Control according to fixed priority list: e.g. based on rated energy efficiency	-
		Level 2 Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat, cogeneration plant, fossil fuels)	-
		Level 3 Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions and capacity of generators)	-
		Level 4 Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)	-
Heating-2d	Sequencing in case of different heat generators	**Level 0** Priorities only based on running time	-
		Level 1 Control according to fixed priority list: e.g. based on rated energy efficiency	-
		Level 2 Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat, cogeneration plant, fossil fuels)	-
		Level 3 Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions and capacity of generators)	-
		Level 4 Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)	-
Heating-3	Report information regarding Heating system performance	**Level 0** None	-
		Level 1 Central or remote reporting of current performance KPIs (e.g. temperature, submetering energy usage)	-
		Level 2 Central or remote reporting of current performance KPIs and historical data	-

		Level 3 Central or remote reporting of performance evaluation including forecasting and/or benchmarking	-
		Level 4 Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	-
Heating-4	Flexibility and grid interaction	**Level 0** No automatic control **Level 1** Scheduled operation of heating system	-
		Level 2 Self-learning optimal control of heating system	-
		Level 3 Heating system capable of flexible control through grid signals (e.g. DSM)	-
		Level 4 Optimised control of heating system based on local predictions and grid	-

Table 5: *Cooling system*

Indicator name	Description of indicator	Functionality level	IFC schema
Cooling-1a	Cooling Emission Control	**Level 0** No automatic control	6.2.3.12
		Level 1 Central automatic control	7.2.3.11
		Level 2 Individual room control	7.2.3.1
		Level 3 Individual room control with communication between controllers and to BACS	7.2.3.5
		Level 4 Individual room control with communication and occupancy detection	7.2.3.9
Cooling – 1b	Emission control for TABS (cooling mode)	**Level 0** No automatic control	6.2.3.12
		Level 1 Central automatic control	7.2.3.11
		Level 2 Advanced central automatic control	7.2.3.9
		Level 3 Advanced central automatic control with intermittent operation and/or room temperature feedback control	7.2.3.11 7.5.3.63
Cooling-1c	Control of distribution network chilled water temperature (supply or return)	**Level 0** Constant temperature control	5.4.3.8
		Level 1 Outside temperature compensated control	7.2.3.9
		Level 2 Demand based control	7.2.3.11
Cooling-1d	Control of distribution pumps in networks	**Level 0** No automatic control	7.5.3.53
		Level 1 on/off control	7.2.3.9
		Level 2 Multi-Stage control	7.5.3.53
		Level 3 Variable speed pump control (pump unit (internal) estimations)	7.5.3.53

		Level 4 Variable speed pump control (external demand signal)	7.5.3.53
Cooling-1f	Interlock: avoiding simultaneous heating and cooling in the same room	**Level 0** No interlock |	-
		Level 1 Partial interlock (minimising risk of simultaneous heating and cooling e.g. by sliding setpoints)	-
		Level 2 Total interlock (control system ensures no simultaneous heating and cooling can take place)	-
Cooling-1g	Control of Thermal Energy Storage (TES) operation	**Level 0** Continuous storage operation	-
		Level 1 Time-scheduled storage operation	-
		Level 2 Load prediction-based storage operation	-
		Level 3 Cold storage capable of flexible control through grid signals (e.g. DSM)	-
Cooling-2a	Generator control for cooling	**Level 0** On/off-control of cooling production	7.5.3.61
		Level 1 Multi-stage control of cooling production capacity depending on the load or demand (e.g. on/off of several compressors)	7.2.3.9
		Level 2 Variable control of cooling production capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	7.2.3.5
		Level 3 Variable control of cooling production capacity depending on the load AND external signals from grid.	-
Cooling-2b	Sequencing of different cooling generators	**Level 0** Priorities only based on running times	-
		Level 1 Fixed sequencing based on loads only: e.g. depending on the generator's characteristics such as absorption chiller vs. centrifugal chiller	-
		Level 2 Dynamic priorities based on generator efficiency and characteristics (e.g. availability of free cooling)	-
		Level 3 Load prediction-based sequencing: the sequence is based on e.g. COP and available power of a device and the predicted required power	-
		Level 4 Sequencing based on dynamic priority list, including external signals from grid.	-
Cooling-3		**Level 0** None	-

	Report information regarding cooling system performance	**Level 1** Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)	-
		Level 2 Central or remote reporting of current performance KPIs and historical data |	-
		Level 3 Central or remote reporting of performance evaluation including forecasting and/or benchmarking |	-
		Level 4 Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection.	-
Cooling-4	Flexibility and grid interaction	**Level 0** No automatic control	-
		Level 1 Scheduled operation of cooling system	-
		Level 2 Self-learning optimal control of cooling system	-
		Level 3 Cooling system capable of flexible control through grid signals (e.g. DSM)	-
		Level 4 Optimised control of cooling system based on local predictions and grid signals (e.g. through model predictive control)	-

***Table 6**: Ventilation*

Indicator name	Description of indicator	Functionality level	IFC schema
Ventilation-1a	Supply air flow at the room level	**Level 0** No ventilation system or manual control	-
		Level 1 Clock control	-
		Level 2 Occupancy detection control	7.2.3.9
		Level 3 Central Demand Control based on air quality sensors (CO2, VOC, humidity…)	7.2.3.5
		Level 4 Local Demand Control based on air quality sensors (CO2, VOC) with local flow from/to the zone regulated by dampers	7.2.3.5
Ventilation-1c	Air flow or pressure control at the air handler level	**Level 0** No automatic control: continuously supplies of air flow for a maximum load of all rooms	7.5.2.31

