iSRIc 2024

International
Smart Readiness Indicator
Conference

CONFERENCE PROCEEDINGS

October 14th & 15th in Germany

Program committee:

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INTRODUCTION

Digitalization is transforming modern society at an unprecedented pace, influencing nearly every aspect of life and work. As technological innovations continue to evolve, the European Union has taken steps to harness these advancements within the built environment, recognizing the critical role buildings play in achieving sustainability goals. A notable example of this commitment is the amendment of the Energy Performance of Buildings Directive (EPBD), which includes a mandate for the development of a Smart Readiness Indicator (SRI). Launched with an initial proposal in October 2020, the SRI aims to assess and encourage the smart capabilities of buildings, promoting energy efficiency, enhanced comfort, and optimized performance.

Against this backdrop, the International Smart Readiness Indicator Conference brings together researchers, policymakers, industry professionals, and innovators to explore the future of building technology and sustainable real estate development. At the heart of this conference lies a focus on the SRI and smart buildings, with discussions centered on innovative technologies, design strategies, and operating models that can advance building performance and sustainability. Key topics include the methodologies and policies surrounding the SRI, the impact of smart buildings on their environment, and findings from various research and experiments related to smart readiness.

The International Smart Readiness Indicator Conference (iSRIc) provided a valuable platform for scientists, companies, and other stakeholders to share their insights and findings with the broader SRI community. The scope is not limited to official EU test phases or country-specific research but extends to diverse projects that contribute to our understanding of smart buildings. A significant highlight of the conference was the opportunity to visit the Energy Lab 2.0 at the Helmholtz Research Infrastructure Living Lab Energy Campus, where experimental buildings showcase innovative, network-based control systems designed to improve energy efficiency through self-adjusting process control.

This conference represents a step forward in creating buildings that are not only smart but also more efficient, comfortable, and capable of adapting to the dynamic energy landscape. Through collaborative knowledge-sharing and hands-on exploration, this event aims to drive progress toward a more sustainable, digitalized future for the built environment.

In conclusion, we, the Program Committee, would like to express our sincere gratitude to all participants, speakers, and supporters. Thanks to your commitment and valuable contributions, the event was a great success. We look forward to future opportunities to discuss and advance exciting topics together.

Prof. Dr. Kunibert Lennerts Tristan Emich

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09:45-10:15	Taraneh Delavar	Aalto University	The role and contribution of SRI-Smart Buildings to Smart Cities	The role and contribution of SRI-Smart Buildings to Smart Cities
10:15-10:45	Felix Rehmann	TU Berlin	Standardizing Key Technologies for Energy Management at Urban Scale through the Smart Readiness Indicator: A Conceptual Framework	Standardizing Key Technologies for Energy Management through the SRI in UBEM: A Conceptual Framework
11:15-11:45	Paul Waide	Waide Strategic Efficiency Europe	Links between the SRI and technical building system audits under the EPBD	Links between the SRI and technical building system audits under the EPBD
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11:45-12:15	Paul Waide	Waide Strategic Efficiency Europe	Exploring energy efficiency relationships between the SRI and EPCs	Exploring the relation of the SRI with energy efficiency in the EPC
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PAPERS

I. Simulation of SRI functionality levels for room temperature control in a typical German office building

Verena Dannapfel [1], Lara Mees [1], Rita Streblow [1], and Dirk Müller [1]

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Abstract

The Smart Readiness Indicator (SRI) offers a strategic approach to overcome obstacles to energetic improvements in German office buildings. Many SRI measures provide multiple benefits, including substantial reductions in energy consumption and enhanced attention to user needs, aligning well with Environmental, Social, and Governance (ESG) objectives.

Our focus is on SRI services for room temperature conditioning, evaluating two delivery systems. We translate the various functionality levels into practical design solutions, illustrated through technical schematics. These technical equipment set ups form the prerequisite for the implementation of different room temperature setpoint profiles, such as those from DIN EN 15232. Integrating SRI into offices can thus enhance demand-oriented room temperature control to increase energy efficiency and improve user comfort.

We assess the impact of various setpoint profiles through annual simulations for a typical German office building. This typical German office building is from the building age class of 1950-1977 as the most spatial dominant and relevant in terms of energy consumption in Germany. The simulation model is based on statistical data towards dimensions and materials and comprises several office room types. The simulation results shall be used for a cost-benefit analysis for control equipment retrofitting including the consideration of both energy demand and comfort targets.

Additionally, a comparative analysis of the quantitative results and the qualitative evaluation systems of SRI and DIN EN 15232 is planned to form the basis for improving the German SRI implementation scheme.

Keywords: SRI, Room Temperature, Offices, Germany, Simulation, Quantitative Assessment, Energy Efficiency, User Comfort, Cost Benefit Analysis, DIN EN 15232

1 Introduction

The European Union (EU) is implementing various measures with the aim of achieving an emission-free building stock. One of the measures envisaged as part of the Energy Performance of Buildings Directive (EPBD) (Europäische Union, 2024) is the introduction of the Smart Readiness Indicator (SRI). This evaluates functionalities in nine technical areas and seven performance criteria, including energy efficiency and user comfort. For non-residential buildings equipped with a heating system or a combined heating and ventilation system with a nominal capacity of at least 290 kW, the SRI assessment is to become mandatory through legislative action by the middle of the year 2027 (European Union, 2024).

At the same time, the Nonfinancial Reporting Directive (NFRD) (Europäische Union, 2014) obliges large companies to report on the sustainability aspects of their business activities since 2014. These include environmental aspects, social aspects, and aspects of corporate governance, also known as ESG criteria (Environmental, Social, Governance) which partly align well with the SRI objectives. With the introduction of the Corporate Sustainability Reporting Directive (CSRD), this obligation will be gradually extended from large companies under accounting law to all medium-sized and small capital market-oriented companies (Europäische Union, 2022).

There are around 300,000 office buildings in Germany, of which around 37 % are owned by companies and 35 % by the public sector (dena, 2023a). Both owner groups shall have an interest in substantial reductions in energy consumption and enhanced attention to user needs, to meet political requirements but also to save operating costs and create an attractive and productive working environment. In the project Klassiqua[1] we want to take a closer look on measures within the SRI and their quantitative effect on both energy demand and comfort using annual simulations in a representative setting.

2 Room temperature control within the SRI

Our focus is on SRI services for room temperature conditioning, whereby we analyse both conventional and thermally activated building systems in office building models for different building age classes in Germany. The development of the SRI system was partly based on existing European standards such as DIN EN 15232. More detailed formulations of the standard are therefore regarded as supplementary specifications in the sense of the SRI.

We translate the various functionality levels into practical design solutions for technical equipment, illustrated through technical schematics as shown in Table 1 exemplatory for the `H-1a heat emission control´ service and functionality levels 2 and 3, whereby 2 corresponds to the most common design

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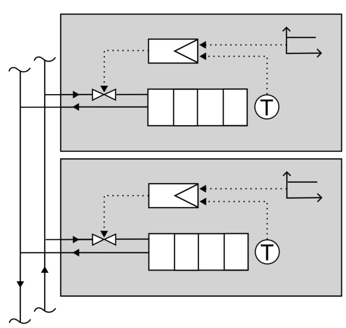
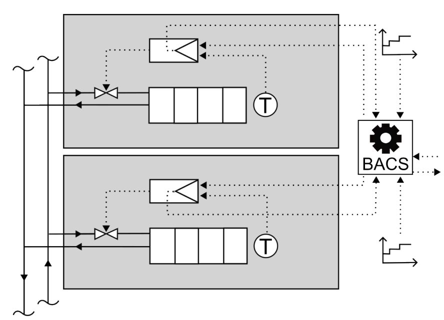
[1] Klassifizierung und quantitative Bewertung von Dateninfrastruktur und Regelungsoptionen in typisierten Simulationen zur möglichen Anpassung des Smart Readiness Indicators, project duration 09/2024 - 08/2027, funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK), promotional reference 03EN1099A

and 3 shows a more advanced system. Level 2 comprises local thermostats or electronic controllers in each room, which were mostly set to a constant value but rarely are able to integrate time profiles. Level 3 comprises a superordinate communication level with a building automation control system (BACS), where time profiles can be set, and local controller information can be acted upon. In this way, demand-oriented operation can also be promoted at the producer level of the building.

