Aspects of Next Generation EPC's Definition v2

The D^2EPC project has received funding from the EU's Horizon 2020 research and innovation programme under grant agreement No 892984

Project Acronym:	D^2EPC
Project Full Title:	Next-generation Dynamic Digital EPCs for Enhanced Quality and User Awareness
Grant Agreement:	892984
Project Duration:	36 months (01/09/2020 – 31/08/2023)

Deliverable D1.6 Aspects of Next Generation EPC's Definition v2

Work Package:	WP1 – Foundations for next-generation dynamic EPCs (dEPCs): Identifying challenges, needs and opportunities
Task:	T1.3 – Definition of the dynamic EPC scheme
Document Status:	Final
File Name:	D^2EPC_D1.6_Aspects of Next Generation EPC's definition v2_KTU
Due Date:	30.04.2022
Submission Date:	29.04.2022
Lead Beneficiary:	Kaunas University of Technology (KTU)

Dissemination Level	
Public	☒
Confidential, only for members of the Consortium (including the European Commission)	☐

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Version History

v	Author	Date	Brief Description
0.1	Lina Šeduikytė	04.02.2022	Update ToC
0.2	Lina Šeduikytė	10.02.2022	First draft with updated information in regard to the first version, sent for feedback collection
0.5	All authors	31.03.2022	Updated information based on input from partners
0.6	Lina Šeduikytė	15.04.2022	Document ready for peer review
0.8	Lina Šeduikytė	26.04.2022	Updated based on peer review comments
1.0	Lina Šeduikytė	29.04.2022	Final version ready for submission

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Executive Summary

The current report is the deliverable D1.6 which aims to present the aspects of the next generation EPC schemes, as defined within D^2EPC. As a second deliverable version, it steps on and further updates the findings of the previous version (D1.3) submitted in M5. D^2EPC aims to analyse the quality and weaknesses of the current EPC schemes and identify technical challenges that currently exist to overcome them, and set the grounds for the next generation dynamic EPCs.

Based on this report's research, it was revealed that the majority of EU countries do not employ by any means BIM documentation and literacy or digital logbooks for the issuance of EPCs. Even though there is the provision of BIM (Building Information Modelling) documentation and digital logbooks in some countries, these are used as a source of information for the EPC assessment procedure or energy simulations.

Based on the findings of this report, it can be stated that:

- BIM is considering as a significant part of DT (Digital Twin) with semantically rich and geometrically accurate data.
- Both BIM and DT concepts are applicable to increase efficiency in AECO (Architecture, Engineering, Construction and Operation) industry throughout different building life cycle stages.
- BIM users can benefit from the reduction of energy due to energy performance-related components: building system analysis and management; asset and space management; simulations on design and operation stages; better decisions for investments; reduction of operational costs (energy as well)

The introduction of novel aspects in the certification process includes the smart-readiness level of the buildings, human comfort-related indicators, and environmental aspects (LCA).

Based on the research of this report, it could be stated that one of the main limitations in the current SRI methodology is identified in the qualitative evaluation of the included services and technologies, and in particular, their presence, without considering for evaluation their actual performance. the information contained within each functionality level may be modelled or documented up to a certain degree when Building Information modelling (BIM) is concerned, however, the capacity of BIM models to define higher functionality levels (representing complex BACS systems and sophisticated solutions) becomes challenging. In addition, according to the analysis under this task, the current state of data for EPC assessment precludes the performance of the SRI assessment. While some screening information for the SRI can be recovered, this information is insufficient to determine the building's SRI score.

Analysis of green building certification systems showed that LEED and BREEAM aim to determine overall sustainability based on factors including design, construction, maintenance and operation. The WELL certification heavily focusses on the factors affecting occupant needs and comfort from IEQ to nourishment, fitness and state of mind. LEVEL(s) is a common European performance-based framework for the sustainability of the buildings, emphasizing essential aspects like - health and comfort - related to the building’s performance enabling the assessment of them via suitable indicators. Among the IEQ components, the most significant for LEED, WELL, and SRI schemes is the indoor air quality (~50% contribution to the total IEQ credits), while visual comfort is the most credited for the BREEAM certification (33%). IAQ and Thermal comfort are credited equally for the LEVEL(s). The comparative assessment performed on those well-established certification schemes and frameworks governing the human comfort has shed light on the domains of indoor environmental quality selected to be examined within the project. The IEQ pillars considered correspond to the thermal comfort, the visual comfort and the IAQ.

In the D^2EPC project, the LCA Indicators for EPCs will significantly contribute to the maximization of the energy savings and the achievement of carbon reductions of the buildings to issue sustainable EPCs. Suggested improvements will speed the transaction into NZEBs, control the building's energy demand, reduce carbon emissions, and enhance public awareness.

Digital Twin concept, Building Information Modelling, and geolocation practices should be adopted for data collection and calculation of a novel set of energy, environmental, financial, and human comfort indicators. Techniques for the correct geolocation of EPCs can be applied both with an automated/semi-automated manner and with a manual user-defined position through a smartphone application/handheld GNSS antenna. The dynamic character of EPC geo-visualisation provides a spatiotemporal element crucial for understanding multiple factors that interact and affect the overall building's energy performance.

The monitoring of buildings' actual energy consumption will enable the development of motivational schemes, which will enforce the continuous improvement of buildings' energy performance. Polluter pays and reward policies will be developed and introduced for those EPC owners who either do not meet or exceed their certificates' expectations, in a similar rationale as with the ETS scheme, aiming to motivate energy consciousness.

The proposed D^2EPC scheme is expected to transform EPCs into a user-friendly, reliable, and cost-effective informative tool for both the wide public (building users, occupants, owners, etc.) and professionals (building managers, engineers, designers, etc.), as well as to establish the grounds for turning EPCs registries into consistent policy feeding mechanisms. The third and final version of the deliverable is due to be delivered on M36 and will include the complete information, concluding the work under Task 1.3.

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List of Acronyms and Abbreviations

Term	Description
AEC	Architecture Engineering Construction
AECO	Architecture Engineering Construction and Owner - operated
BACS	Building automation and control system
BIM	Building Information Model
BMS	Building Management System
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer Aided Design
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardisation
D	Deliverable
DHW	Domestic Hot Water
DT	Digital Twin
dEPC	dynamic Energy Performance Certificate
EBC	Energy in Buildings and Communities
EED	Energy Efficiency Directive
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
ETSI	European Telecommunications Standards Institute
EU	European Union
FM	Facilities Management
GIS	Geographic Information System
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environment Quality

IEA	International Energy Agency
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
ISO	International Organization for Standardization
IoT	Internet of things
LEED	Leadership in Energy and Environmental Design
LCA	Life Cycle Assessment
LiDAR	Light Detection and Ranging
M/480	Mandate M/480, standardization requests issued as the recast of the EPBD
MEP	Mechanical, Electrical and Plumbing Systems
MS	Member State
NDT	National Digital Twin
PIR	Passive infrared sensor
RED	Renewable Energy Directive
SRI	Smart Readiness Indicators
T	Task
TBS	Technical Building Services
TCs	Technical Committees
TVOC	Total volatile organic compounds
WP	Work Package

1 Introduction

1.1 Scope and Objectives of the Deliverable

WP1 aims to explore the technological and market conditions where D^2EPC will be realized, as well as to investigate the challenges of current EPC schemes. This work package will set out the conceptual and contextual ground for the next generation EPCs envisioned in D^2EPC project (state-of-the-art analysis, user requirements, market trends, and detailed D^2EPC scope).

The aim of the Task 1.3 Definition of the dynamic EPC scheme is to introduce and describe the concept of the dynamic EPC scheme, as envisioned in the project. This report is the second version on the Aspects of Next generation EPC's definition and aims to update the general scope and necessary information which have been formulated from the development of the project's tasks up to M20.

1.2 Structure of the Deliverable

The structure of Deliverable D1.6 is as follows:

i) Analysis and decision of the specific procedures and standardized methods which will be exploited, as well as the modifications required to exploit real-time data for the classification of the energy performance of different types of buildings;
ii) Required elements for the inclusion in the dynamic EPC of the novel set of indicators, covering aspects of the smartness of the building, its human comfort as well as its life cycle environmental and economic performance;
iii) Introduction of geolocation practices for the documentation and registration of the EPCs to be delivered by the proposed concept;
iv) Introduction of the digital twin concept and the definition of BIM aspects;
v) Policy implication aspects which concern the new perspectives that the dynamic EPC will create at the policy-making level;
vi) Compliance of these elements with the current EPC schemes and the upgrade requirements to satisfy the proposed novelties.

The revision of D1.3 was performed in (M18-M20). The following sections were updated: 4.1.1. Smartness of the buildings, 4.1.3. Life cycle assessment, 4.2. The introduction of geolocation practices for dynamic EPC, 5. Policy implementation aspects, compliance with the current EPCs schemes and the upgrade of the requirements and Conclusion part. The new sections were added to the deliverable D1.3: Aspects of Next generation EPC's definition v2: 4.1.2.4. Human comfort and wellbeing indicators as envisioned in the dynamic EPC, 4.1.3.4. Findings concerning LCA indicators, 4.1.3.5. Recast of the energy performance of buildings directive, 4.2.4. Geolocation practices for EPC documentation and proposed added values service, 4.3.6. BIM data standard relevant for D^2EPC, 4.3.7. D^2EPC information delivery specification, 4.3.8 IFC parser, 5.1.3 Findings concerning the incentives and restrictions.

1.3 Relation to other Tasks and Deliverables

Task 1.3 analyses and conclusions will be used towards the development of a dynamic EPC for the building and further work of work package two (WP2) and Deliverables D2.1 – D2.4.

2 Methodology

For the definition of the dynamic EPC scheme, the following methods were used:

- Field research in the form of qualitative interviews to identify whether new standards on the topics concerned by next generation EPCs are currently under development.
- Field research in the form of questioner survey related to challenging matters
    i) EPCs issuing, quality and control,
    ii) EPCs calculation software and tools,
    iii) EPCs indicators and
    iv) Qualified experts competence and skills.
- Desk research for identifying novel indicators, new practises of geolocation, BIM, and Digital Twins which could be used for the new dynamic EPC.
- Desk research related to challenging matters of EPCs.

3 The Role of Standardisation in Next Generation EPCs

3.1.1 Current Framework of Standards Used for EPCs

At present, the EPC is one of the most important sources of information regarding the energy performance of the EU's building stock. Furthermore, the effective monitoring of buildings' energy performance and the impact of energy efficient building policies over time, could potentially be achieved by EPCs. EPCs could also prove effective in supporting the implementation of minimum energy requirements within the regulatory process. The revised standards on the Energy Performance of Buildings (EPB) under Mandate 480 is modularly structured beginning with the general framework for energy performance assessment (EN ISO 52000-1 and CEN ISO/TR 52000-2). Given that almost 100 documents are referred to, the table below provides a non-exhaustive overview on how D^2EPC can contribute.

Table 1. List of new EPB Standards under Mandate 480

Identified Standards	Short description & project's contribution
EN ISO 52000 series	General framework and procedures for the EPB assessment. Part 1 of this series provides the methods used in calculating the energy performance factors for reporting. The necessary input data is calculated in the standards listed below.
CEN/TS 16628 and CEN/TS 16629	Basic principles & detailed technical regulations concerning EPB-standards.
EN ISO 52003 series	Basis for issuing the certificate. Includes requirements, indicators, ratings and certificates and defines the general features and their contribution to the overall energy performance.
EN ISO 52010 series	Converts climatic data for use in energy calculations.

EN 15316 series	Heating and cooling efficiencies and system energy requirements are defined by this standard. They include space heating, space emission, space distribution, and domestic hot water (DHW) generation (boilers incl. biomass, heat pumps, thermal solar and photovoltaic systems, building-integrated cogeneration systems, district heating and cooling, air heating and overhead radiant heating systems including local stoves, heating and DHW storage systems excluding cooling) and system inspection.
EN ISO 16484 series **EN 15232**	Specification of the required phases for Building automation and control system (BACS) projects and the hardware required to execute tasks within a BACS. The standard also indicates prerequisites for overall functionality and engineering services needed for building automation and control systems. Control, building automation, and technical building management functions categorized and structured consistent with (BAC). Minimum requirements for the control, building automation, and technical building management functions that contribute to the energy efficiency of a building. Assessment methods to determine the effect of the given functions on a specific building.
EN 16798 series	Standards on building ventilation, including the determination of indoor air quality and indoor environmental input parameters for design and assessment, thermal environment, illumination, and acoustics. Ventilation and air conditioning of non-residential buildings and calculation methods for their energy requirements as well as air flow rates. Energy requirement calculation methods for cooling systems (incl. generation and storage) as well as ventilation and air conditioning system inspection.
EN ISO 52016 series and EN ISO 52017 series	Calculation procedures determining the energy needs for heating and cooling, internal temperatures and, sensible and latent heat loads.
EN 15193 series	Methods to evaluate the energy requirements for lighting.
EN 15323 series, EN 12098 series, EN 15500 series, EN 16946 series and EN 16947 series	Impact of Building Automation, Controls, and Building Management. Requirements on control equipment for DHW heating systems, electrical heating systems, and electronic individual zone control equipment as well as automation, controls and technical building management system inspection.
EN ISO 52018 series	The standard provides an overview of options for the indicators used in thermal energy balances and fabric features in partial fulfilment of EPB requirements.
EN ISO 29481 series **EN 17412** **EN ISO 16739**	Methodology, format, and interacting framework for building information models Concepts and principles for the level of information needed for BIM

	Industry Foundation Classes (IFC) for data exchange in the building construction and facility management industries
EN ISO 19650 series	Data management using BIM.

Interoperability issues between various devices and technological components: Not yet a standard (at least common) information exchange framework among available BIM data for new and old buildings has emerged. This issue hinders the inter-departmental collaboration and exchange of BIM data, which is essential for AEC and FM companies. The standardization and boost of use of non-proprietary standards such as Industry Foundation Classes (IFC) (ISO/PAS 16739) and International Framework for Dictionaries (IFD) (ISO 12006- 3) improve the exchange of data between various BIM systems on object Level and are expected to minimize loss of information and interoperability among BIM platforms. **The enriched BIMs developed within D^2EPC will interact with both new and existing BIM through a list of interoperability services, thus setting the basis for a 'universal' interoperability framework for data exchange among different BIMs.** This list will be developed on the basis of the available standards of Industry Foundation Classes (IFC) or of the International Framework for Dictionaries (IFD).

The aim of this part is to review current standards related to next generation EPC and analyse advancements in the development of new ones.

3.1.2 Field Research for Current Advancements in the Development of New Standards

In order to identify whether new standards on the topics concerned by next generation EPCs are currently under development, a field research in the form of qualitative interviews with relevant European Committee for Standardisation (CEN) Technical Committees (TCs) was conducted. In order to identify whether CEN TCs worked for the development of relevant standards in the field of real-time data and buildings energy assessment, the TCs presented in Table 2 were contacted. The committees were requested to inform whether standards on energy performance of buildings calculations based on real time data were under development. In particular, five CEN TCs that were involved in drafting and publication of the EN ISO "EPB standards"[1, 2] [1], were contacted.

Table 2. List of identified CEN/TCs for communication

CEN Technical Committees (TC)		Contact persons
CEN/TC 089	Thermal performance of buildings and building components	Gaetani Alessia
CEN/TC 156	Ventilation for buildings	Gaetani Alessia
CEN/TC 169	Light and lighting systems	Mlanao Frédéric
CEN/TC 228	Heating systems for buildings	Mira Costa Mercedes
CEN/TC 247	Building automation, control and building management	Gaetani Alessia

[1] The term "EPB standards" refers to those standards that provide a methodology to calculate the integrated Energy Performance of Buildings (EPB). This set of standards were approved in 2017.

[2] https://www.interreg-central.eu/Content.Node/Energy-Performance-of-Buildings-standards.html

CEN/TC 371	Project Committee on Energy Performance of Buildings	Mira Costa Mercedes

The investigation was conducted at the European level since D^2EPC pursues the update of current standards on the classification requirements of buildings applicable to all EU Member States. However, the CEN TCs were also requested to refer to national standards or methodologies as at this level there might be important references for the project. Below is a brief summary of the feedback we received from the CEN/TCS:

The replies of the technical committees were as follows:

- CEN TC 228 confirmed that there is no usage of "real-time data" within this TC.
- CEN TC371 referred to the EPB Center Website. The information retrieved from EPB center was exploited in the desk research
- CEN TC 169 pointed the following standards for consideration:
    - EN 15193-1 Energy performance of buildings - Energy requirements for lighting - Part 1: Specifications, Module M9, and at the national level.
    - DIN V 18599-4 Energy efficiency of buildings - Calculation of the net, final, and primary energy demand for heating, cooling, ventilation, domestic hot water, and lighting - Part 4: Net and final energy demand for lighting
    - DIN V 18599-10 Energy efficiency of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water, and lighting - Part 10: Boundary conditions of use, climatic data
- CEN/TC 89 conducted a survey at the national level. In total, 34 European standardization bodies were contacted, from which 23 votes were obtained. The list of countries that participated in the survey is shown in Table 3.

Table 3. National standardization bodies - CEN TC 089 Voting

Member participation	
Votes cast (23)	Austria (ASI) Belgium (NBN) Bulgaria (BDS) Croatia (HZN) Czech Republic (UNMZ) Denmark (DS) Finland (SFS) France (AFNOR) Germany (DIN) Ireland (NSAI) Italy (UNI) Lithuania (LST) Malta (MCCAA) Netherlands (NEN) Norway (SN) Portugal (IPQ) Romania (ASRO) Slovenia (SIST) Spain (UNE) Sweden (SIS) Switzerland (SNV) Turkey (TSE) United Kingdom (BSI)
Votes not cast (11)	Cyprus (CYS) Estonia (EVS) Greece (NQIS ELOT) Hungary (MSZT) Iceland (IST) Latvia (LVS) Luxembourg (ILNAS) North Macedonia (ISRSM) Poland (PKN) Serbia (ISS) Slovakia (UNMS SR)
Comments submitted	0

Representatives of standardization bodies at national level were asked if they know of any standards or methodologies used in thermal performance calculations based on real-time data that would be relevant for dynamic Energy Performance Certificates. A total of four countries responded positively and provided comments, 9 answered negatively, and 10 abstained. Table 4 shows the comments respondents provided, including CEN TC 089. Belgium, Germany, and CEN TC089 pointed out that the work conducted by WG13 on "Building Energy Performance Assessment Based on In-situ Measurements" should be considered.