		Level 1 On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time	7.2.3.9
		Level 2 Multi-stage control: to reduce the auxiliary energy demand of the fan	7.5.3.38
		Level 3 Automatic flow or pressure control without pressure reset: load dependent supplies of air flow for the demand of all connected rooms	7.5.2.31
		Level 4 Automatic flow or pressure control with pressure reset: load dependent supplies of air flow for the demand of all connected rooms (for variable air volume systems with VFD)	7.2.3.9 7.2.3.5
Ventilation-2c	Heat recovery control: prevention of overheating	**Level 0** Without overheating control	7.5.3.5
		Level 1 Modulate or bypass heat recovery based on sensors in air exhaust	7.2.3.9
		Level 2 Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control	7.2.3.1 7.2.3.5
Ventilation-2d	Supply air temperature control at the air handling unit level	**Level 0** No automatic control	7.5.2.31
		Level 1 Constant setpoint: a control loop enables to control the supply air temperature, the setpoint is constant and can only be modified by a manual action	7.2.3.9
		Level 2 Variable setpoint with outdoor temperature compensation	7.2.3.9
		Level 3 Variable setpoint with load-dependent compensation. A control loop enables the control of the supply air temperature. The setpoint is defined as a function of the loads in the room.	7.2.3.5
Ventilation-3	Free cooling with a mechanical ventilation system	**Level 0** No automatic control	7.5.2.31
		Level 1 Night cooling	7.2.3.9
		Level 2 Free cooling: air flows modulated during all periods of time to minimise the amount of mechanical cooling	-
		Level 3 H,x – directed control: the amount of outside air and recirculation air are modulated during all periods of time to minimise the amount of mechanical cooling. Calculation is	7.2.3.9

		performed on the basis of temperature and humidity.	
Ventilation-6	Reporting information regarding IAQ	**Level 0** None	-
		Level 1 Air quality sensors (e.g. CO2) and real time autonomous monitoring	-
		Level 2 Real time monitoring & historical information of IAQ available to occupants	-
		Level 3 Real time monitoring & historical information of IAQ available to occupants + warning on maintenance needs or occupant actions (e.g. window opening)	-

***Table 7**: Lighting*

Indicator name	Description of indicator	Functionality level	IFC schema
Lighting 1a	Occupancy control for indoor lighting	**Level 0** Manual on/off switch	7.4.3.41
		Level 1 Manual on/off switch + additional sweeping extinction signal	7.4.3.23
		Level 2 Automatic detection (auto on / dimmed or auto off)	7.2.3.9
		Level 3 Automatic detection (manual on / dimmed or auto off)	7.2.3.9
Lighting 2	Control artificial lighting power based on daylight levels	**Level 0** Manual (central)	5.4.3.60
		Level 1 Manual (per room/zone)	7.4.3.41
		Level 2 Automatic switching	7.2.3.9
		Level 3 Automatic dimming	7.2.3.9
		Level 4 Scene-based light control (during time intervals, dynamic and adapted lighting scenes are set, for example, in terms of illuminance level, different correlated colour temperature (CCT) and the possibility to change the light distribution within the space according to e.g., design, human needs, visual tasks)	7.2.3.5

***Table 8**: Domestic Hot Water*

Indicator name	Description of indicator	Functionality level	IFC schema
DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	**Level 0** Automatic control on/off	7.2.3.11
		Level 1 Automatic control on/off and scheduled charging enable	7.4.3.23
		Level 2 Automatic control on/off and scheduled charging	-

		enable and multi-sensor storage management	
		Level 3 Automatic charging control based on local availability of renewables or information from electricity grid (DR, DSM).	7.4.3.39 7.2.3.5
DHW-1b	Control of DHW storage charging (using hot water generation)	**Level 0** Automatic control on/off	7.2.3.11
		Level 1 Automatic control on/off and scheduled charging enable	7.4.3.23
		Level 2 Automatic on/off control, scheduled charging enables and demand-based supply temperature control or multi-sensor storage management	-
		Level 3 DHW production system capable of automatic charging control based on external signals (e.g. from district heating grid)	7.2.3.9 7.2.3.5
DHW-1d	Control of DHW storage charging (with solar collector and supplementary heat generation)	**Level 0** Manual selected control of solar energy or heat generation	7.4.3.41
		Level 1 Automatic control of solar storage charge (Prio.1) and supplementary storage charge	7.2.3.9
		Level 2 Automatic control of solar storage charge (Prio. 1) and supplementary storage charge and demand-oriented supply or multi-sensor storage management	7.5.3.63
		Level 3 Automatic control of solar storage charge (Prio.1) and supplementary storage charge, demand-oriented supply and return temperature control and multi-sensor storage management	7.2.3.5
DHW-2b	Sequencing in case of different DHW generators	**Level 0** Priorities only based on running time	-
		Level 1 Control according to fixed priority list: e.g. based on rated energy efficiency	-
		Level 2 Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat, cogeneration plant, fossil fuels)	-
		Level 3 Control according to dynamic priority list (based on current AND predicted load,	-

		energy efficiency, carbon emissions and capacity of generators)	
		Level 4 Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)	-
DHW-3	Report information regarding domestic hot water performance	**Level 0** None	-
		Level 1 Indication of actual values (e.g., temperatures, submetering energy usage)	-
		Level 2 Actual values and historical data	-
		Level 3 Performance evaluation including forecasting and/or benchmarking	-
		Level 4 Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	-