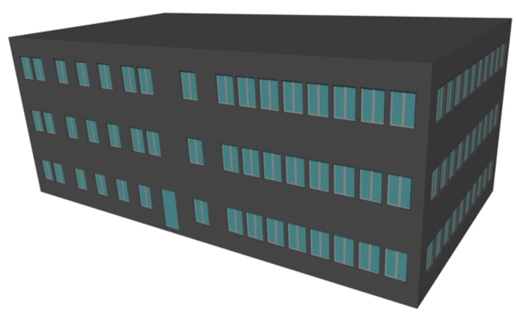
These technical equipments are the prerequisites for different room temperature setpoint profiles. Our profiles are extractions from DIN V 18599, from studies towards energy demand reduction by adjusted setpoint profiles from the residential sector by MAIER ET AL. and SPERBER ET AL. and from DIN EN 15232´s appendix to BACS efficiency classes C and B for offices. The last profiles have been used by the DIN EN committee for precalculations but are not an evaluation condition. While the `room temperature´ in SRI and DIN EN is not specifically determined as room air temperature or operative room temperature, the contexts show a tendency to the meaning of room air temperature. In terms of comfort the operative room temperature is the more relevant. We will examine both air and operative temperature in our simulations to show the discrepance in energy demand and heating profiles.

Table I-1: Practical implementation scenarios of SRI service H-1a and their evaluation

SRI-Service `H-1a Heat emission control´										
	Functionality level									
	2				**3**					
SRI Level description	Individual room control (e.g. thermostatic valves or electronic controller)				Individual room control with communication between controllers and to BACS					
Technical equipment										
	Correlated setpoint profiles				**Correlated setpoint profiles**					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
$T_{set,Day}$ in °C	21	20	19	22	21	21	21	20	20	19
$T_{set,Night}$ in °C	21	20	19	15	17.85	17	15	17	17	16.15
Night schedule	-	-	-	9pm to 5am	10pm to 6am	11pm to 6am	8pm to 6am	10pm to 6am	11pm to 6am	10pm to 6am
Based on	a)	b)	b)	d)	c)	b)	d)	c)	b)	c)
DIN 15232, BACS Efficiency class	C (based on profile 4 simulation results)				B (based on profile 7 simulation results)					
SRI Impact Energy efficiency	2				2					
SRI Impact Comfort	2				2					
References: a) DIN V 18599, 2018; b) Maier et al., 2022; c) Sperber et al., 2024; d) DIN EN 15252, 2017 BACS: Building automation control system; T_{set} = Room temperature setpoint										

3 Simulation model of a typical German office

We quantify the effects of the selected temperature setpoint profiles using annual simulations for a typical German office building. We initially focus on the construction age class 1965 to 1977, which is the most prevalent age group in terms of energy consumption in Germany and is at the same time the most spatially dominant (dena, 2017; dena, 2022). The literature does not yet provide a complete typology for an office building of the assumed building age class, so the simulation model relies on a combination of appropriate ground floor models and statistical data regarding dimensions and materials. Figure I-1 shows our defined office simulation model and an examplatory extract of values for specific aspects and their references. The determination of the layer structures, e.g. of the external wall, is mainly based on a catalogue for building elements for German regions and building ages (ZUB, 2009). The zoning within the floor plan and arrangement of different office types (e.g. individual, group, open space) and other zones was implemented based on guidelines for energetic analysis (dena, 2023b). Simulation results will be obtained in the beginning of 2025.



Aspect	Value	Reference
Length of the building	28,65 m	BMVBS, 2013
Width of the building	15 m	
Number of floors	3	
Net floor area	1109,4 m²	
Share of window area on the facade surface	30 %	
Share of offices in net floor space	72,1 %	BMVBS, 2010
Facade construction	Solid (masonry)	IWU, 2022
U-value external wall	1,29 W/m²K	

Figure I-1: Defined office simulation model

4 Outlook and acknowledgement

The simulation results will be utilized for a cost-benefit analysis of retrofitting control equipment, considering besides energy demand also comfort objectives. Furthermore, a comparative analysis of the quantitative results alongside the qualitative evaluation systems of SRI and DIN EN 15232 is intended to serve as a foundation to enhance the implementation scheme of the German SRI.

Acknowledgement:

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II. Exploring the relation of the SRI with energy efficiency in the EPC

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Abstract

This paper presents findings from the LIFE21-CET-SMARTREADY-easySRI (GA 101077169) project (easySRI 2024) which address exploration of the relationship of the SRI (SRI 2024) with energy efficiency in the EPC. It notes that SRI assessment can be a basis for the determination of BACS factors that can be used to adjust and improve the rating of the EPC. On the other hand, the information gathered for an EPC could also be used to adjust the weighting factors in the SRI assessment via the building's energy balance. In addition, SRI assessments could produce recommendations for improvements that could also be used as part of EPC recommendations and within the renovation passport, thereby stimulating the adoption of better BACS. The establishment of a building logbook is proving to be an important tool that provides a common space for SRI assessment reports and EPCs. The possibility of uploading standardized SRI assessment reports and linking them to specific EPC data fields through automated processes is promising in exploiting synergistic potentials. Recommendations from SRI assessments stored in the building logbook could contribute to future EPC versions and the creation of a renovation passport, including a renovation roadmap.

Keywords: Energy Performance Certificate, Smart Readiness Indicator, Energy Efficiency, Digitalisation

1 Introduction

The Energy Performance Certificate (EPC) displays indicators representing the energy consumption, renewable energy generation and renewable energy self-consumption share of a building. The indicators reported consider the transmission losses, ventilation losses, and solar energy gains through the building envelope, and the energy consumption needed to provide a defined indoor air temperature. This includes conversion losses of heating and cooling systems which are part of the category termed “technical building systems”. Technical building systems are defined as “technical equipment for space heating, space cooling, ventilation, domestic hot water, built-in lighting, building automation and control, on-site renewable energy generation and storage, or a combination thereof, including those systems using energy from renewable sources, of a building or building unit” (Article 2 Definitions EPBD (2024)). In the same Article 2 Definitions of the EPBD, a distinction is made between building automation and control (BAC) listed under TBS and building automation and control system (BACS), as follows: BACS means a system comprising all products, software and engineering services that can support energy efficient, economical and safe operation of technical building systems through automatic controls and by facilitating the manual management of those technical building systems. That means that building automation and control is not only part of the technical building systems but also plays a vital role in the energy efficient operation of technical building systems as a whole. An overarching system or software that coordinates and monitors various automated systems within a building enables centralized control and monitoring of all building functions through a user interface. In practice, this can be done by either a supervisory computer or a software platform.

Basically, there is a challenge in the existing building performance certification framework that overall energy efficiency is intended to be covered in the energy performance certificate, but these usually ignore TBS automation and control, while the SRI also assesses building energy efficiency, but is essentially limited to the building automation and control aspects.

In this paper, we mainly explore how the SRI can facilitate the integration of this energy efficiency potential in the EPC, but also on how to make sure that the SRI and EPC can inform each other, because, for example, the EPC could also support the adaptation of weighting factors in the SRI, while the SRI could provide relevant information on the BACS capability of TBS that is currently ignored in most EPCs. We also touch upon the recommendations of the SRI certificate on how to improve the smart readiness of buildings and the link with the recommendations of the EPC and the Renovation Passport.

2 SRI facilitates the determination of BAC factors for the the EPC

The SRI service catalogue is based on EN ISO 52120-1:2022 (EN ISO 2022)“Energy performance of buildings – Contribution of building automation, controls and building management – Part 1: General framework and procedures” which addresses the topic of building automation and control systems and their contribution to increasing the energy efficiency of buildings. In this regard, the standard presents two methods to determine the BAC contribution to the energy performance of buildings:

- Method 1 - Detailed calculation procedure of the BAC contribution to the energy performance of buildings (detailed method): The output data of this method is a list of building automation and control functions and to each such function the chosen function type. This procedure is suitable for dynamic simulations and allows for quantification of impacts of functions.

- Method 2 – Factor-based calculation procedure of the BAC impact on the energy performance of buildings (BAC factor method): The BAC factor method has been established to allow a simple calculation of the impact of building automation, control and management functions on the building energy performance. The BAC efficiency factors were obtained by performing transient pre-calculations for different building types as mentioned in ISO 52003-1. BAC classes A to D are determined based on a checklist of BAC equipment, specified for non-residential and residential buildings.

These BAC factors represent huge thermal energy savings when moving from class D to C, and still quite significant ones when going from C to B or A. Thus, omitting BACS from EPCs can result in poor EPCs while also undervaluing the contribution that could be made by smarter control. Note, for a non-residential building (e.g. an office) BACS class D scales the primary energy of a EPC by a factor of 1.51, class C by a factor of 1, class B by a factor of 0.8 and class A by a factor of 0.7, thus a building with class D controls would use 216% of the primary energy of one with class A. This illustrates the major impact that control performance can have upon building energy performance. Yet, despite the very significant impact that the sophistication of control has on building energy performance it is currently the case that BACS are seldom, if ever, considered within EPC assessments. This arguably constitutes the biggest failure in current EPCs and is likely to be the major factor (along with user behaviour) in the much reported performance gap between EPCs and actual building energy performance.