In addition to contacting the CEN/TCs a review on the latest trends in terms of standards development based on the CEN and CENELEC Work Programme 2020 was conducted[3] [2]. An overview of the main focus areas of standardization developments and strategic priority areas to be implemented in 2020, related to D^2EPC included *Sustainability in constructions*. Particularly CEN works for the development of standardized methods for sustainability assessments of new and existing construction works (Standardization Request M/350), including standards for environmental product declaration (EPD). Work and activities on other standards include Building Information Modelling standards (interoperability issues and applications of harmonized dictionaries), as well as the thermal performance of buildings and thermal resistance of building products. In CEN/TC 247, the development of a series of standards addressing urban development and use of smart solutions aims to improve the sustainability of urban development.

Table 4. Feedback of CEN TC 089 at national level

Country	Comment with regards to real-time data methods
Belgium (NBN)	See IEA actions – University Leuven , Prof. Roels and team.
Germany (DIN)	The Finish project "RAPID-U" might be a contribution [4] [3]. In CEN/TC 89/WG 13 in-situ methods used in the evaluation of energy performance are standardized, among other co-heating methods for whole buildings[5] [4]. A good overview about "Building Energy Performance Assessment Based on In-situ Measurements" can be found here[6] [5]. When it comes to real-time-data (as well as continuous dynamic calculations of the energy certificate with data from right before), no methods are known. If real-time-weather-dates are meant, use the common simulation and hour-/month-based methods from the common standards (e.g. ISO 52000 or EN-counterparts; methods: all simulation models for buildings like e.g. E+, TRNSYS etc.), possibly with corrections for the conversion of the weather data sets to one average year.
Netherlands (NEN)	The set of European and international (global) Energy Performance of Buildings standards are well-suited for using real-time (hourly) data to evaluate the energy performance of buildings[7] [6].
Portugal (IPQ)	The Portuguese Energy Agency, ADENE, is the responsible authority for the Energy Performance Certification scheme. This agency also participates in H2020 projects with similar topics as the one D^2EPC is involved, like the next generation certificates project X-Tendo[8] [7]. Therefore, we consider that the follow-up could be done with the referenced agency, potentially contacting the Head of Projects, Rui Fragoso (rui.fragoso@adene.pt).
CEN/TC 089 Secretariat	In Annex 71 of the IEA, EBC programme is working on the procedure development to enable to characterize the building envelope in real conditions of use with measurement systems of the building itself in a non-intrusive manner. Although there are significant developments, and the results are promising, there is not a valid procedure. Related with a dynamic energy performance certification (EPC), the

[3] https://www.cen.eu/news/brief-news/Pages/NEWS-2019-040.aspx
[4] https://www.tuni.fi/en/research/rapid-u
[5] Bauwens, G., & Roels, S. (2014). Co-heating test: A state-of-the-art. Energy and Buildings, 82, 163-172.
[6] https://iea-ebc.org/projects/project?AnnexID=71
[7] https://epb.center/
[8] https://x-tendo.eu/

	key point would be the climate standardization and internal conditions (use) of the building. In order for two buildings to be compared, they have to be in homogeneous conditions, both climatic and operating (periods of use, occupied spaces). Since the measures are done under real conditions, further treatment would have to be done to normalize the results and allow comparison.

3.1.3 Novel Elements: Aspects of Next Generation EPCs and Need for New Standards

In the D^2EPC project, calculations concerning the actual energy performance of buildings to issue EPCs, will rely, as in the case of the current practices, on existing standards. Following an initial screening of relevant standards conducted under this task, the analysis will be expanded to the work programs of the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC), International Organisation for Standardisation (ISO) and the European Telecommunications Standards Institute (ETSI). D^2EPC aspires to contribute to the ongoing work on the formation of new and improved standards. If deemed relevant by the consortium members, a New Work Item Proposal will be developed until the end of the project.

D^2EPC project aims to employ the standardization system as a tool for dissemination of the next generation EPC, which will include all novel elements discussed in this report. The investigation of the standardization potential of selected results will be implemented, allowing the project to interact with the related standardization technical committees, such as CEN/TC 89 'Thermal performance of buildings and building components' or CEN/TC 156 'Ventilation for buildings.' This will be done by assessing to what extent the relationship should be established (monitoring their information, attending to TC meetings, establishing formal liaisons, organizing joint events, etc.), capturing their inputs as stakeholders and by using the standardization system as a fast and highly focused dissemination tool to the market stakeholders.

The results of the D^2EPC project will contribute to new standard developments focussed on energy performance assessment. The inclusion of the outcomes of the project in new or future standards, external to the consortium that can be easily used by the European or international industry and research will increase the impact of the project and will positively contribute to the transfer of the knowledge generated within the project to the industry and society. Depending on the ongoing works of the standardization sectors at the moment, this can involve providing information, participating in ongoing works, submitting technical proposals or even promoting the elaboration of new standard documents. Standardization is an external activity that is based in the consensus with stakeholders external to the consortium. Its evolution can have major variations in time; therefore, the decisions regarding the above options (subjects, tracks, etc.) are unpredictable now and shall be studied and taken during the project life, according to this standardization environment.

4 Introduction of the novel indicators and practices in the dynamic EPC

4.1 Novel Indicators

4.1.1 Smartness of the Building

The Energy Performance of Buildings Directive (EPBD), introduced in 2002 [8] and revised in 2010 [9] and 2018 [10], together with the EE Directive (EED), the Renewable Energy Directive (RED), the Ecodesign Directive, the Energy Labelling and the Roadmap of the Energy Union (through Smart Financing for Smart Buildings initiative) are considered among the core EU mandates that promote the energy transformation of the EU's building stock. Although the rationale behind smart buildings has its origins in the 80's [11], the revised EPBD directive pointed out their significance as energy systems enablers, favouring RES application, grid flexibility and energy supply. In view of the Renovation Wave and European Green Deal initiatives, the EU recognizes the necessity to raise awareness of the benefits of smart building technologies, such as building automation and monitoring of building technical systems. In support of the European Union (EU) targets of transforming the overall building stock to highly energy efficient, the EPBD recast directive introduced the Smart Readiness Indicator (SRI) for measuring building 'smartness'. The SRI framework is expected to act as a low-cost tool to encourage the integration of cutting-edge smart technologies in buildings by supporting technological innovation in the construction sector [12]. The rating will reflect the ability of a building to modify its operation according to the needs of the occupants, as well as to signals from the grid for improving the building's overall performance, maximising its energy efficiency and providing flexibility to its overall electricity demand.

For the establishment and the technical support to the development of the SRI, two technical studies have been executed under the authority of the European Commission DG Energy. In particular, the 1st technical study was initiated in March 2017 and concluded in August 2018, conducted by VITO NV, Waide Strategic Efficiency, Ecofys, and Offis [13]. The 2nd technical study was initiated in December 2018 and concluded in June 2020 [14], conducted by VITO NV and Waide Strategic Efficiency. The 1st technical support study main findings as well as the 2nd technical support study outcomes are

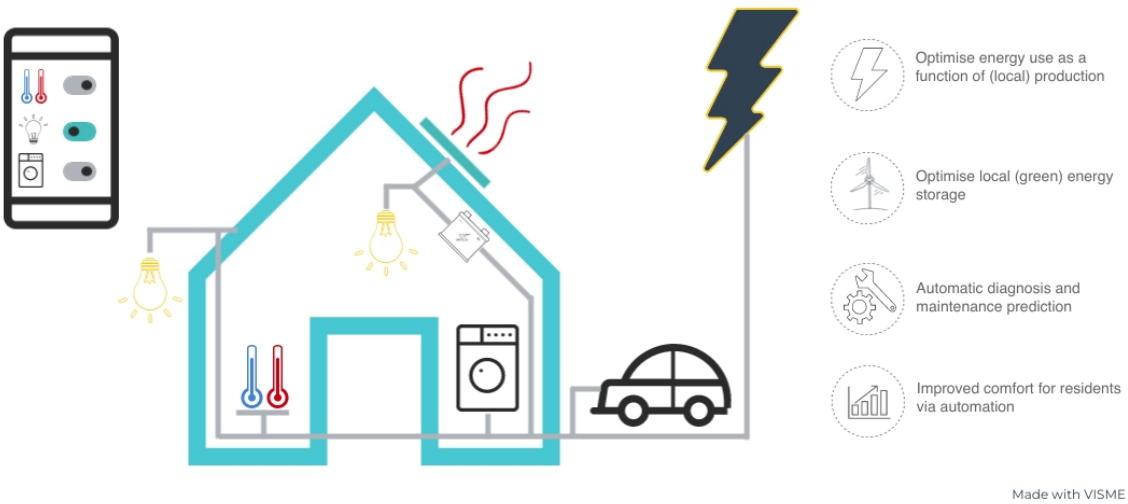

Figure 1: The expected advantages of smart technologies in buildings

summarized within the framework of the final report on the technical support to the development of smart readiness indicator for buildings [15] where the following definition of smartness is used:

"Smartness of a building refers to the ability of a building or its systems to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation to the operation of technical building systems or the external environment (including energy grids) and to demands from building occupants".

The aim of this part is to set the grounds for the inclusion of the building's smartness into the EPC calculation and identify the rationale and required elements under this scheme in accordance to the work conducted under T2.1 Smart Readiness Indicators Analysis for EPCs. Special attention was paid to the SRI final report in order to investigate the aspect of the smartness of buildings as part of the dynamic EPCs.

4.1.1.1 Audience for the SRI

The SRI aims to provide a common language for all the relevant stakeholders of the building sector and favour the uptake of smart technologies as well as stimulate investments. In particular, the SRI audience is identified but not limited to the following categories:

- Building occupants, building owners or investors (of existing and new buildings)
- Facility managers
- Service providers, including building systems developers and manufacturers, design and construction companies, engineering companies, network operators, etc.

4.1.1.2 The SRI Methodology

Key functionalities of smart readiness in buildings

The SRI assesses buildings (or building units), based on the capacity of the SRI service catalogue smart ready services they have or could use to satisfy **three key functionalities** (Figure 1). According to the requirements of the revised EPBD, the key functionalities that have been taking into account with regard to the SRI definition are the following:

1. ***Optimizing energy efficiency and overall in-use performance:*** *The ability of the buildings to perform and operate in an energy efficient manner by adapting its energy consumption, for example by utilizing energy produced from RES*
2. ***Adapt their operation to the needs of the occupants****: The ability of the buildings to adapt its operation mode taking into account the needs of the users, focusing also on the aspect of user-friendliness, indoor air quality and conditions and awareness on energy use*
3. ***Adapt to signals from the grid (energy flexibility):*** *The ability of a building to be flexible concerning its overall electricity demand, as well as its ability to participate in demand-response, in relation to the grid, for example through flexibility and load shifting capacities*

Figure 2. The 3 key SRI functionalities of the SRI Methodology, European Commission

Smart services impact criteria

A smart service can provide several impacts to the building, its users and the energy grid. Therefore, the three key smart readiness key functionalities are further detailed into **seven impact criteria** (Figure 3), namely:

1. energy efficiency,
2. maintenance and fault detection,
3. comfort,
4. convenience,
5. health, well-being and accessibility,
6. information to occupants and
7. energy flexibility and storage

Figure 3. Impact criteria of the SRI Methodology, European Commission

Smart services technical domains

Furthermore, the smart ready services are categorized under various domains. In particular, the SRI services catalogue includes nine domains (Figure 4), namely:

1. heating,
2. cooling,
3. domestic hot water,
4. ventilation,
5. lighting,
6. dynamic building envelope,
7. electricity,

8. electric vehicle charging and
9. monitoring and control.

Figure 4. Technical domains of the SRI Methodology, European Commission

Functionality levels

For each of the services included in the service catalogue, **2 to 5 functionality levels** have been defined. The highest functionality level leads to the highest smartness of the service which means that this particular service offers more added-value impacts to the building, its occupants and the grid in comparison with services of lower functionality levels. It should be noted that the functionality levels are expressed as ordinal numbers, which means that a quantitative comparison between the different services is possible.

Multi-criteria assessment method – SRI score calculation

In order to calculate the smart readiness indicator, a multi-criteria assessment method was formed and proposed so as to include the diverse domains and services. The smart readiness score of a building is a percentage of how close (or far) the building is to the maximum smart readiness that it could reach. According to the methodology, an accumulated SRI score can be derived as follows:

- **Step 1:** The procedure starts with the assessment of individual smart ready services. In detail, services available in the building are inspected and their functionality level is determined. For each service, this leads to an impact score for each of the aforementioned impact criteria considered in the methodology.
- **Step 2:** After the definition of the individual services impact scores, an accumulate impact score is evaluated for each of the domains applied in the methodology. This domain impact score is evaluated as the percentage of how close (or far) the building's individual domains' services are to theoretical maximum individual scores that could be reached.
- **Step 3:** For each impact criterion, a total impact score is then evaluated as a weighted sum of the domain impact scores. In this calculation, the weight of a given domain will depend on its relative importance for the considered impact.
- **Step 4:** The overall SRI score is then extracted as a weighted sum of the seven total impact scores. A corresponding SRI class (seven classes, from <20% to >90%) is also identified.

In order to calculate the weighting sums, with regard to the step 3, the proposes methodology provides default weighting factors which are different depending on the building type (residential, non-residential) and the climate zone. In detail, 5 climate zones (Figure 5) have been defined, namely Northern Europe, Western Europe, Southern Europe, North-Eastern Europe & South-Eastern Europe and typically the heating domain has more importance in Northern areas of Europe, while the relative importance of the cooling domain increases in Southern areas of Europe, respectively. On the contrary, with regard to step 4, the default weighting factors are the same for each building type and climate zone.

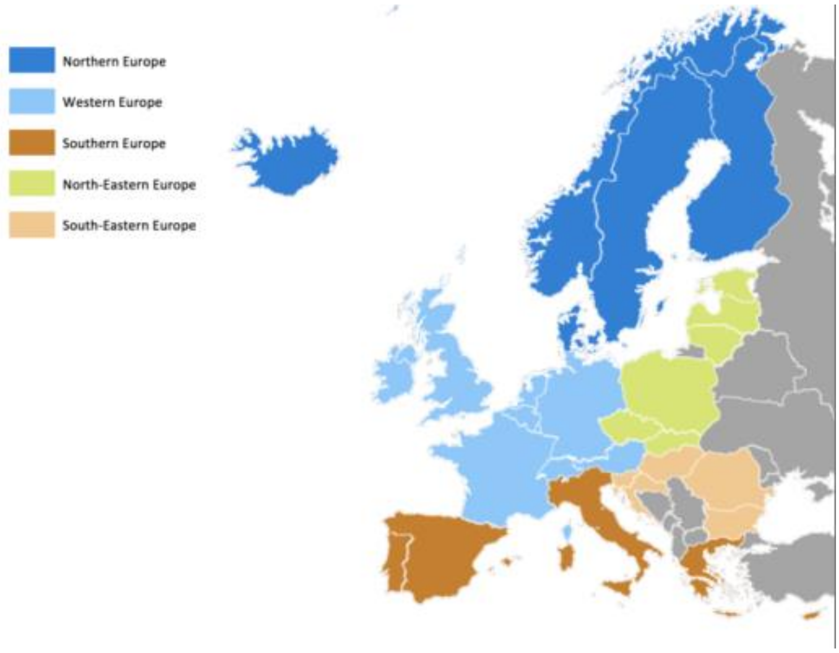

Figure 5. SRI Methodology climate zones, European Commission, SRI training slide deck, Version 1.0, September 2021

The triage process

The SRI methodology applicability varies depending on specific circumstances (building type, climate zone, site specific conditions, etc.). This means that some domains, services and service levels are either not relevant, not applicable, or not desirable and therefore, the SRI needs to be flexible enough to adopt this. In this respect, the assessment procedure includes only the SRI catalogue services that are either present in the building or desirable. Accordingly, the maximum nominal impact score is not simply the sum of the SRI services listed in the catalogue impacts, but the impact sums of the SRI catalogue services that are assessed. The procedure that is followed in order to identify the relevant services for each specific building is called triage process.

4.1.1.3 The SRI Assessment Procedure

The assessment procedure is depending on the complexity level for the definition of the SRI, and there are three main potential SRI assessment methods, two “regular” methods and one meter/measured.

- **Method A** is the simplified approach which is intended to be applied on residential buildings and small non-residential buildings. This method consists of a check-list with limited number of SRI smart services catalogue, including 27 smart services. The method allows (online) self assessment in addition to a formal third-party expert assessment, however only a third-party expert assessment would issue a formal certification. The scope of the simplified method includes the following:

- The method applies the Simplified services catalogue using a check-list approach and allow the possibility of online self-assessment;
- The method should take no more than one hour to be conducted;
- The method should be applied to dwellings with less than < 500m² net usable floor area.

- **Method B** is the detailed SRI approach to be applied mainly on non-residential buildings (new constructions, retrofits and existing buildings). The method would allow the SRI assessment to utilize the full list of detailed services (54 smart services) and it should be conducted by qualified experts. EU member states are allowed to decide the requirements of SRI qualified experts in accordance to the Article 3 of the (EU) 2020/2156. The method potentially allows self-assessment by a non-independent expert (e.g. facility manager), however, only a third-party expert assessment would issue a formal certification.
  - This method is based on the full list of SRI services catalogue using a check-list approach and requires an on-site inspection by qualified experts for the recording of technical building systems and their functionalities;
  - The assessment duration is extended to ½ day to 1 day, compared to the simplified method, depending on the building size and complexity of building services;
  - This method is applicable to non-residential and residential buildings (net surface floor area ≥500m²).

- **Method C** was presented by the technical studies of SRI and promoted a measured method approach where technical systems will be capable of self-reporting functionality levels, thereby supporting methods A and B. Eventually, Method C exceeds theoretical retrieval of building services functionalities and approaches the actual performance of in-use buildings. Method C has been supported by multiple organisations during the stakeholder's consultations during SRI development.