***Table 9**: Electricity*

Indicator name	Description of indicator	Functionality level	IFC schema
Electricity-2	Reporting information regarding local electricity generation	**Level 0** None	-
		Level 1 Current generation data available	-
		Level 2 Actual values and historical data	-
		Level 3 Performance evaluation including forecasting and/or benchmarking	-
		Level 4 Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	-
Electricity-3	Storage of locally generated energy	**Level 0** None	-
		Level 1 Limited: small scale storage (batteries, TES)	7.4.3.17
		Level 2 Storage which can supply self-consumption for > 3 hours	7.4.3.17
		Level 3 Dynamically operated storage which can also feed back into the grid	-
Electricity-4	Optimising self-consumption of locally generated energy	**Level 0** None	-
		Level 1 Short term optimisation	-
		Level 2 Long term optimisation including predicted generation and/or demand	-
Electricity-5	Control of combined heat and power plant (CHP)	**Level 0** CHP control based on scheduled runtime management and/or current heat energy demand	7.43.19

		Level 1 CHP runtime control influenced by the fluctuating availability of RES; overproduction will be fed into the grid	7.4.3.39
		Level 2 CHP runtime control influenced by the fluctuating availability of RES and grid signals; dynamic charging and runtime control to optimise self-consumption of renewables	-
Electricity-8	Support of microgrid operation modes	**Level 0** None	-
		Level 1 Local battery usage	7.4.3.17
		Level 2 Autonomous energy consumption control	-
Electricty-11	Reporting information regarding energy storage	**Level 0** None	-
		Level 1 Current state of charge (SOC) data available	-
		Level 2 Actual values and historical data	-
		Level 3 Performance evaluation including forecasting and/or benchmarking	-
		Level 4 Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection	-
Electricity-12	Reporting information regarding electricity consumption	**Level 0** None	-
		Level 1 reporting on current electricity consumption on building level	-
		Level 2 real-time feedback or benchmarking on building level	-
		Level 3 real-time feedback or benchmarking on appliance level	-
		Level 4 real-time feedback or benchmarking on appliance level with automated personalised recommendations	-

Table 10: *Dynamic Envelope*

Indicator name	Description of indicator	Functionality level	IFC schema
DE-1	Window solar shading control	**Level 0** No sun shading or only manual operation	-
		Level 1 Motorized operation with manual control	6.1.3.36
		Level 2 Motorized operation with automatic control based on sensor data	7.4.3.21

		Level 3 Combined light/blind/HVAC control	7.2.3.9
		Level 4 Predictive blind control (e.g., based on weather forecast)	7.2.3.5
DE-2	Window open/closed control, combined with HVAC system	**Level 0** Manual operation or only fixed windows	6.1.3.50
		Level 1 Open/closed detec-tion to shut down heating or cooling systems	7.2.3.9
		Level 2 Automized mechanical window openingbased on room sensor data	7.2.3.1
		Level 3 Centralized coordina-tion of operable windows, e.g., to control freenatural night cooling	7.2.3.5
DE-4	Reporting information Regarding performance	**Level 0** No reporting	-
		Level 1 Position of each prod-uct & fault detection	-
		Level 2 Position of each prod-uct, fault detection & predictive maintenance	-
		Level 3 Position of each prod-uct, fault detection, predictive maintenance, real- time sensor data (wind, lux, temperature	-
		Level 4 Position of each prod-uct, fault detection, predictive maintenance, real- time & his-torical sensor data (wind, lux, temperature)	-

Table 11: *EV charging*

Indicator name	Description of indicator	Functionality level	IFC schema
EV-15	EV Charging Capacity	**Level 0** Not present	-
		Level 1 Ducting (or simple power plug) available	-
		Level 2 0-9% of parking spaces have recharging points	-
		Level 3 10-50% of parking spaces have recharging points	-
		Level 4 >50% of parking spaces have recharging points	-
EV-16	EV Charging Grid Balancing	**Level 0** Not present (uncontrolledcharging)	-
		Level 1 1-way controlled charging (e.g., including de-sired departure time and grid signals for optimization)	-
		Level 2 2-way controlled charg-ing (e.g., including desired de-parture time and gridsignals for optimization)	-

EV-17	EV Charging Information and connectivity	**Level 0** No information available	-
		Level 1 Reporting information on EV charging status to occupant	-
		Level 2 Reporting information on EV charging status to occupant AND automatic identification and authorization of the driver to the charging station (ISO 15118 compliant)	-

There is a lack of support or limited functionality, which could be addressed for further development to improve data sharing for implementing the Smart Readiness Indicator. The following table (Table 12) summarizes the missing indicator functionality level relevant to the IFC schema. [7]

Table 12: *Summary table of missing indicator functionality level relevant to IFC schema*