It should be noted that the Factor-based calculation procedure in Method 2 of EN ISO 52120-1:2022– relies on the same checklists that are also implemented in the SRI assessment catalogue. Therefore, conducting an SRI assessment will produce all the information required to also derive the BACS factors that could be used to improve the determination of EPC energy performance classes and hence reduce this performance gap. Thus, were SRI assessments also used to inform EPCs the quality of EPCs would be much improved over the current situation.

3 Making sure that SRI and EPC can inform each other

3.1 Linking SRI and EPC

In easySRI, options were explored for how every time an SRI assessment is offered, this could be linked with the EPC status. The following EPC status characteristics are possible:

- No EPC available
    - No building information on TBS available
    - Detailed building data collection on TBS (as built) available
    - Operational data collection by TBS available
    - Energy model available

- EPC available
- EPC available but no detailed data collection (EPC based on default values)

Depending on the EPC status, SRI assessment could make use of the existing information generated during energy performance certification or contribute information for the determination of the EPC. As a means of verification, the SRI assessment report would need to include a reference to the EPC for the assessed building and also the other way round.

It is important that the identity of the EPC and the SRI report is connected with the building and not with the assessor. This is the precondition to follow-up with the changes in the building over time which are also reflected in the different versions of the EPC or SRI assessment issued at a certain point in time.

In terms of process, linking of SRI and EPC can be done through a digital building logbook if one is existent, or manually in the SRI assessment report by means of a respective note. Note, a priori Member state authorities could facilitate such data sharing through linking their EPC & SRI registration systems so that all relevant data on a building is also maintained in a central register and is updatable each time an assessment is conducted.

3.2 Practical considerations

The EPC database can provide valuable information as input into the SRI assessment, and the SRI assessment can generate information that should be taken into account in the energy performance classes and recommendations section of the EPC. However, the condition is that the SRI assessment report and the energy performance certificates are at least stored in the same place. The same applies to other relevant documents such as the renovation roadmap, the inspection report, and energy audit reports. It is also possible that an SRI assessment is requested for a building where no EPC exists. Thus, the exchange and reuse of data is necessary, and the building logbook envisaged by the European Commission seems to be ideal for this purpose.

Note that extant EPC databases are not necessarily suitable as building logbooks to support SRI assessment because the EPC data they contain may only cover data fields that are mandatory for the respective building type (residential or non-residential); that means, even if a residential building is equipped with an active cooling system, technical information would not appear in the EPC database if active cooling is not part of the calculation method for residential buildings (as is the case in Austria for example). Also, inspection of HVAC TBS results in more information being collected than is contained in the EPC, and the same applies to the renovation passport, the SRI assessment, and energy audit reports as set out in the Energy Efficiency Directive. However, it should always be possible to extend the existing EPC database to add additional fields and functions and to further develop it to support the new building logbook.

Another option which is based on the concept of a dynaminc EPC is to create a building data collection process that is being constantly updated and authorized by an authority. The objective of such an approach would be to avoid repeated duplicative data collection, to allow for multiple uses and to avoid liability and ownership issues for building assessment experts which currently prevent them from using data collected by other experts. From such a comprehensive and up-to-date data collection process, assessments could be generated anytime.

4 Facilitation through the easySRI platform

4.1 The easySRI project and easySRI Platform

The easySRI LIFE project is developing a suite of software tools to facilitate the conduct of SRIs within the easySRI Platform. It aims to enable a smooth and extendable web platform that offers services for the automated calculation of the SRI. These include an SRI calculation engine, a Machine Learning (ML) based core engine for optimized building improvement recommendations, and an SRI wizard. The calculation engine computes SRI scores, while the wizard assists assessors and users through the assessment process and helps interpret results. The ML core engine provides recommendations for optimizing a building's SRI, focusing on relevant parameters like improving energy efficiency via enhanced control and at minimal cost. Work is underway (and already quite avanced) in each of these aspects and final results and tools will be delivered in 2025. Apriori, these same tools, which will be provided in amendable formats, could be used by EU member states to facilitate the integration of SRI and EPC assessment and registration software systems, and hence to address the substantial opportunity identified in this paper.

Additionally, innovative business approaches will encourage adoption and actively involve stakeholders in assessing and improving the smart capabilities of their facilities. Specialized workshops and training resources will support the implementation process. In the long term, the project aims to influence the revision of existing standards and integrate its findings into future standards. It will also explore connections with other European initiatives, such as EPCs, B-Logs, and renovation passports, to enhance the integration of the SRI concept into EU policies related to energy and buildings. Finally, through its activities easySRI provides technical support to the development of the SRI framework in Europe. This endeavour materialises under the authority of the European Commission DG Energy ENER and will act as a basis for an effective implementation of the SR, allowing further testing at Member State level.

5 Conclusions and outlook

This paper has identified the major deficieny in EPCs of not taking into account the impact of the quality of control of TBSs that could be remedied by utilisation of the additional information derived from SRI assessments. The tools being developed under the easySRI project could help to support the integration of both certification systems with attendant benefits in terms of improved EPC quality and minimised assessment costs.

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III. Links between the SRI and technical building system audits under the EPBD

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Abstract

The energy performance in buildings directive (EPBD) has mandated audits of key technical building systems in buildings with over 70kW of installed HVAC capacity for many years. In principle, the data collected through such audits might also be used to inform SRI audits or vice versa. This paper reports findings, informed from work conducted under the SmartLivingEPC Horizon Europe project, which analyses the relationship between the two and considers how they could be complementary to one another. In particular, it considers how audits and inspections of HVAC systems and BACS conducted in line with the provisions of the EPBD, could produce outputs that could inform SRI audits as well as EPCs and could be applied retroactively to amend either building asset rating. The synergies in these audits are particularly pertinent considering that in the 2024 EPBD Recast it is mooted that buildings with large installed rated HVAC capacity (>290kW) could be subject to mandatory SRI certification from 2027, and these buildings are already subject to mandatory TBS audits.

Keywords: EPBD, Energy audits, Technical Building Systems**,** Energy Performance Certificate, Smart Readiness Indicator, Energy Efficiency

1 Introduction

The energy performance of buildings directive (EPBD 2024) has required buildings with >70kW of heating or cooling capacity to undergo regular inspections of the heating, cooling and ventilation (HVAC) systems for many years. Specifically, Articles 14 and 15 of the 2018 EPBD recast set out a number of provisions with regard to the inspection (audit) of heating, ventilation and cooling systems. In particular buildings with installed heating or cooling capacity of >70kW such inspections are mandatory with a regular frequency unless alternative measures giving a comparable impact are enacted. Accordingly, most EU Member States require mandatory audits of such systems with a frequency of every 3-5 years.

While the smart readiness indicator (SRI) has been an optional scheme for Member States up till now the recast EPBD 2024 envisages it becoming mandatory for buildings with >290kW of installed HVAC from 2027. As the HVAC in such buildings is already subject to mandatory energy performance inspections (audits) it raises the possibility of identifying the synergies between SRI assessment and periodic HVAC audits to see if each could inform the other and/or if the assessment process could be integrated to produce an SRI and HVAC audit simultaneously from the same inspection.

2 SmartLivingEPC and energy audits

The Horizon Europe SmartLivingEPC (2024) project began in 2022 and will conclude in 2025. It aims to deliver a certificate which will be issued with the use of digitized tools and retrieve the necessary assessment information for the building shell and building systems from BIM literacy, including enriched energy and sustainability related information for the as-designed and the actual performance of the building. The model new certification scheme it will derive will also expand its scope, covering aspects related to water consumption, as well as noise pollution and acoustics. The SmartLivingEPC certificate will be fully compatible with digital logbooks, as well as with building renovation passports in order to allow the integration of the building energy performance information in digital databases. A special aspect of SmartLivingEPC will be its application in building complexes, with the aim of energy certification at the neighbourhood scale.

In particular, SmartLivingEPC aims to deliver a holistic smart Energy Performance Certificate (EPC) spanning relevant life-cycle performance aspects of the built environment. The certificate's scope transcends energy performance, including the smartness, sustainability, and inspection dimension into the certification procedure. Consequently, the SmartLivingEPC energy performance certification scheme aims to integrate the Smart Readiness Indicator (SRI) assessment, Life Cycle Analysis (LCA) and Life Cycle Cost (LCC) assessment, as well as additional human-centric indicators (e.g., Indoor Environmental Quality, thermal comfort, etc.), and others within the Level(s) (2024) framework. Furthermore, SmartLivingEPC will produce a dual enhanced methodology based on the existing CEN standards, for delivering asset and operational ratings. Further, it is intended these assessments will be applicable at both the building and the district scale.