4.1.1.4 SRI Further Development

The SRI scheme was entered into force in December 2020 following a non-committal test phase by MS. Following the successful implementation of the second technical study, two regulations have been established by the EU for the implementation of the SRI in MS.

- Regulation (EU) 2020/2155 for the Delegated Act – establishing an optional common European scheme (definition and calculation methodology) [16].
- Regulation (EU) 2020/2156 for the Implementing Act – detailing the different technical implementation modalities [17].

Being a voluntary scheme, the European Union are currently deciding how to implement it at the national level. Many parts of the SRI, such as weighing criteria, functionality levels, and the smart services catalogue, are subject to the European Union's subsidiarity principle, which gives Member States the authority to make national level decisions. As per usual procedures they need to report and justify back to the European Commission [18].

For further development of the SRI scheme, the SRI self-managed (volunteer based) working group was established with the goal to discuss and identify future pathways of updating the existing methodology, as well as applying SRI's assessment technique C, which is based on measurable data of actual building performance. Within the cope the SRI Topical Group C (TGC) experts also analyse how to make the transition to an in-use/performance-based SRI, analysing the most effective methods for automating the checklist evaluation process on the one hand, and leveraging measured data on the other, as well as defining an additional in-use SRI methodology [17].

In 2021, the SRI Technical support team was established, having the main aim to provide technical assistance for the first phases of testing and implementation of the SRI. The SRI Technical support team is a consortium comprised of four members (VITO, Waide Strategic Efficiency Europe, R2M Solution and LIST) from four EU member states (Belgium, Ireland, France and Luxembourg respectively). The SRI Technical support team has a timeline of planned activities that started in May of 2021 and is expected to last until April 2023. The primary tasks of the consortium are the following:

1. Support for testing and implementation of the SRI
2. Establish the SRI platform
3. Technical assistance for the preparation of EU guidance
4. Investigation of additional EU support for the roll-out of the SRI
5. Awareness raising and dissemination

For the first task, the SRI Technical support team provides help and tailor-made support, in order for the participating Member States to test and successfully implement the SRI during a National test phase that started in Denmark, France, Italy and Austria. For that purpose, an SRI assessment package, consisting of a practical guide and a detailed calculation sheet, is available upon request. For the establishment of the SRI platform, special SRI platform working groups have been established and periodic plenary meetings are planned. The technical assistance for the preparation of EU guidance can be provided on many issues, such as service catalogues, weighting factors, certificate design, information regarding data protection etc. Regarding the investigation of additional EU support for the roll-out of the SRI, sets of surveys, questionnaires and interviews have been planned, focusing on identifying the need for developments and improvements that can be undertaken. Finally, regarding the awareness raising and dissemination activities, the SRI Technical support team offers an SRI training package, an online helpdesk, SRI newsletters and in general, useful information through a frequently updated website

The following activities have been conducted so far in support of further SRI development.

- **The establishment of the Smart Readiness Indicator (SRI) platform** which expected to promote the SRI and best practices. It serves as a debate point for technical, regulatory, and implementation elements of the SRI, as well as an exchange forum for all interested parties and EU countries. The dedicated working groups of the SRI will also be supported by the platform.

- **The release of SRI certificate design survey**: The purpose of this survey is to get feedback from construction industry specialists in order to evaluate certificate design concepts. Stakeholders such as Facility managers, EPC/HVAC assessors, and estate agents are invited to contribute.

- **SRI test phase in EU countries** is currently conducted in four European Union countries: Austria, the Czech Republic, Denmark, and France. Other member states are expected to initiate SRI testing in their regions. With regards to the national testing phase, the following recommendations are currently applying:
  - The Member States should prioritize their national level priorities “Energy performance and operation”, “Response to the needs of the occupant”, “Flexibility of a building’s overall electricity demand” and “All 3 of equal importance” at the beginning of the SRI testing/implementation process.
  - At the EU level, a convergent and consistent methodology between the actual assessment and final SRI results is critical.
  - The Member State customizing of the SRI qualitative evaluation methodology should either be minimal or always be feasible to convert to the EU SRI (default) to compare the smart preparedness level in different Member States and areas.

- There should be EU-wide training and certification programs for assessors. Priority should be given to the section "expert guidance to users," in which the assessor should make recommendations on how to improve the building's smart preparedness.
- An interview with the relevant stakeholders included in the testing phase and verification of high-score functionality should be necessary for SRI method B assessment. A quantitative SRI evaluation (in accordance to method C) that assesses smart performance is required to fully realize the benefits of the qualitative SRI assessment (methods A and B) and may be included in the scope of national testing. The value of the SRI must be turned into tangible results (EU Green Deal, Renovation Wave Strategy) that demonstrate the real effect of smart building technology based on actual building performance data.

4.1.1.5 Deployment of SRI Scheme in D^2EPC Methodology

One of the primary goals of D^2EPC is to provide an indicator-rich certificate that incorporates elements beyond energy which covers sustainability aspects of the building units. The Smart Readiness Indicator (SRI) is one of the innovative indicators in this category which will provided added value for building users. Given that D^2EPC aims to perform all of its evaluations within a digital BIM-based environment, the SRI dedicated Task 2.1 “Elicitation of user and stakeholder requirements & market needs” investigated two implementation pathways for the performance of SRI assessment. At first stage, the possibility of extracting the SRI parameters of a building from the data collected for an asset-based EPC was evaluated. This activity identified the metrics necessary to define SRI functioning levels and assessed their availability in the data required for EPC asset rating in compliance with European EN 52000 standards. The second analysis utilized the vendor-neutral IFC schema developed by *Building Smart International* and evaluated its ability to define appropriate information for extracting the SRI assessment. In particular, this analysis included the alignment of the individual SRI functionalities and the IFC entities. The IFC schema was analysed for its ‘’completeness’’ to define SRI parameters features in accordance to the different Building Automation and Control Systems (BACS) hierarchical levels. ‘’Completeness’’ assesses the adequacy of an information model to express the features of a specific BACS structure. The methodology followed for the implementation of this analysis is shown in

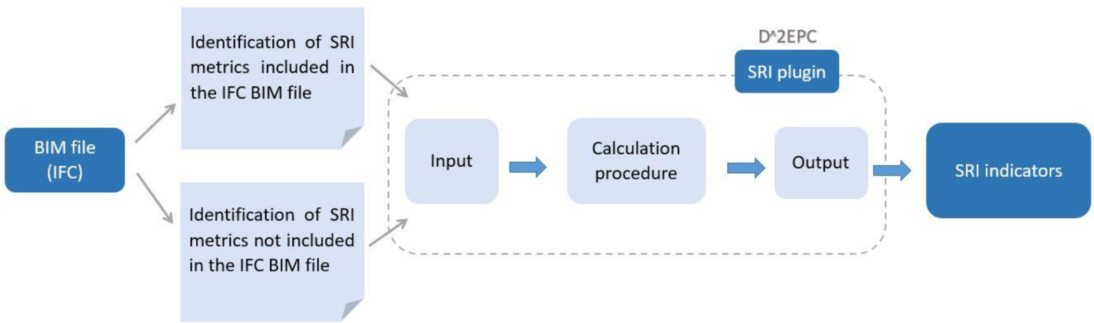

Figure 6. Analysis flow diagram for IFC-SRI assessment

According to the analysis, the current state of data for EPC assessment precludes the performance of the SRI assessment. While some screening information for the SRI can be recovered, this information is insufficient to determine the building's SRI score. Based on the assessment conducted for the alignment of the individual SRI functionalities and the IFC entities, it was revealed, that at the current stage, a significant number of functionality levels are not addressed in IFC based documents This constitutes a significant barrier towards the development of a comprehensive IFC-based methodology for performing the SRI assessment based IFC schema. The analysis shown the limitation of IFC schema to define accurately and thoroughly the controls and relationships of building automation and control systems (BACS) required by high level SRI functionalities. At this stage, complete and thorough BACS modeling documentation is available mainly from suppliers for their respective products, making the process of modifying, modeling, and managing BACS systems largely vendor-dependent. In view of the analysis conducted, D^2EPC solution will utilize IFC schema for the definition of relevant building systems required by the SRI's screening layer. This information is sufficient only for activating the SRI triage process. The required information for the definition of screening layer was defined in Task 2.1 and is expected to be extracted in the BIM parser level by defining a ‘’minimum modelling requirement(s)’’ for each of the screening questions. The ‘’minimum modelling requirements’’ concern IFC entities that should be defined in the BIM model during its development.

4.1.2 Human Comfort

Indoor environmental quality (IEQ) and its impact on occupant well-being and comfort is an important area of research that attracts significant attention from the scientific & industrial community and the regulatory & standardization organizations [19] [20] [21]. Particular focus is given to specific attributes such as sick building syndrome, indoor air quality, thermal and visual comfort and the correlation of these with the operation of buildings.

Indoor Air Quality (IAQ) ensures that the breathing air has a low concentration of certain contaminants identified as the ones to harm the respiratory system. **Thermal comfort** provides a state of satisfaction with the existing thermal conditions. **Visual comfort** ensure that the luminance levels are within acceptable confines. **Acoustic comfort** creates a comfortable acoustic environment without uncomfortable noise.

BPIE & ASHRAE recommendations and policy papers stated [22] [23] that building occupants spend approximately 90% of their time indoors. Specifically, occupants tend to spend at least 1/3 of their day at home on average. The complexity of the relationship between occupant comfort and well-being parameters with IEQ are further aggravated due to relationships that these parameters have with each other as well. In addition, energy efficiency measures in residential buildings have become one of the central concerns [24] and if not carefully considered, could result to low IEQ levels (i.e., airtight constructions, under/overheating & cooling, low lux levels, etc.). According to Figure 7, negative health issues are ~17% more probable across the EU27 when living in a building with poor indoor thermal conditions during winter. 22 million people around Europe (accounting for about 4,4% of the total population) experience poor thermal comfort during both the heating and cooling season. Combined with other negative environmental factors – such as lack of daylight or dump – it is safe to say that 1 out of 6 Europeans live in buildings of poor environmental quality. Other occupant associated factors like lifestyle, demographic factors, social status are also found to have an impact on IEQ that leads to 1 to 3 Europeans living in unhealthy buildings [25]. Since the IEQ contributing factors interrelate with each other, IEQ is required to be addressed by an integrated approach than individually (thermal, visual, acoustic and IAQ) as appropriate attention is not given by the industry to this aspect [26].

The aim of this part is to review certification schemes that assess the environmental impact of buildings throughout their life cycle and are based on a number of factors such as operational processes, heating and cooling energy consumption, water consumption, indoor environmental conditions, land use, transportation, sustainability, etc.

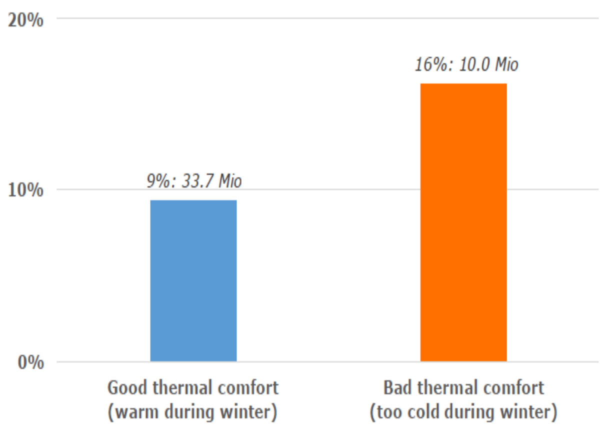

Figure 7. Proportion of adults in the EU reporting a correlation between health and level of thermal comfort in winter. Source: Hermelink & John, 2017 (Ecofys)

4.1.2.1 Methodologies to Assess Human Comfort and IEQ

The main indicators to assess the IEQ of a building and human comfort include the air quality along with the thermal, visual, and acoustic comfort. A number of worldwide-accepted certification schemes that indicate a building has achieved a certain level of energy efficiency and environmentally conscious design have been developed and applied on a large scale. Such schemes assess the environmental impact of buildings throughout their life cycle and are based on a number of factors such as operational processes, heating, and cooling energy consumption, water consumption, indoor environmental conditions, land use, transportation, sustainability, etc.

Table 5 illustrates some of the best-known global green building certifications and frameworks with IEQ under consideration.

Table 5. Summary of building certification schemes that consider IEQ ([27] [28] [29] [30])

Certification scheme/ Framework	Year	Country	Type	Development Phase	Scope	Building Status	Rating Type
LEED	1998	UK	Sustainability Assessment System	In-use	Residential and non-residential	New & Existing	Asset
BREEAM	1990	US	Sustainability Assessment System	In-use	Residential and non-residential	New & Existing	Asset
WELL	2014	US	Performance-Based System	In-use	Residential and non-residential	New & Existing	Asset

SRI	In Progress	EU	Smart Readiness Assessment System	Testing Phase[9]	Residential and non-residential	New & Existing	Asset / Operating (Method C)
LEVEL(s)	In Progress	EU	Reporting Framework	Testing Phase	Residential and non-residential	New & Existing	Asset/ Operating

LEED and BREEAM are considered as sustainability assessment systems that provide third-party verification for the construction, operations design of superior green buildings, as well as neighbourhoods and homes. The Well Building Standard (WELL) certification (US) focuses not only on the building occupants' health but also on their quality of living, productivity and well-being. Smart Readiness Indicator (SRI) is a new methodology with strong focus on the smart technologies of a building. The SRI is a recently proposed common EU scheme to assess buildings in terms of interaction with their occupants, connection to energy grids and efficient operation. Unlike the former described schemes, LEVEL(s) is a framework suitable for the common reporting of the core sustainability indicators (not a green building scheme) featured by the European Commission (The European framework for sustainable buildings [1]), aiming to provide a framework with indicators and a common language for the performance of a building along its life cycle. Environmental indicators - either from LCA, or cost, value and risk perspective - are paired with health and comfort indicators.

4.1.2.2 Analysis of Existing Building Assessment, Rating and Certification Systems for Human Comfort and IEQ

LEED, BREEAM, and WELL are criteria-based tools following a checklist methodology for less complexity. LEED includes these categories of evaluation: integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, IEQ, innovation and regional priority. For the certification of the building, a number of criteria (and corresponding sub-criteria) for each of the 9 categories must be met. Criteria are divided into two distinct categories: Credits (optional) and prerequisites (mandatory) [27]. Based on the number of points gathered during the assessment process, four levels of LEED certifications are awarded. Level 1:40-49 points, Level 2 (silver): 50-59 points, Level 3 (gold): 60-79 and Level 4 (platinum): 80-110.

BREEAM addresses challenges from these environmental sections: energy, health and well-being, innovation, land use, materials, management, pollution, transport, waste and water. The determining factors for the accreditation of each category are the assessment issues containing their own targets and benchmarks [28]. Reaching these targets or benchmarks is awarded with credits. The total score of each category is based on the number of credits gained and the respective weighting of the category. The final performance rating is determined by the summation of the weighted category scores. BREEAM levels of rating are: “acceptable”, “pass”, “good”, “very good”, “excellent” and “outstanding”.

Contrary to LEED and BREEAM, WELL emphasizes more on the quality of the environment and how it affects the occupants, other than the design of the building and its operation. WELL is organized into seven categories of wellness called concepts: Air, Water, Nourishment, Light, Fitness, Comfort and Mind. The seven concepts are comprised of 105 features, which can be performance-based indicators (quantified thresholds for features) or prescriptive indicators that require specific technologies, design strategies or protocols to be implemented. Some of the features are categorized as preconditions that need to be met for the certification to be awarded. There are three levels of certification. The Silver

[9] Method A & Method B. Regarding Method C, the development is at study proposition phase.

(preconditions met and a limited portion of the optional optimizations), the Gold (preconditions + 40% of the optional optimizations) and the Platinum (preconditions + 80%) [29].

As it was described in the previous section, the SRI is a new instrument to rate the smart readiness of buildings, established under the Energy Performance of Buildings Directive (EPBD) 2018/844 [10]. In correspondence to the BREEAM, LEED and WELL certifications, SRI is a multi-criteria assessment method that utilizes a checklist approach (the so-called Technical Building Services (TBS) catalogue) for simplicity. The indicators are defined by the assessment of the existing TBS in the building and their respective functionality level (which scores from 1-5). The TBS is segmented into 9 technical domains (heating, cooling, domestic hot water, controlled ventilation, lighting, dynamic building envelops, electricity, electric vehicle charging and monitoring/control) and rated on 7 different impact categories/criteria (energy efficiency, maintenance and fault prediction, comfort, convenience, health and well-being, information to occupants, energy flexibility and storage) [14].

The IEQ within the SRI scope is indirectly addressed via the assessment process of the TBS capabilities. Building services of 'smarter' implementation are awarded with higher functionality scores resulting to higher scores on Comfort and Well-being impact criteria. Furthermore, the domain weights are adjusted based on geographical criteria in order to address the different climatic characteristics per region. In terms of air quality, modern ventilation systems including central or local demand control based on air quality sensors (CO, CO2, VOC) are graded with the maximum level of functionality. Thermal comfort scoring depends on the functionality level of heating and cooling building services and their relevant significance based on the region. The visual comfort scoring is determined through the level of artificial luminance control of the TBS (i.e., dimming, colour temperature, light distribution) and the climate characteristics of the region (daylight, daylight uniformity, annual sun exposure) affecting the domain weights on the comfort and well-being impact criteria. Acoustic comfort scoring depends on the design choices of the TBS and not their identified capabilities. Therefore, at this stage, noise reduction is not relevant for inclusion in the SRI.

Contradicting to LEED, BREEAM, WELL and SRI (Method A & B), LEVEL(s) introduce **quantification** of indicators [30]. The indicators are derived from the simulation in the planning phase and from measurements in the operational phase. In terms of IEQ, two metrics concerning IAQ (Good quality indoor air and Target list of pollutants) and one metric concerning thermal comfort (% of the time out of defined range of min/max temperature during heating/cooling seasons) are considered. There are three levels of performance assessment supported by the framework. The common performance assessment, the comparative performance assessment and the optimized performance assessment. The first level provides each indicator at its simplest type of use and functions as a common reference for the assessment of a building's performance across Europe. The second level contains a comparative assessment between the case building and other similar buildings at a national or portfolio level. The third level offers the most advanced form of each indicator and provides guidance to the professionals on how to model and improve performance.