Name of the Indicator	Functionality level
HE-1d: Control of distribution pumps in networks	Level 2-4
HE-1f: Thermal Energy Storage (TES) for building heating (excluding TABS)	Level 0-3
HE-2a: Heat generator control (all except heat pumps)	Level 1,2
HE-2b: Heat generator control (for heat pumps)	Level 1,2
HE-2d: Sequencing in case of different heat generators	Level 0-4
HE-3: Report information regarding heating system performance	Level 0-4
HE-4: Flexibility and grid interaction	Level 0-4
CO-1f: Interlock: avoiding simultaneous heating and cooling in the same room	Level 0-2
CO-1g: Control of Thermal Energy Storage (TES) operation	Level 0-3
CO-2a: Generator control for cooling	Level 3
CO-2b: Sequencing of different cooling generators	Level 0-4
CO-3: Report information regarding cooling system performance	Level 0-4
CO-4: Flexibility and grid interaction	Level 0-4
VE-1a: Supply airflow at the room level	Level 0,1
VE-3: Free cooling with a mechanical ventilation system	Level 2
V3-6: Reporting information regarding IAQ	Level 0-3
DHW-1A: Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	Level 2
DHW-1b: Control of DHW storage charging (using hot water generation)	Level 2
DHW-2b: Sequencing in case of different DHW generators	Level 0-4
DHW-3: Report information regarding domestic hot water performance	Level 0-4
E-2: Reporting information regarding local electricity generation	Level 0-4
E-3: Storage of locally generated energy	Level 0,3
E-4: Optimising self-consumption of locally generated energy	Level 0-2
E-5: Control of combined heat and power plant (CHP)	Level 2
E-8: Support of microgrid operation modes	Level 0,2
E-11: Reporting information regarding energy storage	Level 0-4
E-12: Reporting information regarding electricity consumption	Level 0-4
DE-1: Window solar shading control	Level 0
DE-4: Reporting information regarding performance	Level 0-4

EV-15: EV Charging Capacity	Level 0-4
EV-16: EV Charging Grid Balancing	Level 0-2
EV-17: EV Charging Information and connectivity	Level 0-2

4. Architecture principles for the Smart² energy component

4.1 Definition of a parallel layer of information

This task aims to create a parallel layer of information that will complement the already available data for calculating building energy efficiency. This layer will facilitate the simultaneous calculation of the EPC and the SRI. The idea is to utilize building digitisation tools to create a parallel layer of information. Specifically, it will use the IFC literacy of BIM to identify and describe a layer of attributes in a standardised digital format.

As stated by ISO 52003-1:2017, the evaluation of energy efficiency encompasses a broad spectrum of facets within a structure, extending from an overarching assessment of the entire building (inclusive of all its technical configurations) to examinations of its individual technical subsystems, the structural fabric (either in entirety or partially), down to singular components. When the assessment is directed at the entire building, it's termed a comprehensive energy efficiency evaluation. In contrast, when the focus is on any more minor aspect, it's referred to as a segmented energy efficiency evaluation. [10]

According to the methodology described, IFC is adept at delineating and transmitting a building's physical geometry, including energy attributes, construction materials, and properties. It encounters interoperability hurdles during bidirectional data movement. These hurdles emerge as specific software tools can import or export IFC files, with only a handful being proficient in both, as per the official IFC certification table. [11][12][13]

The formal IFC evaluation procedure unfolds in two stages. Initially, a spectrum of object-level models like walls, beams, slabs, and columns is encompassed. Based on the building's complexity and model count, the software cherry-picks the most prevalent models for the certification examination. Subsequently, numerous project models amalgamated from the primary stage's objects are employed for additional certification. If the IFC-formatted entities exchanged are highly complex, software tools might fail to ensure a lossless data exchange, even if they possess an IFC certificate. The certification is more a gauge of information exchange capability via IFCs than the quality of the exchange.[12][13]

The frequency of BIM interoperability issues via the IFC schema is rising with the broadening use of diverse BIM software tools, especially during complex building transfers. Despite the emerging discrepancies, IFC-based data exchange across varied BIM platforms remains viable. They stress the urgency for enhancements in the IFC for a seamless and steady data transfer process. Recommendations for bolstering BIM interoperability have been proposed, suggesting the uniform use of software tools or add-ins by all stakeholders, data converters encompassing mapping between different platforms, and concerted efforts towards refining the IFC schema to curb interoperability issues among BIM platforms. [7]

The following flowchart, Figure 2 shows the minimum input data required. There should be at least the following input data. General data concerning the assessed object alongside the application sheds light on the specific case's contextual framework. Initially, the object type is delineated, which could range from a whole building, building portfolio, building unit, or part of a building to a building element; this extends to the building fabric or technical building system. The object's status as a new or existing building, whether in the as-built or use phase, alongside renovations of existing buildings or extensions to existing buildings, is also highlighted. Following this, the building category is identified, which could either be residential or office spaces. The type of application is then elaborated, which could be aimed at checking compliance with energy performance requirements, energy certification, obtaining building permits, permit to use, tailored energy audits, or energy performance inspections. The type of assessment is also specified, whether it's a calculated design, calculated as-built, measured actual, or measured standard (corrected for climate and use).

Details from the energy performance assessment tailored to individual project characteristics and the assessed object's characteristics are outlined, including reference size, thermal envelope areas, and window orientations. Additionally, ventilation flow rates and illumination per space are discussed to provide a comprehensive understanding of the overall energy performance of the object in question. Through this detailed examination, a thorough understanding of the assessed object and its energy performance in the context of the specific project is achieved. The output data shall also be reported in the same manner as in all EPB standards.