One aspect of the SmartLivingEPCs concerns how audits of HVAC mandated under the EPBD might inform EPCs, SRI assessments and vice versa. This paper summarises the current findings.

3 Energy audits of HVAC under the EPBD

A priori, such audits are conducted in accordance with EPB standards and in particular the HVAC audits required under the EPBD reference the following inspection standards for HVAC systems:

- EN 15378-1:Energy performance of buildings - Heating systems and DHW in buildings - Part 1: Inspection of boilers, heating systems and DHW, Module M3-11, M8-11

- EN 16798-17:Energy performance of buildings. Ventilation for buildings Guidelines for inspection of ventilation and air conditioning systems (Module M4-11, M5-11, M6-11, M7-11)
- EN 16798-1:Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6.

And, for building automation and control systems:

- EN 16946-1: Energy performance of buildings. Building Management System – Inspection of Building Automation, Controls and Technical Building Management Part 1: Module M10-11
- EN/TR 16946-2: Energy performance of buildings. Building Management System – Inspection of Building Automation, Controls and Technical Building Management Part 2: Accompanying prEN 16946-1:2015 (Module M10-11)

Task 2.4 within the SmartLivingEPC project has undertaken an extensive review of these standards to determine their nature, but also to consider how the information that is gathered and reported under their auspices could be used to inform dynamic EPCs (i.e. those that could be updated based on the information reported by such inpsections) and could further be used to inform SRI assessments (or vice versa). The work is ongoing and so this paper reports provisional findings that will be updated within the following 12 month period to include a more systematic mapping of parameters under inspections (audits), EPC inputs with regard to HVAC and SRI inputs with regard to HVAC.

4 Summary of current findings

An example of the fields that are required in the inspection standards and how they relate to fields that could inform dynamic EPCs or SRI assessments is shown the following table for heating systems:

Table III-1: Linkage between fields required in HVAC audits and SRI fields

The heat generator inspection procedure includes inspection methods and procedures on:	Could inform EPC	Could inform SRI
1) Heat generator inspection level identification	prep	prep
2) Heat generator identification	prep	prep
3) Document identification	prep	prep
4) Heat generator visual inspection	Y	Y
5) Heat generator functionality check	Y	Y
6) Heat generator maintenance status	N	Y
7) Heat generator controls, sensors and indicators	Y	Y
8) Meter readings	Y	N
9) Heat generator performance evaluation	Y	N
10) Heat generator inspection report and advice	If adapted	If adapted
11) Heat generator performance advice	Y	TBD
The heating system inspection procedure includes steps on:		
1) Heating system inspection level identification	prep	Prep

2)	Heating system inspection preparation	prep	Prep
3)	Heating system and inspection identification	prep	Prep
4)	Document collection and system identification	prep	Prep
5)	Heating system functionality check	Y	Y
6)	Heating system maintenance status	N	Y
7)	Heating system central controls, sensors and indicators	Y	Y
8)	Meter readings	Y	N
9)	Energyware consumption	Y	N
10)	Space heating emission subsystem	N	N
11)	Space heating emission control subsystem	N	N
12)	Space heating distribution subsystem	Y	Y
13)	Generation subsystem	Y	Y
14)	Storage subsystem	Maybe	Y
15)	Generation subsystem sizing	Y	N
16)	Heating system global efficiency or rating	Y	N
17)	Domestic hot water systems	Y	Y
18)	Heating system inspection report and advice	If adapted	If adapted

In summary there are a considerable degree of overlap in terms of the inspection process for the audits/EPCS and SRIs. While some fields derived are explicitly informative to EPCs and SRIs few inspection fields are currently structured to provide the same information that are needed for ether. When assessing the specific performance parameters that are derived from HVAC audits the most pertinent for EPCs are the system efficiency and the system sizing (including degree of oversizing) and in principle these could be used to improve EPC quality with regard to HVAC performance. For the SRI very few of the reported values map directly to SRI inputs or vice versa. It is a very similar set of findngs for inspections of heating, ventilation and cooling systems. However, in the case of inspections of BACS, there is a much higher degree of overlap with the SRI than for the specific HVAC fields and also the data gathered could be used to greatly improve HVAC performance estimates within EPCs. Yet BACS inspections are currently not usually mandated within the Article 14 and 15 inspection procedures applied in most EU Member States[1].

5 Conclusions

HVAC audits/inspections conducted under Articles 14/15 of the EPBD sit somewhat between asset and operational EPC methodologies and hence could, in principle, inform either. They gather valuable system description and performance data that standard EPC asset methodologies tend to overlook. Furthermore they further convey recommendations that building managers/owners could (should) act upon to improve the energy efficiency of their HVAC systems. In principle, this

[1]See also the isric2024 conference paper by Geissler, Waide, Waide and Koukaras with regard to how EPCs could be substantially improved by incorporating BACS factor information that could be codetermined when conducting an SRI assessment.

information could be used in EPCs to improve the quality of the EPC rating and improve its accuracy; however, HVAC audits tend to occur at different times and frequencies to EPC assessments and thus currently are not used for that purpose. This would appear to be a missed opportunity for several reasons:

- The HVAC is the dominant part of almost all building's energy use and thus EPC ratings are sensitive to the performance attributed to it
- HVAC and BACS systems are likely to be upgraded or replaced much more rapidly than the building fabric thus are inherently more dynamic – significant changes in the HVAC and BACS characteristics can lead to significant changes in the real energy efficiency of a building and EPCs ought to be better at reflecting (and hence encouraging) upgrades
- The EPBD asset methodology makes a number of assumptions about how the HVAC is operated that may be inaccurate – inclusion of the HVAC audit data would allow the actual performance characteristic to be captured leading to more accurate EPCs
- Making use of the BACS audit data to determine the BACS class and BACS factor would allow for a substantial improvement in EPC asset calculations and would also empower BACS upgrades as a cheap and undisruptive means of improving EPC class
- HVAC systems performance could be adjusted (especially in response to audit recommendations) which would improve the real energy efficiency of the building
- Such upgrades or replacements should also be subject to EPBD Article 8(1) and 8(9) requirements regarding the energy performance of technical building systems, thus the audit could both serve as a means of determining the impact that such measures have had while acting as a means of verifying that they have been respected.

Such an integrated approach would also encourage the owners/managers of buildings subject to periodic HVAC audits to consider upgrading the HVAC and BACS system (perhaps through a replacement of all or part of the system) faster than may otherwise be the case as the impact on the EPC rating would be reported at the frequency of the audit. This could be an important stimulus for building owners looking to upgrade the performance to meet minimum EPC rating requirements (now specified within the EPBD 2024 recast).

As the process of conducting an HVAC inspection closely mirrors that needed for an SRI assessment for the HVAC (the same elements are subject to inspection) it would be sensible to integrate the two (especially for buildings with HVAC >270kW) as this would minimise duplicative assessment costs. In practice implmenting such a system could be managed by training HVAC assessors in how to conduct SRI assessments and amending qualification and certification systems to encompass dual assessment. It could be that the HVAC auditors would only also provide the SRI information related to the HVAC and BACS domains but it would be preferable were they equipped to provide complete SRI assessments (at least for buildings with >270kW of HVAC).

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Level(s) (2024) https://environment.ec.europa.eu/topics/circular-economy/levels_en

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IV. Standardizing Key Technologies for Energy Management through the SRI in UBEM: A Conceptual Framework

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Abstract

This research paper proposes a framework to enhance Urban Building Energy Modeling (UBEM) by utilizing the Smart Readiness Indicator (SRI) Use-Cases to standardize the description of ICT in the built environment. Using data from building competition database about the Solar Decathlon, we identify common ICT configurations, such as energy management systems, and model them as archetypes. We further map the data needs of different SRI functionality levels to a meta ontology of building data. The ongoing study integrates these findings into a conceptual data model, which we are currently developing into a logical data model using Django and CityGML. This model will integrate with UBEM tools for urban-scale modeling and simulation, aiming to create digital building archetypes akin to those often used in UBEM. The research offers a scalable solution for modeling ICT and data in smart buildings, by implementing a conceptual and logical data model for the SRI at the urban scale.
Keywords: Information Modeling, Urban Energy Modeling, Digital Archetypes, CityGML

1 Introduction

The Energy sector is governed by regulations. One of the biggest regulatory spaces in the world is the European Union, which consists of more than 500 million people. Governance in the energy sector not only requires different data standards, but also creates new data requirements. An example from the past is the Energy Performance Certificate, which is accompanied by standards and tools that undergo continuous development. Besides classical approaches, such as retrofitting, or exchanging the building equipment, in recent years digitalization has been considered an enabler of decarbonization of the built environment. To address this, the EU proposed the concept of the Smart Readiness Indicator in 2018, which should promote intelligent buildings and their ability to increase energy efficiency, user comfort, and enhanced grid-oriented operation (Amending Energy Performance of Buildings Directive, 2018). Although the SRI is currently not implemented, it might become an essential supplement of the EPC in the future and a key instrument to foster adoption of smart technology in the built environment.