4.1.2.3 Comparative Analysis of Current EPCs Assess Human Comfort

It was observed that LEED and BREEAM rating systems reach a high level of compliance as the environmental concerns are commonly addressed at a percentage of 83% [31]. WELL certification focuses on different concepts as well (like nourishment and fitness), the SRI methodology hasn't been implemented on a large scale, and LEVEL(s) refers to a performance framework instead of a green building certification, thus compliance with the other schemes cannot be examined.

Table 6. Parameters used to assess indoor environment quality in LEED and BREEM certification schemes [14] [27] [28] [29] [30] [32]

IEQ components	BREEAM	LEED	SRI	WELL	LEVEL(s)
Thermal Comfort					
Predicted mean vote (PMV)	+	HVAC systems and building envelope design requirements met from ISO 7730, ISO 17772 or ASHRAE Standard 55.	-	N/A	+
Predicted percentage dissatisfied (PPD)	+		-	N/A	+
Adaptive Comfort Model	-	-	-	+ ASHRAE 55-2013	-
Indoor Air Quality					
Ventilation rate	+ In accordance with relevant standard	+ ASHRAE Standard 62.1 or EN 16798	+	+ ASHRAE 62.1-2013	+ EN 16798
TVOC*	+ < 300 µg/m³ (8-h average)	+ ≤ 500 µg/m³	+	(SCAQMD) Rule 1113 & (CDPH) Standard Method v1.1-2010 & ANSI/BIFMA e3-2011	-
Formaldehyde	+ ≤ 100 µg/m³ (30-min average)	+ ≤ 27 ppb	-	+ ≤ 27 ppb	+ (W.H.O. Guidelines)
CO_2	-	+	+	+ ≤ 800 ppm (1.2-1.8m above the floor)	+ EN 16798
Source emission level	+	+	-	-	+
CO	-	+ ≤ 9 ppm	+	+ ≤ 9 ppm	-
PM_{10}	-	+	N/A	+	+

		< 50 µg/m³		< 50 µg/m³	Mean 24h value 50 µg/m³
$PM_{2.5}$	-	+ ≤ 15 µg/m³	N/A	+ ≤ 15 µg/m³	+ 15µg/m3 (8 h mean)
Ozone	-	+ ≤ 0.075 ppm	N/A	+ ≤ 0.051 ppm	-
Radon	-	-	N/A	+ ≤ 0.148 Bq/L	+ (W.H.O. Guidelines)
Relative Humidity	-	-	N/A	30%-50%	+
Acoustic Comfort					
Ambient noise	+	+	-	+	-
Reverberation time	+	+	-	+	+ (Future Versions)
Composite sound transmission class	-	+	-	-	-
Visual Comfort					
Illuminance level	+ ≥ 300 Lux for 2000 hours per year	+	+ EN 12464-1 and CEN-TR 16791	+ 300+ lux, measured on the horizontal work plane or if <300 lux, tasks lighting to be between 300-500 lux.	+ 300-3000 lux, 500 lux average-maintained illumination in offices (future versions)
Daylight factor	+ > 2% (80% area)	-	+ (triage process)	+ 75% of the area of all regularly occupied spaces is within 7.5 m of view windows.	+ Minimum value 2% (future versions)
Spatial daylight autonomy	-	+	-	+	> 300 Lux at desk

		2 Points: 55% 3 Point: 75%		55%	height for a stipulated percentage of the year (future versions)
Artificial illuminance level	+	-	+ EN 12464-1 and CEN-TR 16791	+	+ (future versions)
Annual sun exposure	+	-	+ (triage process)	+	+ (future versions)
Daylight uniformity	+	-	+ (triage process)	+	-

*In LEED certification system concentration of Total volatile organic compounds (TVOC) is considered as the whole spectrum between n-hexane (C6) and n-hexadecane (C16). The TVOC concentration is expressed by toluene response factor.

The common parameters for human comfort and well-being indicators estimation/calculation addressed in LEED, BREEAM, and WELL certification systems are PMV/PPD (WELL v2), temperature, relative humidity, ventilation rate (rate of fresh air supply), air speed, concentrations of TVOC, formaldehyde, CO2, CO, PM10, PM2.5, ozone, ambient noise and reverberation time, illuminance level, daylight factor and spatial daylight autonomy. Furthermore, these parameters are also found in other green buildings certification systems over Europe and the world, e.g., Level(s) (EU), OsmoZ (France), klimaaktiv (Austria), DGNB (Germany), NABERS (Australia). WELL certification also examines radon, benzene (same as LEVEL(s)), NO2, CS2 and trichloroethylene levels. In the SRI schema, the comfort and well-being parameters are indirectly evaluated via the functionality score of the TBS in the building (IAQ and thermal comfort) or the climate adjustments on the domain weights used in the calculation (thermal and visual comfort). As far as LEVEL(s) is concerned, the ventilation rate, CO2, RH, VOC, R value, PM, Radon and Benzene are examined in terms of IAQ. Thermal comfort is determined via the percentage of time spent outside the predefined limits of temperature during heating or cooling seasons. Two more aspects regarding the visual and acoustic comfort will be developed under EN 158978, EN 12464-1, EN 17037, EN 16798-1 for the former and EN 15978, Directive 2002/49/EC, EN 12354 (part 1- 6) for the latter.

The schemes assign credits to four IEQ components: thermal environment, IAQ, acoustic environment, and visual environment. The LEED system gives 35% for visual comfort, 12% for acoustics, 47% for IAQ and 6% for thermal comfort, while BREEAM gives 33%, 22%, 28% and 17% [22] and WELL gives 13%, 25%, 50% and 13% respectively. The SRI methodology, according to the existing framework, gives 26% for visual comfort, 0% for acoustics, 47% for IAQ, and 26% for thermal comfort. In the LEVEL(s) case, for the time being, only two components are considered, IAQ and Thermal, and are allocated half the credits of the total IEQ credits. Parameters for indoor environment quality are presented in Table 7.

Table 7. Credits assigned to indoor environmental quality in LEED and BREEM certification schemes [32]

IEQ components	BREEAM	LEED	SRI	WELL	LEVEL(s)
Thermal comfort	3	1	5	1	6

IAQ	5	8	8	4	6
Acoustic comfort	4	2	0	2	2[10]
Visual comfort	6	6	5	1	3[10]
IEQ	18	17	18	8	17
Total credits of the scheme	150	110	100	41	100
IEQ / Overall (%)	15%	12%	18%	20%	17%

4.1.2.4 Human Comfort and Wellbeing Indicators as Envisioned in the Dynamic EPC

The works conducted under T2.2 aimed to deliver a novel set of Human Comfort and Wellbeing (HC&W) indicators to be integrated in the D^2EPC scheme. Based on the dynamic nature of the new-age EPC, the performance indicators have been envisioned to be calculated on real-life metering and sensing data acquired by the IoT infrastructure deployed in the project's demonstration cases. This measurement-based approach enables the evaluation of a building's energy consumption from a human-centric point of view in a purely data-driven manner which ultimately lowers the intrusiveness and promotes the overall user acceptance.

The comparative assessment performed on a series of well-established certification schemes and frameworks governing the human comfort has shed light on the domains of indoor environmental quality selected to be examined within the project. The IEQ pillars considered correspond to the thermal comfort, the visual comfort and the IAQ. The inclusion of the acoustic comfort was initially researched as well. However, it was concluded that it mainly concerns architects and interior designers at the design stage of the building and there is no direct relation between acoustic comfort and building energy efficiency. Therefore, it was excluded from the overall analysis.

Relevant Standards and Frameworks:

Beyond the aforementioned comparative assessment, literature research has further taken place on European and national standards addressing the quality of indoor conditions. The outcome highlighted the environmental parameters to be integrated as performance metrics in the HC&W framework, the respective recommended boundaries or categories/limits of operation and, lastly, the evaluation methodologies utilised to transform those metrics into key performance indicators. In the Table 8, the standards and frameworks finally considered are presented per indoor environmental quality domain.

Table 8. Relevant European standards and frameworks

Environmental Quality Domain	Standard/Framework	Description
Thermal Comfort	*DIN EN 15251 [33] – "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics"*	Identifies the appropriate parameters that will be utilised for monitoring and displaying the indoor environment in existing buildings

[10] Future Potential Aspect (Estimated Credits)

	ANSI/ASHRAE 55:2017 [34] – "Thermal environmental conditions for human occupancy"	Examines the Thermal environmental conditions for acceptable thermal conditions in occupied spaces
	EN ISO 7243:2017 [35] – Ergonomics of the thermal environment. Assessment of heat stress using the WBGT (wet bulb globe temperature) index"	Assesses the heat stress in both indoor and outdoor thermal environments with the usage of the Wet Bulb Globe Temperature (WGBT) thermophysiological parameter
	Level(s) 4.2 [36] – "Time outside thermal comfort"	Corresponds to a level(s) indicator which measures the time during which the occupants are satisfied with the indoor thermal environment
Visual Comfort	*EN 12464-1:2021 [37] – "Light and lighting. Lighting of work places Indoor work places"*	Delivers the best practices towards a balanced indoor lighting and specifies the requirements for lighting solutions in terms of quality and quantity of illumination
	EN 17037:2018 [38] – "Daylight in Buildings"	Provides information on the metrics evaluating the daylight conditions along with the calculation and verification methodologies that determine the variability of daylight
	Level(s) 4.3 [39] – "Lighting and Visual comfort"	Corresponds to a level(s) indicator which specificies the indoor electric lighting equipment that achieves sufficient quantity and quality of light
Indoor Air Quality	*EN 16798:2019 – "Energy performance of buildings – Ventilation for buildings"*	Part 1 (*EN 16798-1:2019 [40]*) delivers the Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
		Part 2 (*EN 16798-2:2019 [41]*) interprets the requirements of part 1
	ANSI/ASHRAE Standard 62 [42] – Ventilation for Acceptable Indoor Air Quality Set	*Part 1 (ANSI/ASHRAE Standard 62.1)* applies in spaces intended for human occupancy excluding residential spaces

		Part 2 (ANSI/ASHRAE Standard 62.2) applies exclusively in residential spaces
	Level(s) 4.1 [43] – "Indoor Air Quality"	Corresponds to a level(s) indicator which provides an approach towards ensuring acceptable IAQ by addressing various performance aspects

Environmental Performance Metrics:

The environmental metrics finally selected to be included in the HC&W framework maintain the following characteristics:

- They correspond to well-defined, dynamic quantities
- They are aligned with well-established standards and frameworks
- They can be measured with non-intrusive, smart sensing equipment

Regarding thermal comfort, two fundamental parameters have been examined i.e., the Dry-bulb (air) Temperature and the Relative Humidity as well as their combined effect on the occupants through two thermophysiological parameters (WBGT and Humidex from ISO 7243:2017). In the visual comfort case, the parameter identified to satisfy the set criteria corresponds to the indoor illuminance. Lastly, concerning the indoor air quality, a plethora of measurable quantities have been obtained from Level(s) 4.1 i.e., the ventilation rate and several toxic gas concentrations harmful for the human respiratory system (CO2, TVOCs, PM2.5/10, Radon, Formaldehyde and Benzene). However, the focus has been placed on three "main" IAQ metrics, the CO2, TVOCs and PM2.5, which can be measured through a non-intrusive multisensing solution (based on the outcome of T3.1). The rest of the IAQ parameters have been incorporated in the framework as well, in order to be assessed in buildings where any corresponding measurements are available from existing sensing infrastructure.

Long-term Evaluation Methodologies and Performance Indicators

The definition of recommended boundaries or categories per environmental metric has been based on a hybrid methodology considering both dynamic and static elements. More specifically, for the visual and thermal comfort, building's real-life air temperature and illuminance data are utilised as input to a specialised comfort profiling engine that identifies patterns and trends relevant to the user's behaviour. This dynamic and data-driven approach is based on the assumption that the optimal indoor thermal and visual conditions are essentially dictated by the occupants themselves through a variety of actions (e.g., adjusting the setpoint temperature or switching ON/OFF lights). Therefore, the boundaries can be determined by the user's previous behaviour as reflected in preceding data. In cases when the utilization of the profiling engine is not feasible (e.g., low quality or absence of previous data) or relevant (wellbeing metrics), the respective (static) boundaries and categories have been extracted from the aforementioned European and national standards.

In order to quantify the building's performance in terms of comfort and wellbeing, three long term evaluation methodologies have been utilised i.e., the "Time out of Range" the "Degree Hours" from EN 15251 and the "Footprint of Indoor Environment" from CEN/TR 16798-2.

The "Time out of Range" and the "Degree Hours" methodologies are applied on the pre-defined static or dynamic boundaries. The former calculates the percentage of hours (in an occupied building) when the examined metric is outside the specified range. The latter calculates the occupied hours during which the examined metric is measured outside the specified boundary and further applies tailored weights on the calculation based on the amount of degrees the boundary has been exceeded. Consequently, the two methodologies provide insight on how long and how much, respectively, the indoor conditions deviated from the recommended ones, over a course of a period. Lastly, the "Footprint of Indoor Environment" is applied on the recommended categories/limits in regards to the environmental metrics and calculates the percentage of occupied hours which correspond to each category/limit.

Based on the selected parameters and evaluation methodologies, a set of comfort and wellbeing indicator has been defined to enable the monitoring of the building's progression in regards to human-centric features. The set of indicators is presented in Table 9.

Table 9. Human comfort & wellbeing indicators

Indicator Name	I.E.Q. Domain	Environmental Parameter	Evaluation Methodology	Recommended Boundaries / Categories
Deviation from the temperature range	Thermal Comfort	Indoor Dry-bulb (Air) Temperature	Time out of Range	Profiling Engine
Thermal Degree Hours	Thermal Comfort	Indoor Dry-bulb (Air) Temperature	Degree Hours	Profiling Engine
Deviation from the humidity range	Thermal Comfort / I.A.Q.	Indoor Relative Humidity	Time out of Range	Relative humidity range (Level(s) 4.3)
Deviation from the acceptable WBGT levels	Thermal Comfort	Indoor Wet-bulb Globe Temperature (Indirectly calculated with Air Temperature and Relative Humidity)	Footprint of Indoor Environment	WBGT levels (ISO 7243:2017)
Humidex levels	Thermal Comfort	Indoor Humidex (Indirectly calculated with Air Temperature and Relative Humidity)	Footprint of Indoor Environment	Humidex levels
Deviation from the set Illuminance boundary	Visual Comfort	Indoor Illuminance	Time out of Range	Profiling Engine
Deviation from the standard Illuminance levels	Visual Comfort	Indoor Illuminance	Time out of Range	Illuminance Levels (EN 12464)
Set Visual Degree Hours	Visual Comfort	Indoor Illuminance	Degree Hours	Profiling Engine

Standard Visual Degree Hours	Visual Comfort	Indoor Illuminance	Degree Hours	Illuminance Levels (EN 12464)
CO_2 Indoors	I.A.Q.	Difference between indoor and outdoor carbon dioxide concentrations	Footprint of Indoor Environment	CO_2 Categories (CEN/TR 16798-1/2:2019)
TVOCs	I.A.Q.	Total Volatile Organic Compounds concentration in the indoor air	Footprint of Indoor Environment	TVOCs limits (CEN/TR 16798-1:2019)
$PM_{2.5}$	I.A.Q.	Particulate Matter (2.5 μm diameter) concentration in the indoor air	Footprint of Indoor Environment	PM2.5 limits (CEN/TR 16798-1:2019)
Benzene	I.A.Q.	Benzene concentration in the Indoor air	Footprint of Indoor Environment	Benzene limits (CEN/TR 16798-1:2019)
Formaldehyde	I.A.Q.	Formaldehyde concentration in the Indoor air	Footprint of Indoor Environment	Formaldehyde limits (CEN/TR 16798-1:2019)
Radon	I.A.Q.	Radon concentration in the Indoor air	Footprint of Indoor Environment	Radon limit (WHO Guidelines)
PM_{10}	I.A.Q.	Particulate Matter (10 μm diameter) concentration in the indoor air	Footprint of Indoor Environment	PM10 limits (CEN/TR 16798-1:2019)
Ventilation Rate	I.A.Q.	Roughly estimated based on indoor hourly CO2 concentrations	Footprint of Indoor Environment	Ventilation Rate categories (CEN/TR 16798-1:2019)

4.1.3 Life Cycle Assessment

Novel indicators which should be included in dynamic EPC shall be based on well-established databases across Europe concerning the environmental impact of building materials (EcoInvent, BRE Greenguide, etc.) and they will result in a life cycle assessment of the buildings, as well as of individual components of the building (building envelope, building systems, building materials, etc.). This assessment will also provide the option to the building design engineers to improve and optimize the environmental performance of the building, based on changes to be integrated at the initial design stages of the building.

The aim of this part:

- Identification of existing LCA indicators and methodologies applied in the procedure of the energy performance of buildings, the type, and functional units based on real-time data. At the point of submission of the D^2EPC project proposal and to the knowledge of the consortium, such indicators or methodologies do not exist. However, the project considered it important to validate and verify this assertion.
- Description of the trends and developments in the field of LCA methodologies and tools developed in accordance with the content of the IEA EBC Annex 72, concerning the Assessment of Life Cycle Related Environmental Impacts Caused by Buildings
- Identification of possible gaps or discrepancies in the degree of novelty of the project

The new findings anticipated from the project will provide a valuable contribution to the dynamic EPC scheme examined in WP1, which focuses on the required elements for the inclusion in the dynamic EPC of the novel set of indicators, covering aspects of the life cycle environmental and economic performance of the buildings.

4.1.3.1 Current Status of LCA Indicators in the EPC Scheme

Life Cycle Assessment (LCA) is the most efficient and practical method for evaluating and recording technological opportunities and possibilities to mitigate any procedure or material's ecological consequences [44]. The life cycle of a system encompasses a meaningful impact on its overall environmental performance, whereas some indicative primary factors influencing the overall environmental performance of a system are the energy and the materials expended for the extraction of raw materials, transportation, repair and disposal life-cycle stages [45]. The ISO 14040 [46] and ISO 14044 [47] international standards give common direction for LCA implementation and have developed this approach as a structured and systematic technique to determine the possible environmental impacts of goods and services on the life cycle [48]. This approach is focused on all a system's 'cradle-to-grave' flows, inputs, and outputs, producing qualitative results for investigating the future creation of a process or the whole system and allowing the related environmental impacts to be evaluated [44].