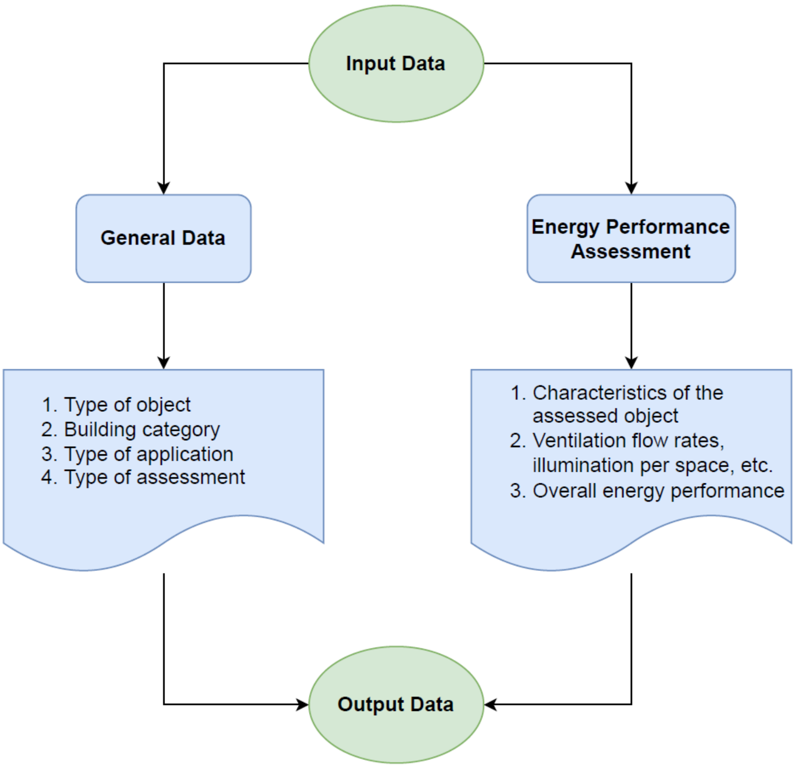

Figure 2: *Input data required*

Based on the energy performance indicator's value compared to reference values, many ways can be developed to communicate the overall or partial energy rating of a building or a building feature. The default energy rating techniques listed below are described in depth.

The default energy rating method with two reference points is structured to understand a building's energy performance comprehensively. The performance scale is designed to range from A, representing buildings with the best energy performance, to G, meaning those with the worst energy performance. This method introduces two key references: the energy performance regulation reference (Rr) and the building stock reference (Rs). Rr is placed at the boundary between two classes, such as classes B and C, while Rs is placed at the edge between another two classes, for instance, D and E. A building with a net delivered energy equal to 0 is also designated at the top of one of the classes, like class A. Subclasses may be defined to expand the classes to provide a more nuanced rating. For example, class A can be further developed into subclasses A+, A++, and A+++.

On the other hand, the default energy rating method with a single reference point simplifies the rating process. The performance scale in this method also spans from Class A to Class G. Similar to the two-reference points method. Subclasses can be defined to provide a more detailed rating; for instance, class

4.2 Content and architecture energy module

This section presents the content and architecture of the energy module of the Smart² platform. The energy module will include procedures for extracting SRIs through EPC input data, cross-correlating EPC and SRI classes, and an API for documenting the required attributes from an IFC document for SRI extraction. Several broad design concepts have been identified and applied to the Smart2 platform through the many standards and approaches investigated. Following these guidelines seeks to create an open and generic platform that all suppliers, vendors, and potential consumers can utilize to the fullest extent. The system architecture is designed based on current standards. In later stages, it will incorporate some external models for further analysis and future efforts and set a clear path for enhancing the consideration of smart readiness aspects in building energy performance. It has generic and standard solutions for which several essential technologies (commercial, open source, etc.) are available.

The content and architecture of the energy module within the Smart² platform will be structured according to the Model-View-Controller design pattern. ASP.NET Core MVC is a cross-platform, open-source framework that allows the creation and hosting of dynamic, powerful, and extensible web-based applications. With ASP.NET Core, you can develop on various platforms – Windows, macOS, and Linux, deploy your application to the cloud, and create services and mobile backends. It includes three main programming models useful for smoothly developing applications: MVC, Razor Pages, and Web API.

The Model-View-Controller pattern is a design pattern that promotes strict separation of concerns between the various components of an application. Separation of concerns is a term used to describe this isolation. Virtually all aspects of ASP.NET MVC are to keep divergent sections of an application isolated from one another in almost every way. This separation of model, view, and controller code ensures that MVC applications have a logical structure, even for the most complex sites. It also improves the testability of the application.

MVC applications need to distinguish between models, views, and controllers. Models represent data and the accompanying business logic. Controllers interact with user requests and implement put logic. Lastly, views build the user interface. By examining how ASP.NET Core MVC processes a user request, you can understand how the data flows through the models, views, and controllers before being sent back to the browser. [14]

The energy module of the Smart² platform consists of four main core components, illustrated in Figure 3, each designed to fulfil specific models and functions within the backend of the web platform. An overview of the approach that will be used to achieve the Smart² content and architecture is presented in Figure 4.