The EPC has already been integrated into Urban Building Energy Modeling (UBEM), e.g. in (Heidenthaler et al., 2023) and hence there might be synergies with the SRI as well. UBEM is the modeling and simulation of the building in the urban environment to provide information about building design, operation, and policymaking (Hong et al., 2020). As a minimal overlap of the two approaches, the standardized processing of information on buildings, as well as the assessment of their potential can be considered. Further overlaps are conceivable, for example, in the modeling of flexibility. To discuss whether the SRI might be suitable to standardized modeling of general aspects of digitalization it needs to be extended, because, it is currently focused on large buildings, not districts (Märzinger & Österreicher, 2020), and lacks integration into general digitalization practices of the built environment (Fokaides et al., 2020). By using the SRIs' functionalities as Use Cases, we provide providing the basis for data and technology mapping, to analyze and compare the digital capability of building operation at scale and integrate them into further building and digital practices. The integration of this information into UBEM and models of the urban environment in general can help foster integration of general digitalization practices into the urban scale, by offering a chance of standardized modeling of such services and instruments. This working paper addresses the points by providing insight into three questions:

- How can the SRI be used for standardized modeling of digital applications in the building sector?
- How can the data needs and ICT requirements be used to generated digital archetypes?
- How can this information be modeled and utilized at urban scale, supporting the SRI's goals?

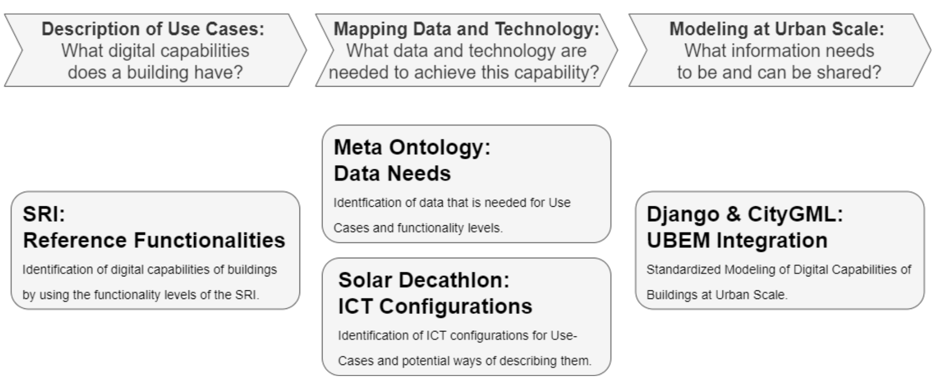

Figure IV-1: The proposed approach. The SRI is used as methodology, to provide standardized Use-Cases. A conceptual model and archetype can be developed, by understanding its typical data needs and ICT. Finally, a concept is derived to model the information at urban scale, using Django for APIs and CityGML for standardized modeling.

2 Methodology

The three key steps of the methodology are shown in Figure IV-1. In the first step, the SRI is introduced as a tool to provide a standardized set of Use-Cases is discussed. In the next step, digital archetypes for these services are created, by mapping a meta ontology and identify data needs, as well as mining a public database with building documentation to identify ICT. Finally, based on the lessons learned, a concept of a data model is presented. The data model is currently and development, using Django and CityGML.

2.1 Use Cases - Using the SRI for standardized modeling of digital capabilities?

The Use Case methodology is to describe scenarios, where software is useful, or scenarios, where the methodology describes the response of a system after an external request. The SRI uses the terminology in the first sense. The advantage and disadvantage, at the same time, is that there is no need for a precise modeling language, such as UML. As terminology in digital technologies in buildings can be fuzzy (Rehmann et al., 2022) the SRI and its Use Cases provide a first step toward structuring scenarios in building operation. Additionally, the SRI has the potential for increasing data availability at urban scale, with the functionality levels providing insight in what level of information are available within the buildings and Use-Cases con-texts. To apply the SRI as a modeling tool, one needs to understand the data which needs to be present within a specific functionality level, as well as the ICT used for it. The latter, being a proxy on how to integrate the data on a technological level. Obviously, further burdens to integration, such as privacy concerns, or organizational inertia remain.

2.2 Mapping Data Needs - What data is required to support the capabilities?

By mapping the data needs of an SRI service and its functionalities, we derive what data needs exist for each level. Mapping data needs requires an overview of possible data in the built environment. (Luo et al., 2021) identify ten categories of data in buildings (Energy use data, Onsite power generation data, Indoor-Environmental data, outdoor environmental data, Equipment operational data) in a meta ontology. (Xiong et al., 2024) add one more data category (Cyber (IoT) device data), tags for further refinement, and provide use cases that are mapped to these data needs. We adapt this approach to identify data needs for the use cases of the SRI. Storage management is considered as the same category as demand management. Additionally, it is assumed, that each service level had at least the requirements from the previous service level. For example, service level 2 inherited all data needs from service level 1. This approach is quite intuitive and helps to understand, what kind of data needs to be measured, collected, and analyzed to obtain which SRI service level. However, it neglects the ICT infrastructure to do so and the control strategies, which are essential parts of the SRI as well.

2.3 Mapping Technologies - How is the data obtained and processed?

By mapping technologies to Use Cases and functionality levels, a realistic understanding of how the data is obtained and processes is derived. However, to our knowledge, there is no database or data available that cover a huge number of buildings and their related smart functionalities. As a proxy, we use the building competition developed and described by (Voss et al., 2021) that provides information about the Solar Decathlon (SDE), its buildings, and the used technologies. A variety of information is available, from jury ratings to detailed project manuals. While the SDE mainly focuses on residential buildings in newly built constructions, it offers the advantage of a database representing over 20 years of building history in six regions of the world to develop a robust data model. It also offers the benefits of having highly detailed, but realistic built information. Reflecting on what kind of information might be available, at non standardized level. Hence, we argue, if the model cannot be filled with data from the SDE, it is even more unrealistic in practicable scenarios. To access the database and analyze information, we used a data mining approach, using Selenium to download all files, automatically search them for the keywords: *Monitoring, Control System, Control Strategy, Building Automation, Energy Management and Demand Response*. Reports containing these keywords were tagged. From the tagged words, three projects were randomly selected. If each of the functionality levels have at least an exemplary description, a digital archetype can be devised. The data collection and standardization in the SDE documentation is fuzzy and open to interpretations in the matching to functionality levels.

2.4 Standardized Modeling - How is the information modeled at an urban scale?

Based on the previous three subsections, the following information should be included in the data model: General information about the SRI (SRI Services, assumed functionality levels), about the data needs (Type of data, energy form, spatial and temporal scale), and about the ICT (Technology, communication technology, Control Strategy). Sharing information about the data needs, can be considered a proxy for sharing the actual data to the public and hence keeping relevant information about real time energy consumption private. The model will be created using CityGML and the Application Domain Extension concept (ADE).

3 Discussion and Outlook

Three questions have been raised and answered in this working paper. First, the SRI is used a tool for providing Use Cases and to increase understanding which digital capabilities a building has. Second, using the functionality levels and to map data needs and identify ICT configurations, typical configurations of digital capabilities are derived. Finally, a conceptual and logical model is derived, to model the SRI and the digital capabilities of buildings at urban scale. This model and its information can be integration into other technologies, such as UBEM. This is of benefit for stakeholders in the energy system, because it provides information for better understanding the capabilities of buildings at scale, such as their demand flexibility. For example, by analyzing the ICT, it's possible to understand whether flexibility actually can be provided based on communication infrastructure or operation mode. However, modeling the digital technologies and digital capabilities of buildings at urban scale leads to at least as many similar uncertainties as modeling urban energy demand. The mapping and information collection is labor-intensive.

Future version of this article will provide information about the mappings and the collected in form of a database and a database schema. This concept will be linked to a simulation model to display the advantages of standardized modeling of digital archetypes. In doing so, the proposed research evaluates the SRI as a model to describe digital applications such as Energy Management Systems in a standardized manner and provides insight on how to provide an abstraction of the use cases in a structured manner. We are currently working on integration into the CityGML and EnergyADE concept, extending the code by (Remmen, 2022).