According to the applicable criteria, LCA may help recognize opportunities to enhance the environmental performance of the product or service under review, inform decision-makers in business, government or non-governmental organizations to choose specific environmental performance metrics and market goods or services [48]. At the beginning of the construction design process, LCA is a valuable tool as it measures the buildings' possible environmental effects and carbon emissions. At this point stakeholders and consumers can take alternative strategies to improve their sustainable design [49]. However, it should be noted, that the LCA findings are not absolute because they are locus-specific and, as such, cannot be transmitted directly across countries and regions; they are also based on device constraints, hypotheses and accessibility of energy/resources. Nevertheless, in order to compare alternative technological solutions, structures, or procedures, LCA results can still be used [50].

The LCA seems to be the most commonly used approach to evaluate the efficiency of goods and practices, including construction materials, in terms of sustainability [51]. The development and the use of buildings in the EU account for approximately half of all our produced energy and resource utilization [52] [53] and approximately one-third of the EU's use of water [54]. The sector also produces about one-third of all waste [55] and it is correlated with environmental stress conditions that exist at various phases of the life cycle of a building, along with the manufacture of building materials, design, usage, reconstruction and waste disposal [56]. They require empirical, accurate, consistent and comparative data to allow experts, decision-makers and developers across the EU to make use of life-cycle factors, which then, in return, would have to be focused on specific building success measures that incorporate the priorities of various public and private criteria [57]. The introduction into the building envelope of either existing or new buildings of environmentally sustainable products that have considerably reduced embodied energy and emissions, that have the potential to be reprocessed after their first usable life and cause limited environmental contamination, will greatly minimize the total environmental effect of the built environment and the building industry [58].

The achievement of the goals of the Energy Performance of Buildings Directive (EPBD) (2010/31/EU) [59] to turn the European building stock into almost zero energy and of the Energy Efficiency Directive (2012/27/EC) [60] to meet its 20% energy efficiency goal by 2020 has put immense pressure on all phases of the construction sector's production process. The production and employment of renewable technology and energy-efficient structures, including the use of recycled materials in both new and renovated houses, were projected to make up a significant proportion of the contribution. In addition, the Ecodesign Directive (2009/125/EC) [61] laid down a roadmap for refining and improving the performance of a range of energy-related materials, especially materials used in construction, like windows and insulation materials, intending to minimize their environmental consequences and generate energy and cost reductions for both industries and consumers. As noted in the Roadmap to a Resource Efficient Europe (COM(2011)571) [62], the goal is to achieve a high resource and cost-effective conversion of the building stock, which is intended to be accomplished by the use of life-cycle methods for achieving advanced design features, the use of advanced recycled materials and high CDW recycling rates. Via the communication 'Towards a Circular Economy: A Zero Waste Policy for Europe' (COM(2014)398) [63], the EC launched the intention to shift the economy away from the straightforward 'take-make-consume and dispose' paradigm toward a more circular economy in all industries. The European IPP Communication (COM (2003)302) [64] defined LCA as the best mechanism for evaluating the possible environmental consequences of materials. Accordingly, the need for improved quality-assured life-cycle data availability has contributed to the introduction of EPLCA, which seeks to support the market and government demands regarding accessibility, interactivity, and quality of life-cycle data and surveys [58]. The EC has also established a standard series, which creates a system for assessing the energy performance of buildings using a life-cycle methodology, considering the performance details and capabilities of a construction (EN 15643-2:2011) [58]. The methodology extends to all types of structures, and the sustainability evaluation utilizes both quantitative and qualitative metrics to measure the environmental, cultural and financial performance of establishment work [65].

4.1.3.2 Comparative Assessment of Current Advancements in the Development of LCA Indicators

Service standards and principles of the European Commission include the costing of any action taken for the EPCs' issuance and procedures, guided by the benefit of the European citizen. According to this, the development of indicators of an economic nature, such as energy €/m² of building systems whether it is of electricity, oil, or gas utilization, will enable the interpretation of the individual elements of buildings' energy performance into normalized monetary values, based on the well-established concept of whole life cycle costing. The delivery of such indicators will also enable the employment of EPCs for the financial assessment of buildings' energy upgrade measures. It will allow the exploitation of the information produced by EPCs by energy audit processes, bridging the gap between the energy-related directives of EPBD and the energy efficiency. This will be accomplished, in compliance with the IEA EBC Annex 56, with the inclusion of the documentation of the economic indicator, which may be employed in EPCs based on the inputs, the outputs, the scope, and the normalization factors.

According to the European Commission and its Communication on Integrated Product Policy (COM (2003)302, [65]), it was depicted that more consistent data and consensus LCA methodologies are needed. A thorough evaluation of all nine types of potential material environmental effects, including the eutrophication and acidification potential of building materials in the whole building, based on EU data collection activities and current harmonization programs, should be followed up. The definition and assessment of the type and functional units of the LCA indicators for EPCs, such as "energy savings", expressed in "embodied energy/m2" and "carbon reductions", expressed in "carbon dioxide equivalent/m2" should provide the option to the building design engineers to improve and optimize the environmental performance of the building, based on changes to be integrated at the initial design stages of the building. The anticipated benefits of EPC systems can only be achieved through an appropriately endorsed management and control system. Sustainability assessment methods and systems, such as Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED), contribute to a concise framework for building owners and stakeholders by applying third-party verification and certification assessment of the sustainability performance of a building. This procedure improves performance across all the most environmentally important factors and metrics.

The EN 16798 [67] series Standards on building ventilation are accompanied by the specification of indoor environmental input parameters for construction and measurement of indoor air quality, thermal climate, illumination, and acoustics. According to Directive 2018/844/EU [68] and the 2009 World Health Organisation guidelines, a methodology based on the European standards should be followed to calculate the energy performance per season and year. The higher the comfort levels are, and therefore the indoor air quality, the healthier and greater the performance of the buildings will be for the owners/users and the energy balance.

Following the desk research carried out on this topic, energy-related financial indicators are not found to be included in current EPCs schemes and procedures in any EU Member State. It appears that, in several countries, the energy cost and the carbon dioxide emissions per m2 are included in the EPC procedures. Regarding the environmental/LCA-related financial indicators included in the EPC procedure, it was recognized that environmental-related financial indicators are not taken into consideration for the EPC issuance.

It was revealed as well that in many EU countries, the necessity of the carbon footprint assessment based on a complete life cycle analysis has arisen [69]. Environmental indicators, present in energy certificates today, are usually linked to carbon dioxide emissions, such as calculated during exploitation derived from primary energy. Carbon dioxide emissions vary from country to country depending on each country's energy system, particularly by the factor of the primary to final energy conversion. Nowadays, energy carriers' primary and final energy demands, such as oil or gas, are estimated as equal. The rationale behind the Primary Energy Conversion Factor is the conversion of final energy consumption to primary energy consumption for the production of an electric unit or thermal energy [70]. Additionally, the comfort factor is combined in assessment systems, but it is not calculated in the analysis. However, any comfort appraisal or the use of recycled resources with low environmental effects from a life-cycle perspective as part of a country's EPC measurement tool has not yet been included [71]. Countries are increasingly engaging residents in reducing non-renewable primary energy from their homes, either by raising the share of RES or upgrading the building envelope [72].

While indoor environmental quality requirements (including air quality, thermal comfort, risk of overheating and ventilation, lighting and acoustics) are laid down in EPCs, they are not protected by current EPC regimes and are not included in the calculation process for EU countries' certification, as field and desk research has shown [73] [74] [75].

4.1.3.3 Aspects of Next Generation EPCs in View of LCA Indicators

In the D^2EPC project, the LCA Indicators for EPCs will contribute significantly to the maximization of the energy savings and the achievement of carbon reductions in the buildings for the issuing of truly sustainable EPCs. Suggested improvements will speed the transaction into NZEBs, control the building's energy demand, reduce carbon emissions and enhance public awareness. The methodology for using the real-time data collected for the development of the LCA Indicators will also be formulated, as well as relevant guidelines, will be developed. The LCA Indicators for EPCs will significantly contribute to the maximization of the energy savings and the achievement of carbon reductions of the buildings for the issuing of truly sustainable EPCs.

The D^2EPC project also aims to propose additional indicators demonstrating buildings' environmental performance for their introduction to the next-generation EPCs. For the development of the environmental indicators, LCA methodologies and tools will be employed for the efficient energy design of buildings and for enabling the parameterization of its embodied energy and primary energy demand to be included in dynamic EPCs. These procedures will be implemented in accordance with the content of the IEA EBC Annex 72, concerning the Assessment of Life Cycle Related Environmental Impacts Caused by Buildings.

Additionally, LCA could involve whole building cradle-to-grave assessment. This could potentially be faced through the calculation of LCA-related indicators, which will be based on well-established building materials LCA databases (e.g. EcoInvent, BRE, Greenguide, etc.). Buildings are also anticipated to adapt their operation mode in response to the occupant's needs by maintaining healthy and convenient indoor climate conditions as per the revised EPBD (2018/844/EU).

On the basis of the findings of the D^2EPC, the project will lead to the transition from the EPC to a systemic instrument that recognizes the whole life cycle of a building as a structure and will encourage best practices in the field of resource performance, a core policy concern for the EU. In this sense, it is expected that the next EPC generation envisaged by the D^2EPC project will provide guidance and decision-making on matters related to the sustainable management of natural resources.

4.1.3.4 Findings Concerning LCA Indicators

Developing and implementing environmental key performance indicators (KPIs) is a critical step toward meeting energy-saving goals for both new and existing structures. The information provided might stimulate the user to compare and estimate their monthly building system expenses and be aware of their building's overall energy consumption. European standards, as well as EU Member States' initiatives in this area, are laying the foundation for the industry's future growth. The significance of employing LCA methodologies for efficient energy design of buildings and for enabling the parameterization of their embodied energy and primary energy demand is emphasized for their inclusion in dynamic EPCs.

The majority of the European funded sister projects, such as X-tendo and U-CERT, examine indicators relevant to smart readiness or internal air quality and overall comfort. They do not take into consideration the LCA methodology and furthermore the environmental approach of the next-generation EPCs. Nevertheless, the Energy flexible DYnamic building CErtification – E-DYCE project makes efforts in assessing the correlation between buildings, their surroundings and climate with specific indicators, like the urban heat island degree-hours (UHIdh) and urban cool island degree-hours (UCIdh) which compare the outdoor temperature in rural and urban areas.

The progress of the D^2EPC environmental indicators is based on the Level(s) [76] scheme, the EU sustainability assessment for constructions outline. Level(s) is the most recent European approach to analyzing and reporting on a building's sustainability performance over the course of its whole life cycle, with the effects correlated to European sustainability targets. The Level(s) approach uses existing standards to create a shared identity for sustainable development, providing a foundation for quantifying, analyzing, and understanding the life cycle. It also addresses a variety of circularity attributes, providing indicators that can assist in understanding how to expand the building's functionality.

Through the analysis of the D^2EPC project, a complete list of 17 data results terms were identified for stages of (a) construction materials, (b) transportation to site, (c) construction/installation process, and (d) end of life, as well as the total values for each indicator. The environmental footprint for each construction material and each type of structural element is measured as a consequence of a value. The environmental D^2EPC indicators, which highlight how a building's sustainability affects the environment, are recommended for inclusion in the next-generation EPCs.

4.1.3.5 Recast of the Energy Performance of Buildings Directive

The European Commission proposed a recast of the Energy Performance of Buildings Directive [77] under the Fit for 55% Package framework on December 15, 2021. The set of measures aims to put Europe on track to cut carbon emissions by 55% by 2030.

With changes to definitions of energy performance standards, revisions to national building renovation plans, and a new requirement for life-cycle emission calculations for new builds, the suggested revised version of the Energy Performance of Buildings Directive introduces new standards for energy performance to reduce carbon emissions the built environment. Under Article 2, the proposal added many new definitions that raise the standard for renovation endeavours [78]:

A zero-emission building is one with exceptional energy efficiency, with renewables covering the small amount of energy necessary, whether generated locally, by an energy community, or through district heating and cooling. As of 2030, this will be the norm for new structures and the level that deep renovations will achieve.

A building that meets the following characteristics and performs at or near the cost-optimal level (to be determined under Article 6) is referred to as a nearly-zero energy building.

Converting a structure to a substantially zero-emission structure until 2030 or a zero-emission structure after 2030 is referred to as a deep renovation.

National Building Renovation Plans, formerly known as “Long-Term Renovation Strategies”, will need to be updated to include a timeline and national goals by 2030, 2040, and 2050, according to Article 3. By 2027, member states must ensure that all public and non-residential buildings are at least class F or class E, with all residential structures achieving class F or class E by 2033 based on Article 9. To meet these goals, 15% of the current building stock, which is projected to be around 40 million structures across the EU, would have to be renovated.

By 2030, all new buildings and until 2027, public buildings must be zero-emission, and life-cycle Global Warming Potential will be calculated for big new structures from 2027 and all new buildings by 2030 according to Article 7. This will take into account the structures’ entire life-cycle carbon emissions, including production and construction, usage, and end-of-life phases.

The amended EPBD aims to cease all financial assistance for fossil fuel boilers by 2025, giving member states a legal basis for abolishing them based on Article 11. The proposal also calls for pre-wiring for new and refurbished structures and the placement of charging stations in office buildings in accordance with Article 12. New provisions of Articles 13-19 are also introduced to improve the Smart Readiness Indicator and Energy Performance Certificates, providing data to owners and buyers and ensuring uniformity across the EU.

4.2 The Introduction of Geolocation Practices for Dynamic EPC

In the concept of adopting a harmonized framework for the assessment of the energy performance of buildings and the energy need of dwellings, buildings and regions Energy, the definition of the geolocation of an EPC in the real 3D world and in real-time/near-real-time framework is of great importance.

- The correct geolocation of a dynamic EPC will significantly enhance the comprehension of the energy performance status of each dwelling/building at a specified monitored time frame
- Newly generated EPCs will be able to adopt a spatial and visual connection of a building's location with other important climatic factors (climate change indices, neighbourhood greenness, incoming sunlight etc.)
- Data on EPCs issued by D^2EPC framework can be correctly exploited to produce and visualize statistics for EPC documentation

The aim of this part is to present a geolocation concept and dEPC statistics generation and visualisation tool.

4.2.1 The Definition of Geolocation

In the context of the D^2EPC project, each dwelling/apartment/building of subject is described based on its 3d BIM model for asset based ratings and additional sensors for the operational rating. These models depict the correct building proportions and scale, and their correct geolocation is still to be defined.

For the D^2EPC framework, the "manual" selection on a map is selected as the geolocation practice, either on using pin on map or by adding address (geocoding). The end users provide the geolocation of their asset in the process of assessing a new dEPC on a form provided by the D^2EPC main platform. To ensure a homogenous common EPC scheme, at least for European level, a unique Projection/Coordinate System is expected. For the case of D^2EPC, the selected coordinate system is the World Geodetic System11 (WGS) 84 also known as WGS 1984 or EPSG:432612 as it is a global system and the most common among WebGIS applications.

4.2.2 Geolocation Practices for EPC Documentation and Proposed Added Value Service

For the D^2EPC framework, the "manual" selection on a map is selected as the geolocation practice, either on using pin on map or by adding address (geocoding). The end users provide the geolocation of their asset in the process of assessing a new dEPC on a form provided by the D^2EPC main platform. To ensure a homogenous common EPC scheme, at least for European level, a unique Projection/Coordinate System is expected. For the case of D^2EPC, the selected coordinate system is the World Geodetic System[13] (WGS) 84 also known as WGS 1984 or EPSG:4326[14] as it is a global system and the most common among WebGIS applications.

The EPCs issued by the D^2EPC framework are saved in a common database mentioned in the system architecture as D^2EPC repository. Each tuple of this database represents a dEPC issuance and contains

[11] https://en.wikipedia.org/wiki/World_Geodetic_System

[12] https://en.wikipedia.org/wiki/EPSG_Geodetic_Parameter_Dataset

[13] https://en.wikipedia.org/wiki/World_Geodetic_System

[14] https://en.wikipedia.org/wiki/EPSG_Geodetic_Parameter_Dataset

data regarding each dwelling/building such as the BIM model, the owner ID, EPC rating, etc. However, according to the EU's GDPR compliance regulations, the exact location of a user's building will not be saved in the database. Thus, an alternative method will be selected for storing the "approximate" geolocation of an EPC by either using the zip code or adding a small random component to the longitude and latitude values.

The D^2EPC project aims to propose and establish a new, common -across all EU MSs- dynamic and digital methodology for issuing dEPCs. Deriving from the project's goal, the Business Scenario (BS) of the project BS C: "Evaluation and Benchmarking of more certificates for policy making/ marketing / business purposes" focuses on developing added value services and creating extra revenue streams to the project.

The D^2EPC WebGIS (Web Geographic Information System) application is a dynamic tool for EPC documentation proposed for covering the requirements of BS C. The main functionalities of the application cover the generation of anonymised statistics per region and the visualisation on a map, the provision of analysis tools such as the comparison and querying of regional dEPC statistics and the provision of operational rating visualisation tools for pilot case buildings and the 3D visualisation for demonstration purposes. The potential end users for the application include several D^2EPC stakeholders namely, authorities/ registries/ public bodies, Energy Service Companies (ESCOs), Real Estate agencies, the Building services industry, researches and academia, environmental organisations and standardisation bodies. The technical use cases of the WebGIS application are shown in Figure 12.