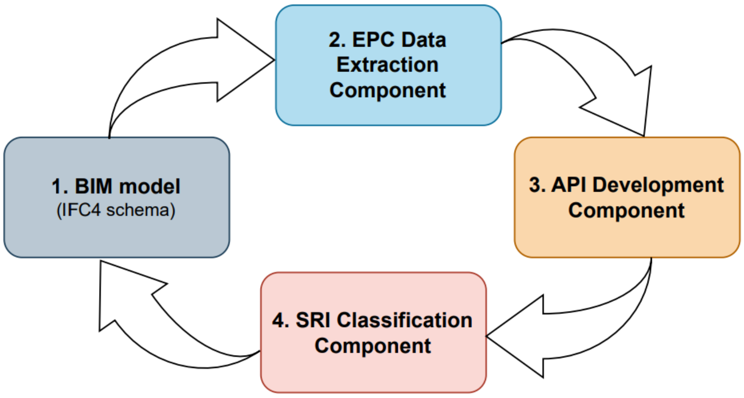

Figure 3: *Energy module components*

The layers shown in Figure 4 **Error! Reference source not found.**are described below:

[1]. The **Physical Layer** consists of one of the core layers. This layer extracts and collects input data from BIM models (.rvt, .nwd, .dwf, etc.) and .ifc files (ifc4 schema).

[2]. The **Information Layer** consists of three main models. This layer collects the necessary building information. Mainly identifies information needed for the EPC and the SRI assessment, metric data included in the .ifc file and metric data **not** included in the .ifc file.

[3]. The **Processing Layer** identifies the missing information required for the assessment of the SRI. Initially, it handles the overlapping and missing data. Next, a parallel layer of information complements the already available data for calculating building energy efficiency. Using API and ifcOpenshell library, all the required attributes and data are extracted from an IFC file for SRI extraction. All the data is processed into a commonly accepted format and streamed to the Calculation engine.

[4]. The **Representation Layer** constitutes the layer offered for interaction with the end-users.

The Smart^2 platform also provides a user authentication service. A more efficient and dynamic interaction with end-users is considered through the mobile-friendliness feature of the developed components.

The ISO/IEC/IEEE 42010:2011 standard, combined with Service-Oriented Architecture (SOA) principles, is advantageous for developing the Smart^2 platform. The Smart^2 platform aligns with this standard, providing a comprehensive blueprint for system structure design, evaluation, and upkeep. It outlines essential components, establishes a theoretical framework, and details the necessary elements for an architectural outline. The standard also advocates using architectural perspectives, frameworks, and description languages to enhance and unify architectural documentation processes.

Initial Design: A comprehensive development approach should be embraced, especially at the outset. It's essential to validate and stabilize the primary design before adding more features. This ensures that all vital functions and systems are established early to meet core requirements. Adopting this strategy reduces the need for revisions and enhances flexibility as the design evolves.