Acknowledgement

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V. Hypothesis for defining functional entropic interactions in the construction sector

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Abstract

In this article, we propose to share our concrete experience of construction projects, from design to execution, within the framework of energy measurement analysis. Firstly, we will attempt to define the concept of entropy as applied to construction, and more specifically to establish links between the design, execution and use phases. An approach known as "building entropy", which could be a new cross-disciplinary approach, intrinsically interwoven thanks to the management of data. Beyond the traditional definition of entropy and its three laws of thermodynamics, which are easily quantifiable in the construction industry, the broader analysis of the life cycle requires continuity in measurement: measurement is quantity, quantity is data. We therefore set out to make the link between the entropic quantification of construction and then the measurement of uses through the entropy of data.

To follow, we postulate that the dichotomy between the use phase and the design phase due to a lack of coherence between the different measurement approaches is a source of energy entropy. At the same time, we rely on the idea that the conjunction of the two models of entropy, thermodynamics and information, can become a theoretical common denominator making it possible to give more meaning and continuity from cradle to cradle. Our hypothesis is that the entropy common denominator could be an important key to linking the construction phase with the use phase in tools for measuring the life cycle of buildings.

Keywords: Entropy, data, metering, buildings, cradle to cradle, life cycle assessment.

1 Introduction to the problem

"The ecological transition is the indispensable horizon of our societies, the digital transition the great transformative force of our time. The former knows its destination but is struggling to map out its path; the latter is our everyday life, a permanent force for change, but one that is not pursuing any

particular collective objective. One has the goal, the other the path: each of the two transitions needs the other!" (Francou et al., 2019)

With the arrival of the new EPB standard in April 2024[1], the European Union is making a formal commitment to decarbonising buildings at the level that matters most to users. This new energy standard is based on two elements. The first involves continuity and improvement of existing buildings; the second, which is of greater interest to us, involves monitoring buildings to ensure that the energy targets set at the design stage are met over time. Our research, both at university and in design offices, focuses on the complex relationship between these two issues: the EPB calculation of buildings and the management of results over the long term through energy monitoring. These two subjects are not so simple to link together to give meaning and coherence throughout the life of the building (LCA) and we are forced to note a wide difference between the figures announced at the moment of the technical completion of the buildings and, a few years later, the reality on the ground with the users. This raises the useful question: 'How can we link the data from building energy simulations with the reality of use?

At this time, the process is far from optimal, with different digital measurement, design and usage tools being used more often than others. At the same time, there is little research literature linking energy simulation and optimisation tools with quantified long-term usage analyses. The biggest problems concern the limitations of current forecasting techniques, such as the need for large datasets, generalisation problems and the high computational complexity of deep learning models (Hussain et al., 2021), compounded by modelling uncertainties or the quality of post-construction data (Carstens et al., 2018). Some works contribute to the advancement of research (CEREMA, 2021; Novel et al., 2019), but remain a niche field. Optimisation is integrated into both timeframes (simulation and uses), but they do not make any real links with the other part in the process of digitalizing and quantifying building energy. This fragmentation phenomenon is also linked to the multiplicity of construction contexts and subsequent uses (Adolphe et al., 2017). BIM (with the IFC protocol) is becoming an important part of the cross-disciplinary construction process, from design to everyday use. However, it is still mainly a data medium to which various measurement tools are applied, without necessarily integrating one with the other. This is a dichotomy that we are endeavouring to reduce in the specific field of the projects we are working on (Simoens et al., 2024), and we offer an overview of our analysis in this article, based on the identification of cross-cutting issues.

[1] Directive 2024/1275 of the European Parliament of 24 April 2024 on the energy performance of buildings was published on 8 May 2024 and came into force on 29 May 2024 with a transposition deadline of 2 years for member states (cf. 26 May 2026).

1.1 Entropy from stylus to renovation

1.1.1 Challenges

The term "carbon accounting" has been used for more than 30 years[2] to describe initiatives aimed at internalising the issue of climate change into company operations and CSR policy (Le Breton and Aggeri, 2015). These issues have recently accelerated in Belgium with the need to quantify Scope 2 and 3 for multinationals planning their carbon reduction targets for the period 2030-2035. This has led to unexpected demands on subcontractors, who are themselves faced with questions about Scope 2 and therefore their own GHG production. As a result of the European Green Pact[3], there is now greater awareness of the impact of construction on the carbon footprint of smaller companies, which, it should be remembered, accounts for around 37% of total greenhouse gas emissions (United Nation Environnement Programme, 2022). This new awareness is influencing the work of design offices and forcing them to integrate carbon accounting not only during the construction phase, but also throughout the building's lifecycle. The Belgian scientific centre for construction, Buildwise[4], is already integrating this link between construction and use through the new construction timeframe:

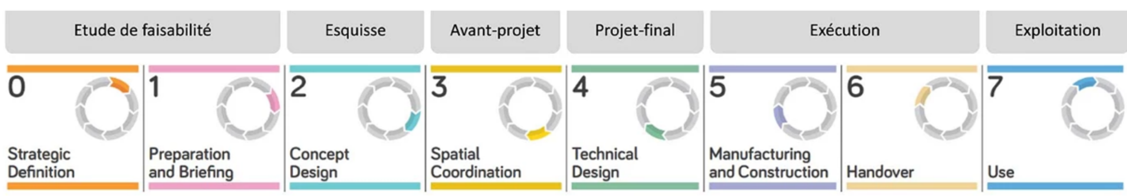

Figure V-1: A model for the adoption of information structures that should lead to greater consistency, reproducibility and predictability in a performance-based approach to projects. Buidlwise, Reflection on the phasing of a construction process, 29 March 2024

However, the links between construction and use are not, strictly considered, exploitable, given the differences in the software systems used either to design or to manage buildings, with or without digital twins. In an attempt to find practical links, we are going to try to define specific theoretical links between these two essential and constituent moments in the life of a building. It should be noted that our approach is based solely on induced emissions, i.e. emissions produced by real estate activities, excluding avoided or sequestered emissions (Daunay et al., 2019).

[2] Following on from the Earth Summit in Rio (1992).

[3] The European Commission has adopted a series of proposals aimed at adapting the EU's climate, energy, transport and taxation policies with a view to reducing net greenhouse gas emissions by at least 55% by 2030 compared with 1990 levels.

[4] https://www.buildwise.be/en/

1.2 Entropy concept applied to buildings

1.2.1 Building applications

The construction of a building can be defined in terms of the energy consumed in the manufacture of the materials, the construction and the facilities required for this construction (transport, assembly, etc.). To quantify these data and give them meaning at site level, Belgium has developed the GRO method, based on the ISO 14001 and 50001 approaches combined with specific TOTEM tools (LCA analysis) and the calculation of the EPB. All of these environmental management tools (EMS) can be used to develop a monitoring method for each stage of the project, which already meets the DNSH(European Commission, 2021). Strictly speaking, the tools do not measure the entropy of a building during the design and construction phase, but they do provide data for an induced analysis, particularly of the entropic increase of buildings during the construction phase.

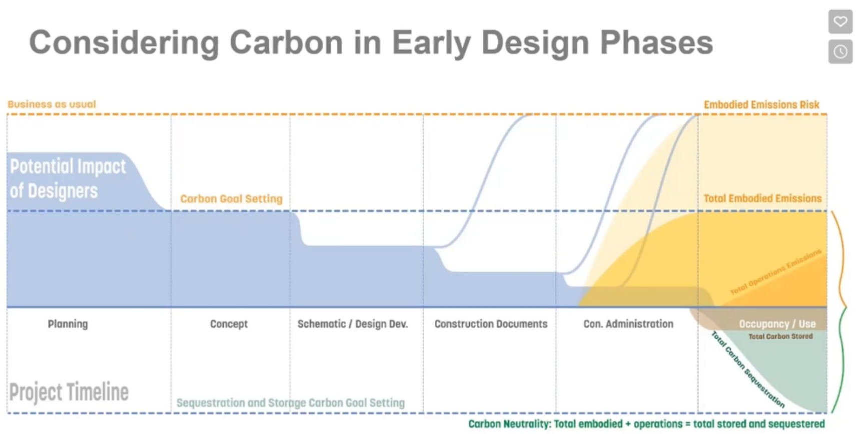

Figure V-2: Concept diagram of the potential impact of designers regarding carbon budget of projects over the project life en incluant l'usage de la maquette numériqueet le LCC. Sasaki, Carbon conscience tool, Realizing climate action ambitions, ASLA conference, 29 October 2023.

The integration of entropic principles into the context of architectural production and its realisations allows us to understand that any isolated system tends to increase its entropy (disorder) over time and thus dissipate energy during the construction phase, but also by increasing the risks tenfold in the context of use and linked to errors in implementation. To counter these risks, the introduction of environmental passports during the construction phase enables better control of the risks of deviations in accordance with standard EN 15978.[5]. To this end, we are currently working on a 7,920 m² building for the University of Mons, for which the architects' bid called for a carbon footprint of 857 kg CO_2eq/m², compared with the national average of 1,250 kg CO_2eq/m² for industrial and office buildings. Today, during the construction phase, we have been able to further reduce this target to

[5] Contribution of construction works to sustainable development - Assessment of the environmental performance of buildings - Calculation method

755 kg.CO_2eq/m², demonstrating our capacity for entropic reduction throughout the project and construction phase.