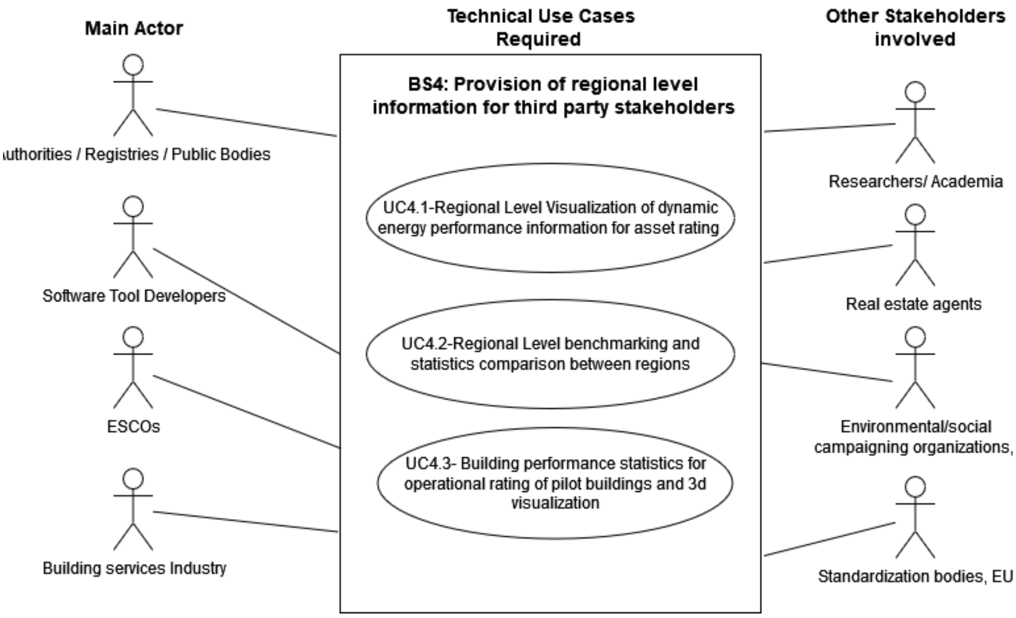

Figure 8. WebGIS technical use cases

The main functionalities of the tool are the following:

- The generation of statistics for dEPCs issued using the D^2EPC Calculation Tool by correlating the EPC grades and geolocations approximates with pre-defined geographic regions, namely the EU's Nomenclature of territorial units for statistics[15] (NUTS):
    - NUTS level 0: countries
    - NUTS level 1: major socio-economic regions

[15] https://ec.europa.eu/eurostat/web/nuts/background

- NUTS level 2: basic regions for the application of regional policies
- NUTS level 3: small regions for specific diagnoses

- The visualisation of the generated statistics on a map accessible via web browsers
- The provision of spatial & attribute querying tools
- The provision of OGC (Open Geospatial Consortium) services[16] to authorized users for further exploration and analysis of the data on external GIS tools
- The visualisation of Building Information Models (BIMs) using 3D graphics and on map (for authorized users and pilot case buildings)

Some of the basic features of the D^2EPC WebGIS are given here. Note that for demonstration purposes the geo-database is populated with dummy values.

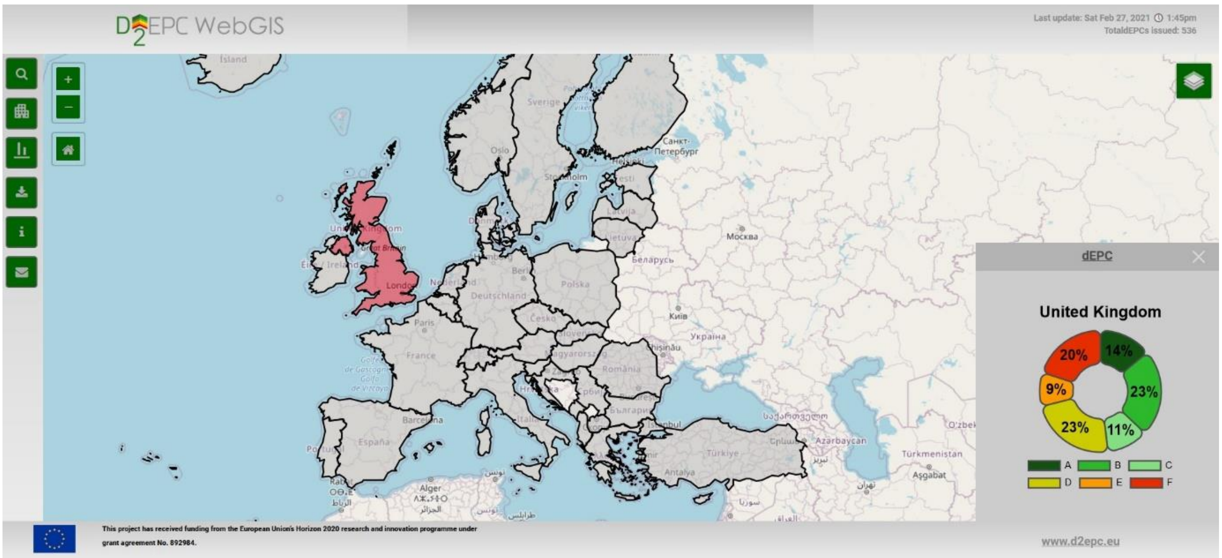

Figure 9. Visualisation of EPC statistics for selected region on map

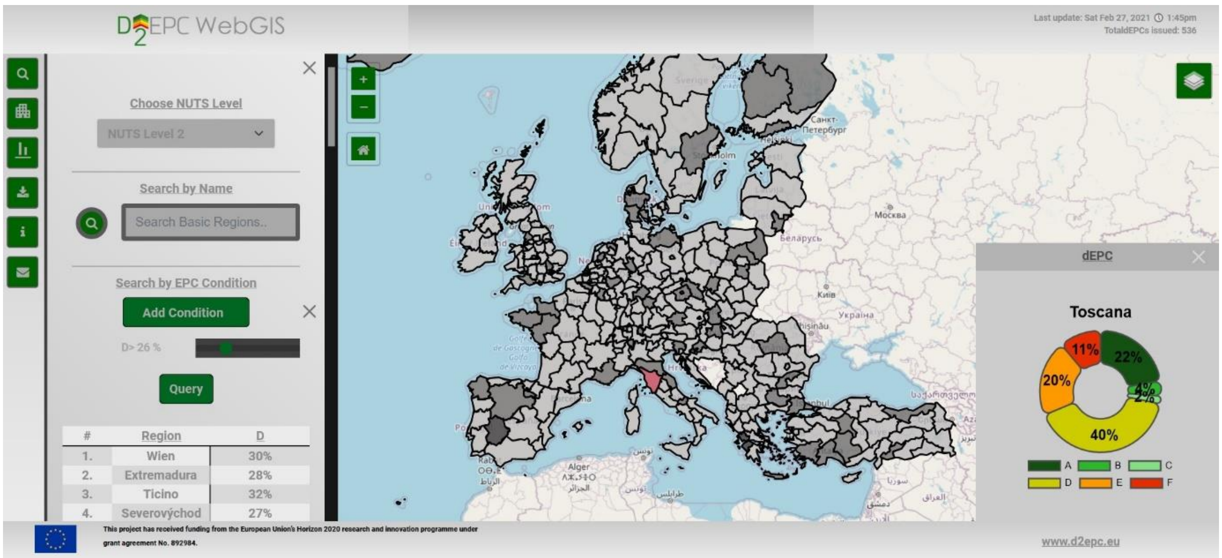

Figure 10. Attribute query and visualisation of dEPC for selected region

16 https://www.ogc.org/standards/

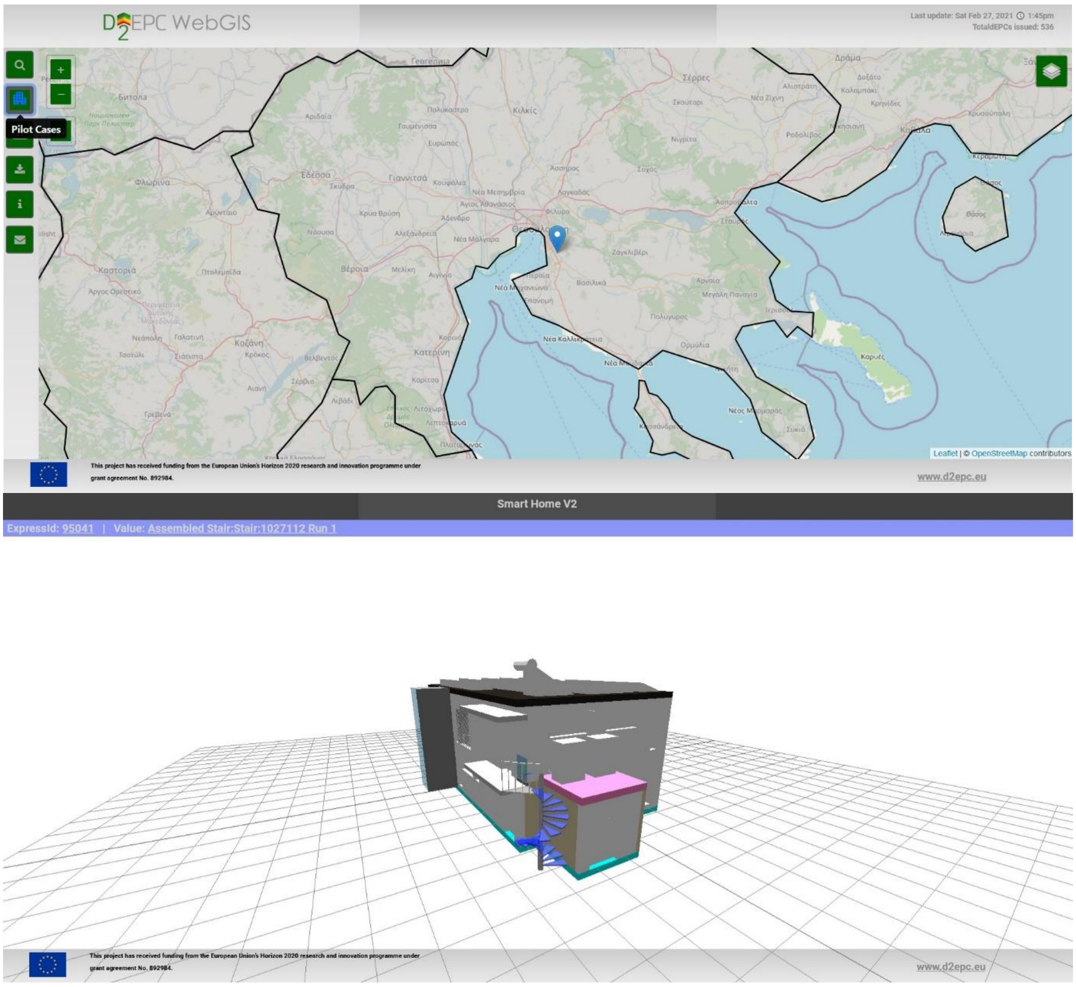

Figure 11. Geolocation on map (2D) of a pilot case building (up) and visualisation of its 3D BIM model (down)

4.3 The Introduction of the BIM and Digital Twin Concept for Dynamic EPC

The aim of Building Information Model (BIM) and Digital Twin (DT) is focused to make a digital representation of the built asset. In order to facilitate processes of plan, design, and construction with digital technologies, it is more popular to use BIM acronym as a definition of digitalization. However, both above-mentioned innovations are targeted to the same goal to get more efficiency, sustainability and benefits within processes of building life cycle by use of digital data.

The aim of this part is to present BIM and DT concept, maturity levels and how these digital tools can contribute to the D^2EPC .

4.3.1 The Definition of BIM

As a promising technology in the construction industry, the concept of BIM became widespread on the market early in 2000s. The definition of BIM is proposed as following: “overarching term to describe a variety of activities in object-oriented Computer Aided Design (CAD), which supports the representation of building elements in terms of their 3D geometric and non-geometric (functional) attributes and relationships” [85]. Well-defined semantic and geometrical data of each element and the ability to enable collaboration among stakeholders during the facility life cycle can be referred as a key feature of BIM. According to BIM purpose, the application of it is observed during throughout all asset life cycle stages. Architects, engineers, and constructors utilize BIM through the design and construction stage while gaining benefits from errors reducing, improving construction efficiency, communication and data exchange as well as costs and time monitoring. Facility managers utilize BIM as a tool for maintenance planning and execution. As far as it contains relevant information, BIM can be used during the demolition phase [86].

Maturity levels of BIM

Regardless of the increasing utilization and researches on BIM in the last decades, the description of the concept is still variable. Despite that, there are established conventional categories of BIM implementation indicator called "Levels" [87]:

- **Level 0** – the roots of BIM, 2D CAD files is used for the design and product information.
- **Level 1** – this stage enables to create 3D CAD models to represent the design and geometrical data. Digital data sharing is available, although different project models or parts are not linked into the general BIM model.
- **Level 2** – the advantages of BIM are utilized at this level. Common Industry Foundation Class (IFC) format enables information exchange among separate BIM discipline software tools. Shared elements include well-defined semantic and geometrical data. Models at this level might have construction and organizational sequencing data, as well as cost information.
- **Level 3** – the emphasis of this level is stakeholders' collaboration through the use of the same model stored in the cloud. It will ensure related data accessibility throughout all building life cycle stages. At this stage, the model contains construction sequencing, costs, and management related information. The development of standard libraries with object data that include manufacturers' information is crucial at this point.

4.3.2 The Definition of Digital Twin

The concept of Digital Twins has evolved since it was first mentioned in 2002. In scientific literature the definition of DT varies depending on the author, despite that it supplements each other. The first definition was proposed by Grieves [88]as following: **"Digital Twin is a combined virtual information that fully represents a physical product, any information that could be acquired from the real product, can be retrieved from its Digital Twin as well". In recent years several analyses of the concept were conducted to identify common characteristics of DT. As in the former definition, it is stated that Digital Twin should represent a physical asset in the most detailed way, including all available technical, operational, and organization information of all stages. The synchronization between physical data and a digital model is defined as a spine of the concept. Based on real-time data, it is available to run simulations in virtual space to predict the behaviour of the physical asset.** Interaction and convergence of these two worlds are described as two key aspects of DT [89] [90]. Predictions performed shall be implemented for the successful use of DT. The interaction between digital and physical objects needs to be automatic and bidirectional. In this case, the data collected from physical asset goes to Digital Twin as well as physical product reacts to information received from the digital one [91]. Correspondingly, the study [92] summarized the overall description: "Digital Twins will facilitate the means to monitor, understand and optimize the functions of all physical entities, living as well as non-living, by enabling the seamless transmission of data between the physical and virtual world".

Maturity levels of DT

Digital Twins comes at all kind of forms and levels of maturity. As far as these levels are concerned, five levels describing the maturity of DTs are proposed [85]:

- **Descriptive** – first stage of appearance of DT includes collecting and visualizing data of physical assets (photogrammetry, 3D modelling, laser scanning, etc.).
- **Informative** – analysis and segmentation of the collected data. It includes the evaluation on certain situations or past events, as well as generating insight based on the collected information.
- **Predictive** – this maturity level involves real-time monitoring using integrated sensors, intimately linked to simulation platforms through digital twin. It aims to the prediction of physical asset future behaviour and their performance based on what-if scenarios. (What will happen?)
- **Prescriptive** – related to predicted information and Artificial Intelligence (AI) based reinforcement learning, DT proposes solutions and interventions to improve the performance of facilities.
- **Transformative** – the highest level of maturity enables physical changes when utilizing machine-to-machine data exchange. Interaction with the physical world is bidirectional, and any deficiencies or improvement abilities, detected in the virtual model leads to modification of physical asset without human intervention.

As a good example of the progressive use of DT could be presented UK experience with "***The Gemini Principles***" [93]. Digital Framework Task Group (DFTG) brought together experts from academia, industry and government for guidance of digital transformation. The idea was to create Digital Built Britain that will give a result of Digital Twins ecosystem connected by shared data, which is secure, will include existing and new built environment, and increase commercial competitiveness and public wellbeing. The quality of life and wellbeing of people living in cities might be improved by the conjunction of smart infrastructure, modern methods used in the construction sector, and digital data. UK has a strategy to create digital models of transport networks, hospitals, houses, schools and give it to the local and central government as a tool for better decision making.

In the National Digital Twin (NDT), when it creates value, digital twins will be connected. It is expected that with time NDT will be diverse and connected. It is expected that NDT, which is conducted by Gemini principles, will give benefit to the society, economy, business, and environment.

The introduced Gemini principles declare clear purpose, being trustworthy and functioning effectively. Gemini principles are simple, introducing and encouraging innovations, helping the industry to develop DT, which can become part of NDT. Nine Gemini principles are presented: public good, value creation, insight, security, openness, quality, federation, curation, and evolution. It is expected that NDT will include private and public investments.

4.3.3 BIM and Digital Twin Collaboration

Both BIM and DT concepts are applicable to increase efficiency in Architecture Engineering, Construction and Owner - operated (AECO) industry throughout different building life cycle stages. BIM aims to improve collaboration of stakeholders and resources management on design and construction phases such as:

- Simulation and analysis (energy, structural performance, lightning, sustainability, hydraulics, noise, transport or human flows, etc.)
- Scheduling and cost estimation
- Construction logistics and clash detection
- Existing conditions modelling
- Code validation
- Digital fabrication
- Quality control and safety management
- Construction simulation and visual communication

With the highest level of BIM maturity, asset life cycle management and demolition option could be added to the former list.

Continuously, DT focuses on linkage to physical object through data flow, analysing collected material, and making changes in physical assets during the life cycle. The key elements of DT can be the followings:

- Sensing and monitoring (vital for DT)
- Life cycle based decisions
- Linked data, Internet Of Things (IoT), knowledge basis
- Simulation, prediction, learning
- Interoperability between ICT platforms
- Asset management and optimization
- Disaster planning and risk management

Considering the collaboration of these concepts, it is stated that it is beneficial for DT to incorporate BIM. In this case, BIM is utilized as a semantically rich 3D base for further use in various applications. Enriching the primary model with sensor data and linkage to the physical world actuators enables the use of Digital Twin concept [94] . In this scenario, DT is introduced into the construction site in the early phase, which enriches the model with essential data for further asset management. Noticeably, BIM integration as a starting point of DT boosts up the procedure, avoiding data collection and classification, leading straight to predictive maturity level at the early asset construction phase. For example, photogrammetry can be utilized in the first level of DT (descriptive) as it contains visual interpretation information of the building envelope. Unfortunately, data capture is time consuming, and the process requires additional intervention; also, the result of this method is non-interpreted data and do not contain any semantics, which is crucial for analysis.