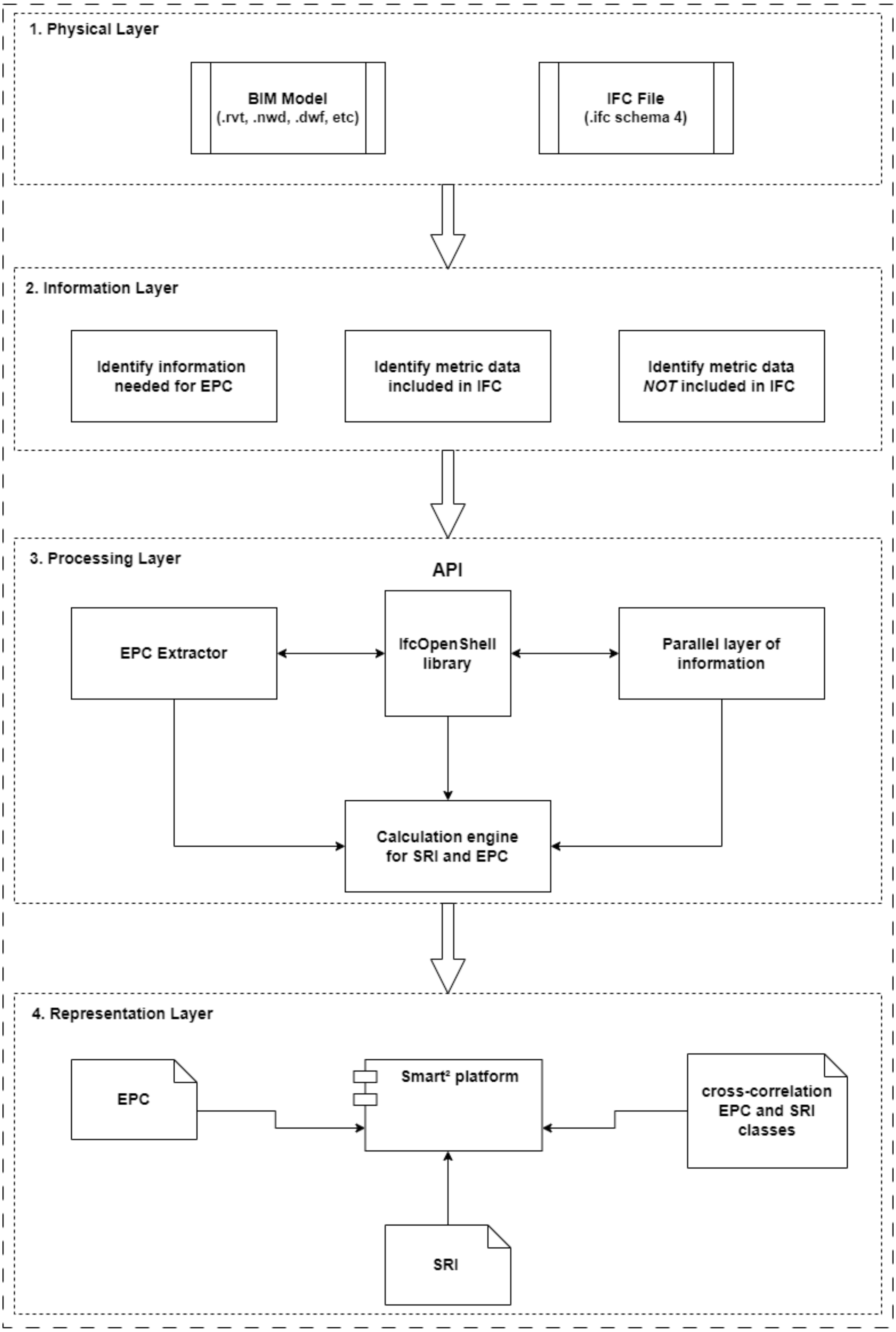

Figure 4: *Smart² Layered Architecture*

Modular Design Approach: The design should be structured into separate models, e.g. BIM-IFC module. A distinct set of functionalities or concerns should be expressed by each component, ensuring high internal cohesion and low coupling between the components. This methodology makes the system's maintenance, scalability, and extensibility simpler.

Defined Interactions: Components should communicate using well-defined interfaces rather than directly accessing one other's internal workings. This idea encourages a robust and secure design by reducing the architecture's dependencies and potential weak points.

Reusability: The architecture should recognize and abstract shared functionalities into broader architectural pieces or shared libraries. Examples include centralizing and reusing joint data parsing or extraction functionality across components. [16]

4.3 Development of API for documenting required attributes from an IFC document for extraction of SRI

Web Application Programming Interface (API) is a framework that enables you to build Representational State Transfer (REST) enabled APIs. REST describes an architectural style that takes advantage of the resource-based nature of HTTP. HTTP is a communication protocol designed to transfer hypertext-based resources across computer networks. HTTP is now one of the most popular protocols for building applications and services. REST-enabled APIs help external systems use the business logic implemented in the application to increase the reusability of the application logic. Today, REST is used to add essential capabilities to a service. Services that use the REST architectural style are also known as RESTful services. RESTful services use different HTTP verbs to allow users to manipulate their sources and create a full API based on resources. Web API facilitates two-way communication between the client system and the server through tasks such as:

- Instructing an application to perform a specific task
- Reading data values
- Updating data values

Web API enables to obtain business information using REST without creating complicated XML requests such as Simple Object Access Protocol (SOAP). Web APIs use URLs in requests, eliminating the need for complex requests. REST and Web API enable all applications, including mobile device applications, to interact with services. In particular, REST and Web API provide the following benefits for mobile applications:

- They reduce the processing power needed to create complex request messages for data retrieval.
- They enhance the application's performance by reducing the data exchange between client and server.

In this task, an API will be developed to document the required attributes from an IFC document to extract SRI. The IFC parser API will be built using the IfcOpenShell library. The IfcOpenShell library is an open-source toolkit and geometry engine that facilitates the creation of digital platforms for the built environment. It is available in two programming languages, C++ and Python. Also, It offers functions to read, write, and modify BIMs using IFC. IfcOpenShell C++ offers classes and functions to read, write, and modify all IFC schemas, serialisations, and geometry. Based on the OpenCASCADE geometry kernel, IfcOpenShell C++ offers multicore conversion of implicit IFC geometry into explicit polygons for CAD systems. Perform geometric analysis through BVH trees, voxels, and 2D drawing generation.[14]

IfcOpenShell using Python has a utility module that reduces common model analysis tasks to one line of code. Offers a high-level API for native IFC authoring use cases across all disciplines, whether it is adding objects, managing classifications and documents, connecting distribution ports, or critical path analysis. For the needs of this study, preliminary work was done using ifcOpenShell Python and Pandas module. It is an open-source library providing high-performance, easy-to-use data structures and data analysis tools for the Python programming language. As mentioned in section 2.3, an IFC model is a collection of elements (e.g. doors, windows, construction tasks, materials, etc.) with relationships to other elements in a graph-like database. Together, these elements and their relationships describe the digital built environment. Each element has a type known as an IFC Class. These classes define the attributes that the element may store. For example, the IfcWall Class can store a Name and Description attribute. This IFC database can be stored in many formats. The most common is the .ifc format, which keeps data in plain text. The workflow of the overall information extraction procedure is presented in Figure 5. As a first step for the required information exchange and extraction, the BIM file of the building should be exported to an IFC file using the BuildingSMART IFC schema. The IFC reference file enables communication between software tools for further data extraction and analysis. IFC file parsing application (API) is based on linguistic analysis. [15] The parsing process consists of the following steps:

- conversion of the character sequence into a word sequence
- grammar check
- data structure construction of composed words and values.