1.2.2 Application to uses

The GRO method enables building monitoring to be quantified and valued, but it does not impose it. Often, the construction market is separated from the maintenance market. It should be noted that Belgium is attempting to apply energy accounting to buildings, but local authorities are very far from doing so. For instance, the vision of Wallonia's long-term energy renovation strategy for buildings has led to the development of an incentive plan called POLLEC.[6]. However, we note that very few local authorities are aware of the issues involved and that few are working together to establish a minimum threshold of data that will enable the models to be optimised. The aim of these various property strategies is firstly to identify the best solutions for reducing consumption (optimisation, insulation, grouping of uses, etc.), while respecting a coherent building life cycle in terms of CO_2 and then to decarbonise residual consumption. Each strategy should make it possible to provide the various structures, starting with an inventory of their assets and based on a study of present and future needs, with a clear operational vision of the scope of the choices and work to be carried out to achieve carbon-neutral public assets by 2035-2040. However, this perspective does not include the issue of gathering data grouped at the scale of a given territory in order to improve the models according to types of use. In fact, our field experience shows that two equivalent or similar buildings can provide highly variable data depending on their occupants, a problem regularly identified in the scientific literature(Carstens et al., 2018; Hussain et al., 2021).

2 The hypothesis of a global measure of building entropy

2.1 Datasphere and data at the heart of the issues

To develop our research, we are basing ourselves on the globalised approach to data through the concept of the Datasphere(Grumbach, 2022) itself referring to the terrestrial symbiotic actions of the Gaia hypothesis (Lovelock, 1973). The theory of the Datasphere is based on the transversality of data in the world for any object or life form. From our DNA to a building, data becomes the lowest common denominator (PCDN). This approach gives meaning to J. Lovelock's hypothesis linking the interactions between living beings and the components of the Earth. We still need to define the links between the users of a building and the building itself.

[6] Local energy and climate policy.

2.2 Linking the material and human worlds to understand them, measure them and reduce their entropy

As stated earlier in this article, it is particularly difficult to link the design of buildings to environmental objectives that cannot, moreover, be achieved by users(Peñasco and Anadón, 2023). This raises the question of simulation models, which are essentially based on energy model issues without incorporating questions of use, which are delegated to other systems, themselves constrained by quantified approaches linked to IPMVP-type protocols.[7]. These protocols and calculation methods are not sufficiently consistent to reduce estimation errors, which can have a major impact on the objectives set by Europe. It is fundamentally necessary to create a link between these two types of measurement by establishing common ground between the principles of the laws of thermodynamics and those of data entropy, which go hand in hand with the entropy of uses. Our current line of research is based on a hypothesis which assumes that reducing constructive entropy can reduce the risks of use by reducing the parameters to be measured. In other words, we are seeking to reduce the noise in the usage message (2thlaw of information) in order to reduce the interpretations and entropic risks that could follow. A model could emerge including building design parameters that would have determined an entropic impact on uses and thanks to more complex logarithmic models. This type of modelling has already been initiated in the context of systemic design of plans, demonstrating that plan models, depending on the shape of the container (external walls, entrance ports and windows), could be simulated by more than 90% by algorithms compared with the equivalent work of architects(Huang and Zheng, 2018; Chaillou, 2019).

3 Conclusion

In this short article, we propose to briefly analyse the important dichotomy between design and use in life cycle analysis. This result is partly linked to the orientation of simulation models, which attempt to respond to one of the two objectives without taking into account the complexity of the other. Based on this day-to-day observation, through our work in design offices and our scientific research, we are currently seeking to define the possible links between design and implementation in order to enable better integration and develop cross-disciplinarity without losing data quality. Based on the laws of Lavoisier and Shannon, linking energy and usage issues through a common data base, our current aim is to refine the socio-determining factors of usage that can have an impact on energy consumption in a building. These determining factors will then be able to feed into building simulations and refine the results for greater energy efficiency.

[7] International performance measurement and verification protocol

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VI. The role and contribution of SRI-Smart Buildings to Smart Cities

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Abstract

The increasing population, coupled with the movement towards cities and dense urban areas, presents numerous challenges to cities. This study investigates the role and contribution of the Smart Readiness Indicator (SRI) in the context of smart buildings and smart cities and examines how the SRI can facilitate the future success of smart cities. We developed a framework by integrating the SRI with a well-known smart city model and collected data with content analysis and expert interviews. The framework evaluates the relationship between SRI and the smart city model with six dimensions: smart economy, smart mobility, smart people, smart governance, smart environment, and smart living. Our findings indicate that a building-level SRI clearly and directly impacts smart city performance with the highest impact on the smart economy. It also substantially affects smart mobility, environment, and living. However, its influence on smart governance is lower, and no link was found with smart people according to our framework. In conclusion, the development and success of smart cities heavily depend on integrating smart building frameworks and indicators that measure and enhance urban functionalities. This study suggests that the SRI framework should be broadened to encompass the "smart people" dimension, also enhancing its focus on accessibility.

Keywords: Smart city, Sustainable cities, Digital Cities, Smart Readiness Indicator, SRI

1 Introduction

The increase in population along with the movement of the population to cities and dense urban areas creates challenges in the society. In the 1950s, only 30% of the global population resided in urban areas, the United Nations (UN) projects that by 2050 this section will constitute 66% of the total population (Yin et al., 2015). UN-Habitat reports that cities are responsible for 78% of global energy consumption and generate over 60% of greenhouse gas emissions (UN-Habitat, 2020).

Digitalization is regarded as a fundamental component for attaining the climate goals set by the European Union (Janhunen et al., 2019), which include achieving climate neutrality by 2050 (Märzinger & Österreicher, 2020). The smart city concept fundamentally supports environmental sustainability, with its primary objective being the reduction of greenhouse gas emissions in urban areas through the implementation of innovative technologies (Ahvenniemi et al., 2017). Smart cities represent an advanced iteration of green and sustainable urban concepts, incorporating elements of intelligent city frameworks with a broader socio-economic perspective. This integrated approach maintains the core functions of traditional urban environments while employing cutting-edge technologies to achieve optimal sustainability and efficiency across diverse urban domains (Winkowska et al., 2019).

Smart cities encompass a hybrid concept that integrates physical infrastructure, tangible urban realities, actual residents, and concurrent virtual environments within cyberspace (Carglia & Granell, 2012), (Stamatescu et al., 2019). Marrone & Hammerle, 2018, identified two predominant approaches in contemporary smart city discourse: a technology-oriented approach and a people-oriented approach. According to Harrison et al., 2010, a smart city is defined as one that integrates physical, technological, social, and business infrastructures to enhance the collective intelligence of the urban environment. Such cities utilize a range of devices including computers, smartphones, the internet, and social networks to facilitate data collection and connectivity.

Digital solutions have the potential to enhance efficiency in urban service delivery, especially as cities face the challenge of accommodating growing populations with finite resources due to rapid urbanization (Ahvenniemi & Huovila, 2021). The current version of the smart readiness indicator (SRI) framework primarily concentrates on assessing the resilience and energy performance of individual buildings, yet it has the potential to serve as a valuable instrument for managing building utilities at the urban level (Plienaitis et al., 2023). Understanding the role and contributions of SRI-Smart Buildings is crucial as cities globally adopt smart technologies to enhance urban living. To support the wider adoption of SRI, this study explores opportunities for integrating the SRI methodology at the smart city level, considering its potential impact on various dimensions of a well-know smart city model.

The present paper is divided into four section. The second section introduces the SRI-smart city framework, data collection and analysis. The results are described in the third section, and finally conclusions are drawn in the fourth section.

2 Methodology

The study developed and utilized an SRI-smart city framework to evaluate the linkages between the SRI main domains (heating, domestic hot water, cooling, etc.), and six smart cities' key dimensions: smart economy, smart mobility, smart environment, smart people, smart living, and smart governance. The SRI-Smart City framework developed for this study is visible in Appendix 1.

Due to the wide variety of smart city models and definitions, we developed a four-step criterion to select the appropriate smart city model for the present study. The model was required to be applicable in European countries, measure smartness, provide sufficient information on methods and metrcis applied to assess smartness, and cover a wide range of city functions. For the present study, we selected the smart city model developed by Giffinger et al., 2007. The model was chosen for its broad acceptance and comprehensive coverage of the six, previously mentioned, key smart city dimensions.