In the ideal scenario, Level 3 BIM with relevant and reliable data, supplemented with real-time data flow and actuators in physical assets, turns into a transformative Digital Twin. BIM integration as a part of Digital Twin is presented in Figure 16.

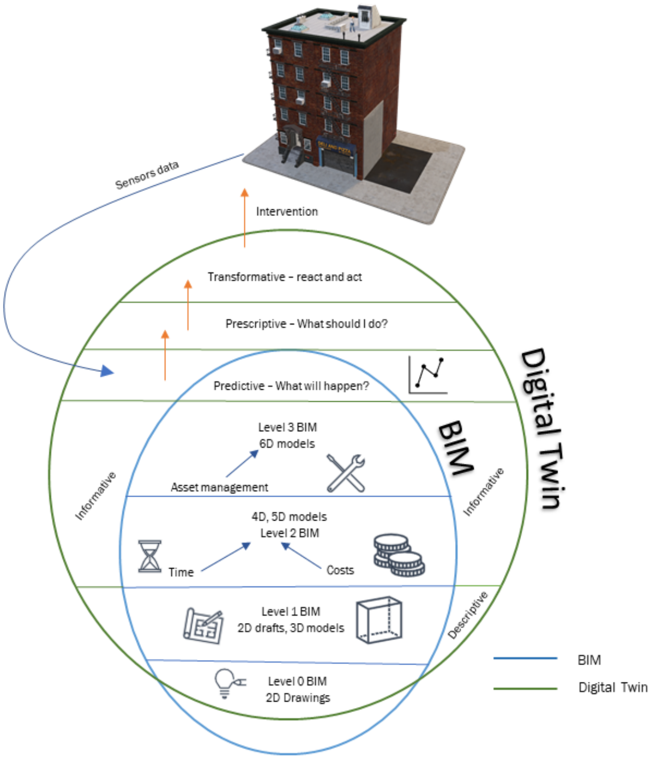

Figure 12. BIM integration as a part of Digital Twin

4.3.4 Gaps in Representation and Data Collection for Digital Twins

One of the challenges of DTs implementation is identified as improvement in data availability and accessibility. The integration of building asset relied on data such as envelope, operational, historical asset evolution information requires Big Data platforms for scalability and ubiquity. As far as DT is concerned for providing additional features of asset health at the moment, it needs to be used in near real-time.

As prediction feature is concerned, an asset monitoring system is needed to be implemented in DT. As well as basic information of the physical object is required; at this stage, DT must involve information of factors that affects the condition of the asset or its parts. It means that geometry (object) based data (3D model) is a priority to express and define real-world assets. In this case, there are many technologies on how to define asset geometry virtually: CAD, BIM, photogrammetry, light detection and ranging (LiDAR) etc. These technologies differ according to data quality, semantic richness, accuracy, technological heaviness. In terms of distinctions, an important aspect would be boundary representation. Some of the mentioned technologies lack of separated boundary representations of individual objects, e.g., photogrammetry, LiDAR. In this case, there are fused surfaces, which reduce the possibility to define individual objects, e.g., set limits, determine boundaries, define by attribute. Some of the technologies are based on clearly separated object boundaries, e.g., BIM. Therefore, it could be extremely valuable to DT, when it‘s necessary to set attributes, link real-time data, attach documents or shortcut with a particular object (asset). Object-based information is related not only to asset itself but also to the processes where it is involved. At this stage, the need of data from different sources and in a short time period is clearly visible. Despite the fact that data silos exist, there is still a lack of effort for collecting and integrating data into warehouses [95].

One of the tasks to solve is the quality and reliability of the collected data. A variety of errors occurring in data collection process can be provided. The incremental errors may emerge in large scale monitoring systems due to misaligned data. In this case, a large number of minor deviations can result in incorrect results. Other misleading results can occur due to failures in the monitoring system as well as software or hardware sensor faults. To avoid it, the use of algorithms of data integrity checks can be performed for the collected data quality improvement [95] [95].

Due to the wide variety of stakeholders and used software within the building life cycle, diversity of data formats and standards are obvious nowadays. However, DT requires full-fledged data, which is distributed across different sources and in different kinds of data formats. It rises an interoperability issue. Strong global efforts and confidence of industry are focused on openBIM and GIS data formats: IFC (Industry Foundation Classes), cityGML (City Geograghic Markup Language), LandXML (Land Extensible Markup Language). However, it is still usual to encounter interoperability issues between the different domains (infra, buildings, GIS). Even in the same domain, there are significant lacks concerning data exchange between the different disciplines (architecture, structures, mechanical, electrical and plumbing systems (MEP) systems) [97]. The next significant kind of data standardisation in AECO industry is the construction (asset) information classification system (CICS). It isn't based on a particular data format but could realise local language and specificity of national or regional construction context. However, from a global interoperability point of view, we have plenty of CICS globally, e.g., Uniclass2015 (Unified classification system for the UK construction industry), CCS (Cuneco Classification System, Denmark), CoClass (Swedish digital classification system), Omniclass (North America classification system for the construction industry), Natspec (national not-for-profit organization that is owned by the design, build, construct and property industry through professional associations and government property groups, Australia)), Talo2000 (Finnish building classification system), NL-SfB (Dutch construction classification system), etc. Despite the fact that it's a way to standardise data locally, it's still an issue from a global interoperability point of view [98].

4.3.5 Insights of Digital Twins for Dynamic EPC

As far as DT is concerned for the Operation and Maintenance (O&M) management [96], key features can be linked to EPC. Since DT consists sensing and actuating devices practises of the physical assets at O&M it is enabled to conduct energy performance evaluation. Few directions of collected data application can be highlighted.

- DT as a tool for prediction and visualization of user behaviour impact for EPC – it allows to supply the information to end-user of his actions importance in comprehensible way. For example, DT observes and analyses recurring efficiency harmful behaviour with the prediction of such acts impact to EPC. In this scenario, end user is well informed that his behaviour causes greater energy consumption values in comparison to those provided in EPC and energy performance class could be reduced. As well as informing on harmful behaviour, DT could promote action plans to perform a better result.
- Transformative DT in purpose to achieve and sustain the highest energy efficiency class of the building available. At this point, DT scope is broadened with the ability to make changes in physical asset regarding the predictions on energy efficiency improvement based on collected data. In this scenario, DT eliminates the end user's faults on energy savings (switching off the lights, other appliances, HVAC adaptation to user needs, etc.).
- O&M management framework for DT can be adopted as a core for monitoring appliances deterioration impact to energy efficiency class. DT sensing and monitoring features using smart assets or Internet of things (IoT) can be used to prevent an inefficient appliance from affecting energy uses. For example, according to abnormalities in energy consumption, DT alerts and informs the user or facility manager on the exact inappropriate device and its impact on EPC rating. As far as impact exceeds the limits, service or update shall be performed.

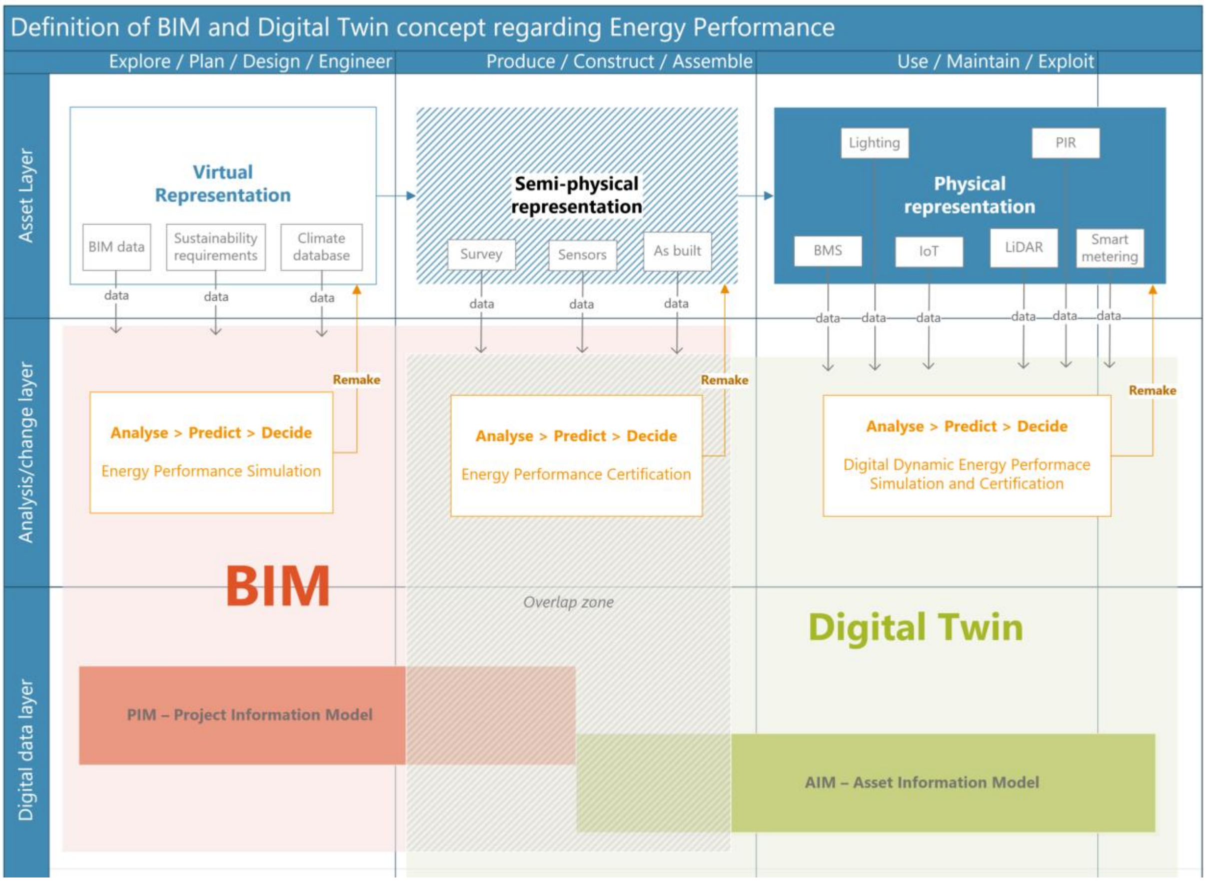

Figure 13. Definition of BIM and digital twin concept regarding energy performance

Figure 17 represents a definition of BIM, and Digital Twin concept regarding energy performance within different stages of building (asset) life cycle: plan and design > produce and construct > use and maintain. There are 3 layers, which represent a different type of approach.

The first one is called "asset layer", which is intended to represent the virtual, semi-physical, and physical development of assets, together with stored information, installed sensors, real-time data, etc. A virtual representation of asset is better known as BIM model, together with existing GIS data, space plan, regulation requirements, climate norms, common disciplines as architecture, structures, and MEP systems.

"Analysis/change layer" shows common logic of digital data use for analysis, prediction, taking decisions, and finally making "nearly best" and reasonable changes within the asset, e.g. in order to get required energy performance value, it's necessary to simulate heat losses vs. heat gains, take into account HVAC parameters, hot water preparation, renewable energy sources, electricity consumption, etc. Within a production/construction stage analysis-decision could be related to certification of the particular energy performance of an already built asset by taking into account physical values.

The third stage of the asset life cycle in Figure 17 is linked with use and maintenance activities. There are given some state-of-the-art components of the digital twin, usually used nowadays, e.g. IoT devices, smart meters, reality capture technologies (photogrammetry, LiDAR), lightning sensors, movement detectors, passive infrared sensors (PIR), actuators, and sensing from Building Management System (BMS), etc.

The bottom layer represents the main constituents of BIM model regarding the group of information management standards [99]. Part 1 is intended for the definition of concepts and principles. Part 2 is focused on the delivery phase of the asset (design and construct). Part 3 based on information management within operational phase of the assets (use and maintenance). The standards state that project information model (PIM) is an information model relating to the delivery phase of an asset, and asset information model (AIM) is an information model relating to the operation of an asset.

It's obvious that some parts of BIM and digital twin concepts overlap. Nowadays BIM model is usually based on uses within plan, design and construction stages (3D modelling, cost estimation, clash detection, scheduling, energy simulation, etc.). However, BIM is well known and magnified regarding relations with facilities or assets management. Here we have some kind of overlap between the BIM and digital twin data, concepts, and boundaries. Digital twin starts his life, then a physical asset appears. If there is no physical asset, it couldn't be the twin of something. BIM starts his life from the initial stage (from an idea) and develops digital and machine-readable data from the beginning of the asset life cycle, i.e., such kind of data and information could be especially valuable in later stages of asset life cycle. It's beneficial to make further investigations regarding the determination of how BIM data could facilitate the development of digital twin if taking into account that BIM is a part of digital twin (Figure 18). Figure 19 is giving the approach of SRI domains related to dynamic data within the digital twin concept.

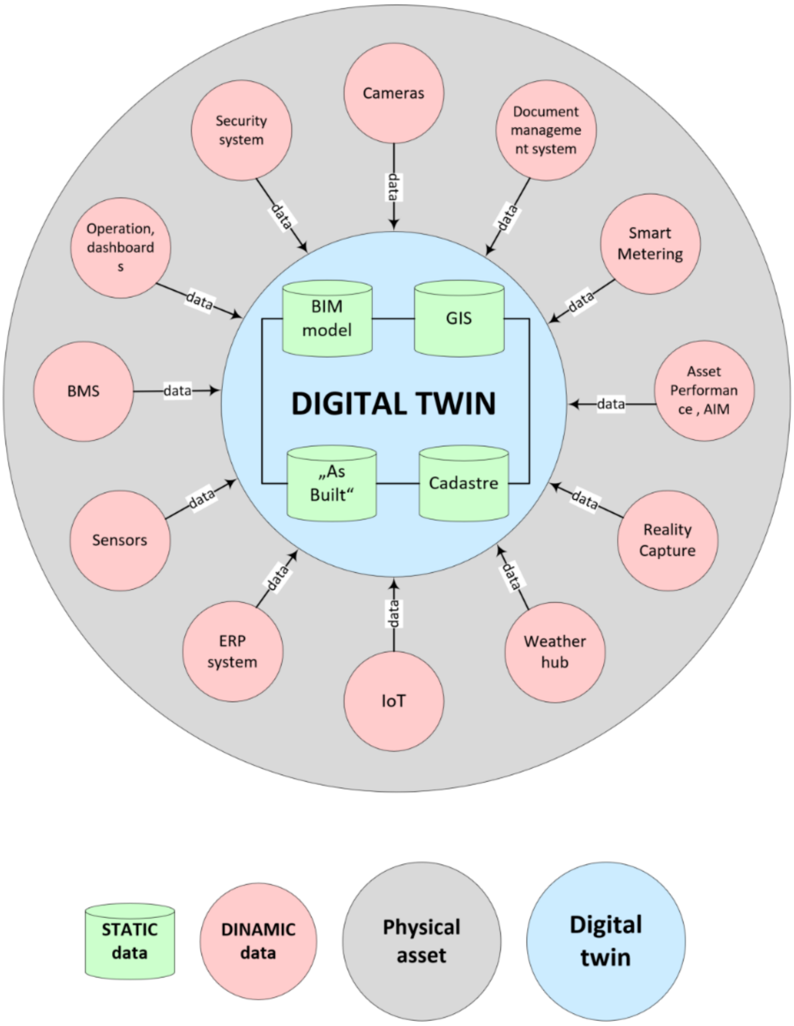

Figure 14. Approach of historical (static) and real-time (dynamic) data within the digital twin concept

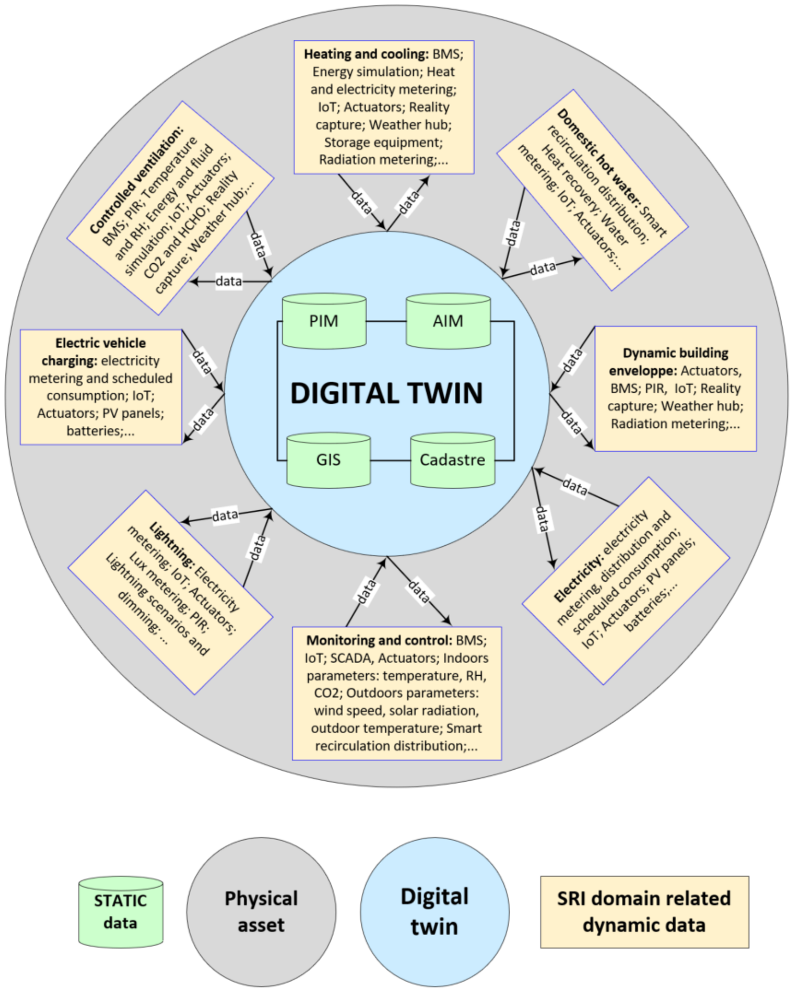

Figure 15. Approach of SRI (Smart Readiness Indicators) domains related dynamic data within the digital twin concept

4.3.6 BIM Data Standard Relevant for D^2EPC

Building's life cycle begins with the planning/design stage, where BIM comes as the main technology to provide machine-readable and semantically rich data for further tasks. Usually, these tasks are called BIM uses and require data for particular activities such as surveys, calculations, simulations, inspections, management, production, etc. The BIM model typically provides elements-distinguished geometry and their attributes about significant objects' properties, classes, types or any kind of metadata.