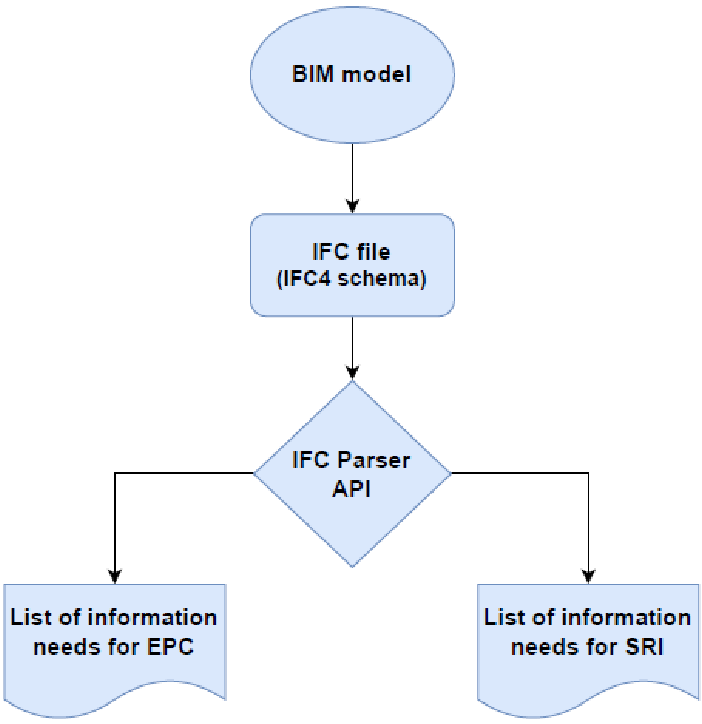

Figure 5: *IFC Parser Workflow*

Figure 5 illustrates the rational of the IFC parser. This method provides a comprehensive way to gather essential information about a building's technical systems. As a result, all the extracted data can be stored in different formats like .xls, .csv, .json, .xml, etc.

```python
import ifcopenshell
import pandas as pd

# Reading IFC file
ifc_file = ifcopenshell.open('datasets/Type_1.ifc')
print('IFC reading successfully completed!')

# Print the schema name
print(f"IFC schema: {ifc_file.schema}")
print("")

extracted_material_data_for_walls = []

# Function to extract the element area (2 cases)
def get_element_area(element):

# Function to calculate the material layer volume
def calculate_material_layer_volume(layer_thickness, area):

# Function to calculate the mass of a material layer
def calculate_material_layer_mass(volume, density):

def extract_heat_transfer_coefficient():

def extract_thermal_conductivity(element):

def extract_material_layer_density(constituent_material):

def extract_material_density(material):

def get_wall_materials():

get_wall_materials()

df = pd.DataFrame(extracted_material_data_for_walls)
df.to_csv('extracted_material_data_for_walls.csv', index=False)
```

Figure 6: *Functions to extract wall materials*

5. Conclusions

In this deliverable, we have undertaken a thorough examination of the Energy Performance Certificates (EPCs) and Smart Readiness Indicators (SRIs), shedding light on their essential roles in the realm of building energy performance assessment. Our analysis has revealed several critical insights and conclusions:

- Need for Integration: The demand for energy-efficient and smart buildings is growing rapidly. To meet this demand effectively, there is a compelling need to bridge the gap between EPCs and SRIs. These two tools, while distinct in their objectives, can complement each other to provide a more comprehensive assessment of building performance.
- Alignment Opportunities: We have identified numerous alignment opportunities between EPCs and SRIs. By integrating these tools, we can facilitate wider adoption, enhance calculation methods, and transform them into valuable decision-making tools for stakeholders in the building community.
- Overlapping Information: Our analysis has highlighted significant areas of overlapping information between EPCs and SRIs. Building orientation, heating and cooling systems, lighting, hot water systems, renewable energy sources, and climate data are common elements that both assessments require. Leveraging this overlapping data can streamline the assessment process and reduce duplication of efforts.
- Missing Information: While there is overlap, we have also identified areas where EPCs and SRIs lack critical information required for a comprehensive assessment. Notably, SRIs emphasize the functionality and integration of building automation and control technologies, which are not fully integrated into EPC methodologies. Addressing these missing elements is crucial for capturing the true potential of smart technologies in enhancing building energy efficiency.
- Utilizing Industry Foundation Classes (IFC): The utilization of IFC attributes for SRI calculations presents a promising avenue for enhancing data compatibility and extraction. By identifying gaps and proposing further development fields in ISO 16739-1:2018, we can better align IFC attributes with SRI requirements, improving the integration of this valuable resource.
- Parallel Layer of Information: The concept of a parallel layer of information, coupled with the development of an API for extracting required attributes from IFC documents, offers a practical approach to bridge the gap between EPCs and SRIs. This parallel layer can streamline data collection and analysis, ensuring that both tools benefit from a unified source of information.

This deliverable underscores the importance of aligning and integrating EPCs and SRIs in the pursuit of more sustainable and energy-efficient buildings. By leveraging overlapping information, addressing missing elements, and harnessing tools like IFC attributes and parallel layers of information, we can advance the capabilities of these assessments. The path forward involves active collaboration among stakeholders, including building professionals, policymakers, and technology developers, to realize the full potential of EPCs and SRIs in promoting a greener and smarter built environment.

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