Finland was selected as the test environment for evaluating the SRI-Smart City framework for several key reasons. According to Janhunen & Junnila, 2022, the SRI framework may face limitations in regions with distinct climate characteristics, such as cold climates, which often have relatively clean electricity systems. Nordic countries, including Finland, are notably committed to climate change mitigation (Anttonen et al., 2023). Additionally, Finland's early adoption of the SRI framework (Janhunen et al., 2019), and its leading role in digitalization within the real estate and construction sectors make it an ideal setting for this study.

To gather practical insights and assess the SRI-Smart city framework (shown in Appendix 1) a hybrid workshop was organized representing in total 10 in-person and online participants. 3 of the participants were smart city specialists, 6 had a solid experience with SRI and the real estate sector, and 1 was urban planning specialists.

The workshop included a comprehensive overview of the developed SRI-Smart City framework, and it was structured to accommodate a diverse audience. Additionally, two participants submitted their completed SRI-Smart City frameworks following the workshop, contributing further insights and feedback. This approach facilitated a thorough exchange of knowledge and ensured a broad range of perspectives were incorporated into the evaluation process.

To categorize and prioritize the insights, the ABC classification method, known as Pareto's law, was utilized (Bhattacharya et al., 2007). This method allows for the segregation of items into three distinct categories: Class A, representing highly relevant insights (2); Class B, signifying moderately important (1); and Class C, encompassing the least important data points (0).

The selected participants provided valuable feedback for the future development paths for the SRI-smart city framework. Their diverse insights were instrumental in understanding the practical application and perceived effectiveness of integrating SRIs into the smart city model.

3 Result and discussion

The findings from the expert evaluations offer critical insights into how the SRI can drive forward smart city initiatives. These insights reveal that while the SRI significantly contributes to several key dimensions of smart cities, such as the smart economy, smart mobility, smart environment, and smart living, its impact on the dimensions of smart people and smart governance requires further refinement.

Based on the expert evaluations, the contributions of the SRI to various dimensions of a smart city were assessed. The SRI-Smart city framework used key dimensions of a smart city: smart economy, smart mobility, smart environment, smart living, smart people, and smart governance. Figure *VI-1*, depicts the expert evaluation of the SRI contribution to key dimensions of a smart city.

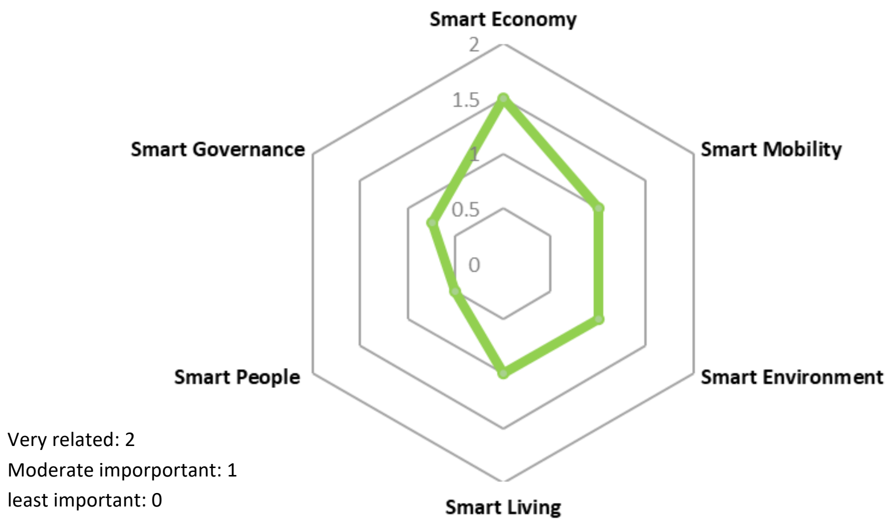

Figure VI-1. Expert evaluation on SRI contribution to smart city dimensions.

The findings from the expert evaluations offer critical insights into how the SRI can drive forward smart city initiatives. The results indicate that the SRI moderately contributes to several key dimensions of a selected smart city model, specifically smart economy, smart mobility, smart environment, and smart living, as depicted in Figure *VI-1*. The insights gathered from the SRI-smart city framework are summarized by the key dimensions.

Smart Economy: Experts unanimously agreed that the SRI plays a crucial role in enhancing the smart economy. This can be attributed to the SRI's ability to measure and promote the adoption of technologies and infrastructures that support economic activities, innovation, and competitiveness.

Smart Mobility: The SRI’s emphasis on intelligent infrastructure and data-driven transport solutions appears to be pivotal in advancing mobility solutions within urban settings.

Smart Environment: The positive evaluation of SRI’s contribution to the smart environment dimension highlights its effectiveness in promoting sustainable practices and technologies. This includes energy efficiency, waste management, and the use of renewable resources.

Smart Living: The experts also recognized the SRI's importance in enhancing the quality of life through smart living solutions. These include smart health services, education, safety, and overall urban living standards. However, there was some divergence in opinions regarding the dimensions of smart people and smart governance. The SRI contributes positively to these areas, there might be some limitations or areas requiring further development.

Smart People: The linkage between the SRI and smart people was not unambiguous. The mixed evaluations could stem from the SRI's focus, which may not fully encompass aspects related to citizen engagement, education, and inclusivity. While the SRI promotes technology readiness, it might not fully address the socio-cultural aspects of a smart city.

Smart Governance: The variability in expert opinions towards smart governance suggests that while the SRI provides a framework for intelligent urban management, there could be challenges in its implementation or scope. Effective governance in smart cities requires not just readiness but also adaptability, transparency, and responsiveness, which might not be fully captured by the SRI metrics.

4 Conclusion

This article evaluates the role and contribution of SRI-smart buildings to smart cities by establishing an SRI-smart cities framework and conducting a workshop with experts to gather their insights. The findings indicate that the SRI has a moderate contribution to the smart city concept, particularly in the areas of smart economy, smart mobility, smart environment, and smart living. However, the linkage between SRI and the dimensions of smart people and smart governance is less clear.

The proposed SRI-smart city model allows city developers to asses the building stock's current state on a building and city level simultaneously. This allows more specific analysis of the key focus areas of the city and assist in identifying the areas for further development.

Expert evaluations reveal that while the SRI is valuable in promoting and measuring city readiness in key dimensions critical to smart city development, there is room for improvement. The strong positive feedback for smart economy, mobility, environment, and living highlights the SRI's role in these areas, but mixed responses for smart people and governance suggest the need for further refinement. By linking the SRI with the smart city model, cities can leverage the strengths of both frameworks, ensuring that advancements at the building level are aligned with and contribute to the overarching goals of smart city development. Future research should address these limitations by developing additional metrics or integrating more comprehensive indicators for socio-cultural and governance aspects.

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Appendix 1: SRI-Smart city framework

Table VI-1: SRI-Smart city framework

<table>
<tr><td rowspan="5">The SRI Framework
• Heating
• Domestic hot water
• Cooling
• Ventilation
• Lighting
• Dynamic building envelope
• Electricity
• EV charging
• Monitoring and control</td><td>Smart Economy</td><td>Smart Mobility</td><td>Smart People</td><td>Smart Governance</td><td>Smart Environment</td><td>Smart Living</td></tr>
<tr><td>• Innovation spirit,
• Entrepreneurship
• Productivity
• Ability to transform.
• International embeddedness
• Economic image & trademarks</td><td>• Local Accessibility
• (Inter)National accessibility.
• Availability of ICT infrastructures
• Sustainable Resource Management</td><td>• Level of qualification
• Affinity to lifelong learning
• Social and ethnic plurality
• Participation in public life
• Creativity
• Flexibility
• Cosmopolitanism
• open-mindedness</td><td>• Participation in Decision making
• Public and social service
• Transparent Governance
• Political Strategies Perspective</td><td>• Attractivity of natural conditions
• Pollution
• Environmental Protection Sustainable Resource Management</td><td>• Cultural facilities
• Education Facilities
• Social cohesion
• Health conditions & individual safety
• Housing Quality
• Touristic attractivity</td></tr>
<tr><td>SRI linkage</td><td>SRI linkage</td><td>SRI linkage</td><td>SRI linkage</td><td>SRI linkage</td><td>SRI linkage</td></tr>
<tr><td>A: very related, 2
B: moderately important, 1
C: least important, 0</td><td>A: very related, 2
B: moderately important, 1
C: least important, 0</td><td>A: very related, 2
B: moderately important, 1
C: least important, 0</td><td>A: very related, 2
B: moderately important, 1
C: least important, 0</td><td>A: very related, 2
B: moderately important, 1
C: least important, 0</td><td>A: very related, 2
B: moderately important, 1
C: least important, 0</td></tr>
<tr><td>Notes</td><td>Notes</td><td>Notes</td><td>Notes</td><td>Notes</td><td>Notes</td></tr>
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