In the case of digital and dynamic energy performance certificates, it's important to consider relevant D^2EPC attributes, which could be provided by the BIM model, starting from the building plan/design stage and updated in the following stages (construction, operation & maintenance). These attributes, in the later stages, might be significantly valuable and considered as part of Digital Twin and and/or Digital and Dynamic Energy Performance Certificate.

The next critical factor in providing the appropriate attributes is the BIM data standard. The most popular and useful today is IFC - Industry Foundation Classes, which is an international standard ISO 16739-1:2018 [100]. It's an open standard for BIM data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry [101]. IFC is a standardized, digital description of the built environment, including buildings and civil infrastructure, which is vendor-neutral, and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases. More specifically, the IFC schema is a standardized data model that codifies identity and semantics (name, IDs, type), attributes (materials, physical properties), relationships (including locations, connections, and ownership) of buildings' elements, abstract classes (performance, costing), processes (installation, operations) or stakeholders (owners, designers, contractors, suppliers, etc.) [102].

4.3.7 D^2EPC Information Delivery Specification

In order to provide necessary and standardised BIM data, it should be facilitated by the methodology of information management. One of the key documents is an Information Delivery Specification (IDS), which could be a computer interpretable document that defines the model-based Exchange Requirements. It defines how elements, classifications, properties, and even values and units need to be delivered and exchanged. This can be a combination of IFC, classifications and properties. This is the standard to use to define your Level of Information Needs. It brings validation of IFC to the client, the modeler and the Software Tools that perform (automated) analyses. It is a core component that can be used as a contract to deliver the correct BIM data. It holds the ability to create localized and use-case specific requirements (e. g. D^2EPC requirements). The IDS is the foundation for reliable and predictable data exchange workflows [103].

D^2EPC requires modern and specific attributes about building elements, e. g. Smart Readiness Indicators (SRI), Human-comfort and wellbeing indicators, LCA indicators, cost and economic indicators. In this case, these attributes usually are not predefined in IFC schema or other BIM data standards. However, D^2EPC relevant attributes could be predefined in IDS as an information requirements in the beginning building life cycle stages. The IFC standard could facilitate data exchange by providing entities intended for input of arbitrary properties (e.g., IfcPropertySingleValue). This provides the IFC with a metamodel that permits numerous semantic extensions, making it possible to cover a wide range of application scenarios independently of the implementation. This flexibility is desirable for many scenarios where special objects and properties are not defined in the IFC standard, for example, applicability of BIM data related to D^2EPC [104].

Most BIM authoring software have already implemented the ability to input arbitrary properties using the IfcPropertySingleValue entity with the attributes 'Name', 'NominalValue', 'Type' and 'Unit' to provide a generally applicable template mechanism in your application. Therefore, D^2EPC relevant attributes could be provided by IFC entities, which serves as an information container.

The several important components regarding IDS and D^2EPC should be determined:

- Syntax of attribute name (e.g. SRI-Lighting_1a)
- Syntax of property (attribute) set (e.g. D^2EPC_Properties)
- Data type (e.g. string, integer, real, enumeration, etc.)
- Unit (m3/d, nondimensional, etc.)
- Relation to IFC element (e.g. IfcSpace, IfcWall, etc.)

4.3.8 IFC Parser

The IFC parser aims to select and extract only the D^2EPC related data from the IFC file, which is a representation of the BIM model. The IFC Parser (API) serves regarding the needs or BIM uses i.e., extracting list of the material parameters of the building envelope for the energy calculations, SRI, Human comfort indicators or other important data.

The relation between IDS and the IFC parser is very close because IDS specifies attribute names, which is necessary for parsing procedures. In this case, the IFC parser takes a particular attribute name and provides an attribute value. The iteration loop goes through all IFC entities and looks up only the necessary data for D^2EPC purposes.

5 Policy Implementation Aspects, Compliance with the Current EPCs Schemes and the Upgrade of the Requirements

5.1 Incentivization and Restriction Significance in Next-Generation EPCs

While there has been steady progress in the adoption of the EPBD in all EU Member States, there is still room for further adaptation of the policies indicated by the directive. EPCs have stood at the forefront of the EPBD related policies since 2002. Nevertheless, established energy efficiency evaluation and qualification techniques and processes, implemented across Europe, pose many challenges at the level of policy ramifications. The appropriate management of big data concerning the actual energy performance of the European building stock can drive the developments in the field of policy-making in the EU. Should the appropriate buildings' energy monitoring infrastructure be developed, EPC registries have the potential to become the EU monitoring database of the actual energy consumption of the European building stock.

The D^2EPC project intends to:

- Identify existing incentivization and restriction policy schemes applied in the procedure of the energy performance of buildings based on real-time data. At the point of submission of the D^2EPC project proposal and to the knowledge of the consortium, such policies or methodologies do not exist. However, the project considered it important to validate and verify this assertion.
- Examine and describe the trends and developments in the field of policy implication, and deliver a comprehensive scheme, based on the ETS, which will quantify and define the types of awards and penalties.
- Identify possible gaps or discrepancies in the degree of novelty of the project.

The new findings anticipated from the project will provide a valuable contribution to the dynamic EPC scheme examined in WP1 (T1.3), which focuses on clarifying the integration of the updated reference values into the calculation process, the redefinition procedure for buildings energy class, the methodology based on which the awards and penalties will be monetized and the types of implementing the proposed penalties or awards (e.g. tax reliefs, charges, trading schemes, etc.).

5.1.1 Current Status of Motivational Schemes for Conscious Energy Users in the Building Sector

Through the implementation of various laws, directives and measures, major efforts are being made to enhance the environmental consciousness and sustainability of the construction industry. In the light of comprehensive life cycle requirements, work towards increasing the sustainability of the construction industry is encouraged in the existing laws, which endorse the identification of opportunities for energy and cost savings, the productive use of environmental assets, and the achievement of waste minimization [105].

The Energy Union and the Energy and Climate Policy Framework for 2030, have demonstrated significant initiatives to minimize greenhouse gas emissions by at least 40% by 2030. They have set an energy conservation goal of 32.5% by 2030 [106]. As one of the leading energy users in the EU, the construction industry accounts for about 40% of overall energy consumption and 36% of CO_2

emissions; thus plays an important role in the EC initiative for an energy-saving target. An unprecedented 97% of the EU building stock (tight to 30 billion m^2) is known to be unsustainable in terms of energy, although 75-85% of it will proceed to be used by 2050 [107]. The EU has announced a series of directives and policy tools to phase out unsustainable buildings in this sense. An integral part of the Energy Performance of Buildings Directive (EPBD), adopted in 2002 [8] and amended in 2010 [9] and 2018 [10], is the Energy Performance Certificates (EPCs). The EPBD is the regulatory and policy mechanism for enhancing the energy efficiency of buildings around Europe, emphasizing existing and new buildings. The projected energy savings from the theoretically acceptable implementation of the articles of the Directive articles are estimated at 60 Mtoe by 2020, whilst the conversion of current buildings into Near Zero Energy Buildings is required by 2050.

Current EPC schemes are based on a cradle-to-site rationale, completing their mission after the delivering of the certificate to the building user, overlooking the user's behaviour and the actual energy performance of the building that might change dynamically within time. The dynamic EPCs will allow for the monitoring of the actual performance of building users on a regular basis and the introduction of intelligent financial schemes associated with output-based assessment. These schemes will either be based on financial awards (e.g., tax reliefs) for those building owners who exceed EPC expectations or on penalties for the "unconscious" users, not meet the EPC expected class, based on the "polluter pays" principle. Incentives that encourage consumers/owners to achieve energy savings of their buildings by providing targeted guidelines and requirements of a particular level of energy performance could be adopted by the Member States. D^2EPC aims to introduce next-generation dynamic EPCs' where their issuance will be according to real-time energy consumption values. In practice, there is no enforcement compliance in EPC implementation [108].

Following the desk research, it is depicted that none of the EU Member States apply incentives or penalties concerning the owners' compliance or non-compliance with the certificated assessment, in case of re-assessment of an EPC, based on operational data. The assessment and re-assessment of EU EPCs are based on relevant estimations and energy calculations on the properties of the building and the installation; namely, they are asset rating focused. In the case of an invalid or incorrect certificate, fines are applied to the owners. Otherwise, penalties are rare and are mainly addressed to energy auditors. No statistical data indicate the frequency and level of penalties [109].

Legal actions may be taken, merely if complaints are received [73] [110]. Until minimum requirements are met, graded sanctions are imposed concerning the error's intensity, type, and repetitiveness [111][112]. Other penal consequences may be imposed in a case of fraud [69][113]. Furthermore, penalties are anticipated for not meeting ventilation requirements or not ensuring regular inspection of the central heating systems of buildings [114][115][116]. The inspectors and EPC audits' infringements are punished with suspension or removal from the registries [113]. An incentive-based solution to the EPC will profit and encourage consumers to shift their behaviour to enhanced usage of resources and trust in selecting the best path as well as working on saving energy and eco-friendly practices. In several countries, incentives are provided only in terms of tax deductions; either as reduction of construction tax burdens for new private buildings, renovations or as taxation of real estate [112][113]. The introduction of the 5% additional habitable space grant for buildings reaching A class, with a minimum of 25% of their primary energy usage derived from RES, seems to be another opportunity centred mostly on modern, big buildings [114].

5.1.2 Aspects of Next Generation EPCs in View of Motivational Schemes

Under the policy implication rationale, the D^2EPC project intends to deliver a framework of proposals concerning the required upgrade of standards, to enable the integration of the dynamic certificate concept into the EN ISO 52003-1 [117] and EN ISO/TR 52003-2 [118] standards, as well as to other relevant standards of the Commission mandate M/480 [119]. The progress envisioned in the D^2EPC project will allow the integration of new methodological schemes into the EU energy policy framework. The monitoring of the actual energy consumption of buildings will enable the development of motivational schemes, which will enforce the continuous improvement of buildings' energy performance. The proposed scheme will provide sufficient background for the redefinition of EPC related policies, through regular benchmarking and upgrades of the reference buildings. Furthermore, the D^2EPC project aspires to develop a novel methodology, according to which the energy behaviour of building users will be evaluated on a regular basis (at least on an annual time step). Should their energy performance exceed the expectations of their energy class, a flexible award scheme will be developed and adopted. In the opposite case, the polluter pays principles will be applied. The implementation of the proposed project is also anticipated to foster the energy-saving consciousness of buildings users, through their regular information on the actual energy performance of their buildings and suitable incentivization. The proposed D^2EPC scheme is expected to transform EPCs into a user-friendly, reliable, and cost-effective, informative tool for both the broad public (building users, occupants, owners, etc.) and professionals (building managers, engineers, designers, etc.), as well as to establish the grounds for turning EPCs registries into consistent policy feeding mechanisms.

D^2EPC envisions the transition of the EPC registries to the driving force of the EU policies in the field of energy and buildings through the next generation EPCs. Real-time and regular documentation and analysis of the actual energy buildings performance provided through advanced buildings energy monitoring infrastructure will present buildings as operated, and dynamic EPCs will record the modifications over the life of a building. The proposed data availability and accessibility within D^2EPC will extend the limits of the EU energy-related policies in buildings on the prevention and correction level, and the aggregated EPC advanced information can be used for efficient energy planning. Polluter pays, and reward policies will be developed and introduced for those EPC owners who either do not meet or exceed the expectations of their certificates, in a similar rationale as with the ETS scheme, aiming to motivate energy consciousness.

5.1.3 Findings Concerning the Incentives and Restrictions

Through the progress of the D^2EPC project, no new legislation concerning the incentivization and restriction policy schemes applied in the procedure of the energy performance of buildings based on real-time data has been launched. Thus, no additional information to the one already provided till now in this document cannot be presented concerning the dynamic EPC scheme aiming at explaining the incorporation of new reference values into the calculation process, the redefinition procedure for building energy class, the manner by which rewards and penalties will be monetized, and the forms of penalties or awards that will be implemented (e.g. tax reliefs, charges, trading schemes, etc.).

5.2 Current Status of Compliance with the Current EPC Schemes and Upgrade Requirements

EPC is an obligatory rating scheme in the case of constructing, selling, or renting a building in the Member States, in which the energy efficiency of the building is outlined. The main objective of the EPC is to be employed as a transparent information tool for building owners, occupiers, and real estate stakeholders who want a detailed energy performance of their property and recommendations for energy upgrade of building improvements regarding energy performance. Given that, EPCs could act as a decision-making criterion on energy efficiency property improvements by providing recommendations for the cost-effective or cost-optimal upgrading of the energy performance. D^2EPC will provide the means and state of the art technology for improving performance assessment and certification, strengthening the role of the EPC in the real-estate market and rendering it as a tailor-made instrument with personalized instructions for homeowners, investors, and construction professionals. For this reason, this report identifies the methodologies currently used for the issuance of EPCs on a European level, explores the technological and market conditions where D^2EPC will be realized, as well as investigates the challenges of current EPC schemes. This mapping of the national approaches for the issuing of EPCs will enable the assembling and reviewing of all the available methodologies, distinguishing between the methodologies that are exclusively based on calculated energy consumption (asset rating) and the methodologies that use actual energy consumption data (operational rating). Building owners, occupiers, and mostly real estate stakeholders are among the most important information sources regarding energy performance in the EU's building stock.

The recast of the EPBD in 2010 (Directive 2010/31/EU) on the energy performance of buildings as well as its amendment in 2018 (Directive 2018/844/EU) strengthened the role of EPCs and significantly contributed in the methodology towards more energy-efficient EPCs. Current practices and tools of energy performance assessment and certification applied across Europe face several drawbacks and discrepancies. D^2EPC intends to analyse the quality and the drawbacks of the current EPC schemes, identify technical challenges that currently exist in order to overcome them (e.g. performance gap, etc.), and set the grounds for the next generation dynamic EPCs for buildings. The proposed framework sets its foundations on the smart-readiness level of the buildings and the corresponding data collection infrastructure and management systems. It is fed by operational data and adopts the 'digital twin' concept to advance Building Information Modelling, calculate a novel set of energy, environmental, financial, and human comfort/wellbeing indicators, and through them the EPC classification of the building in question. Under the project vision, the proposed indicators will render dynamic EPCs a realistic, accurate, and comprehensive tool that can lead the transformation of the European building stock into zero-energy buildings and stimulate energy efficient behavioural change of the building occupants.

Despite the positive contribution that current EPCs have had on improving the energy performance of buildings, experience has unveiled a number of constraints and limitations. The underlying fundamental objectives to be addressed in this report are:

i) the analysis and comparative assessment of current EPC schemes,
ii) the definition of user and market requirements and needs, in respect to the targeted project vision which should be addressed or connected to the D^2EPC framework,
iii) the definition of the dynamic EPC scheme proposed by the project taking into account existing solutions and operational challenges, and
iv) the system specifications and detailed architecture of the D^2EPC approach, which will drive its implementation.

The methodology followed in this report consists of field research committed as a set of statements with questions relevant to challenging matters of (i) EPCs issuing, quality and control, (ii) EPCs calculation software and tools, (iii) EPCs indicators, and (iv) Qualified experts competence and skills, and desk research committed as a set of statements with questions relevant to challenging matters of EPCs. Concerning the field research, the extraction and circulation of a questionnaire to a list of stakeholders took place. The investigation concluded in the following questions aiming at stakeholders' knowledge:

1. What is the period of validity of an EPC currently issued in your region/country?

2. In case of re-assessment of an EPC based on operational data, are there incentives or penalties in relation to the owners' compliance or non-compliance with the certificate assessment/rating?

3. Is BIM documentation and literacy or digital logbooks employed by any means for the issuance of EPCs in your region/country?

4. In the case of a Building Management System (BMS) existence, to what extent is the data documented by BMS employed in the issuance or re-issuance of operational EPCs?

5. Is Geographic Information System (GIS) information exploited for issuing, validating, monitoring, and verification processes of the EPC calculation?

6. Does the EPCs procedure in your region/country include any energy-related financial indicators (e.g., energy €/m²)?

7. Does the EPCs procedure in your region/country include any environmental/LCA related financial indicators (e.g., embodied energy/m²)?

8. Does the EPCs procedure in your region/country include any indoor air quality indicators (e.g. CO2 concentration/m²)?

9. Do the EPC auditors have access to joint databases concerning the properties of building systems and building elements?

10. Is there a provision for systematic and regular evaluation/assessment of the energy assessor's competencies and skills?

The Stakeholder Circle® was employed for the identification and categorization of the main stakeholders, as those who affect and those who are affected by practices and policies related to EPCs - and understand their needs. The prioritization of the stakeholders, based on the same tool, aimed at the definition of the appropriate sample for the implementation of the field research and employed their power, proximity, and 'urgency'. With regard to the desk research, the methodology involved first carrying out an overview of fifty-two reports to identify the challenges, the needs, and the opportunities of current EPC schemes. This was followed by the extraction of twenty-five statements relevant to several constraints and limitations in the EPC procedure and a comparative assessment of EPC schemes in the twenty-seven EU Member States.

Despite substantial gaps in the existing European EPCs procedures, D^2EPC ambitiously aims to set the grounds for the next generation of dynamic Energy Performance Certificates (EPCs) for buildings. Therefore, the proposed scheme will contribute to the redefinition of EPC-related policies and the update of current standards, along with guidance for their implementation, and will introduce incentivization and restriction practices into the EPC rationale. The collective analysis of data for the specific features of EPCs revealed that among the twenty-seven (27) EU Member States, fourteen (14) had adopted the methodology exclusively based on calculated energy consumption. In some Member States, both the actual and calculated energy consumptions are foreseen. In addition, for new and existing buildings, the period of validity of an EPC is up to ten (10) years in most EU countries. It is recommended, and in some countries required, to be updated following a major reconstruction-renovation of the building envelope or the technical systems, even if the works take place before the expiry date. Furthermore, none of the EU Member States apply incentives or penalties concerning the owners' compliance or non-compliance with the certificated assessment, in case of re-assessment of an EPC, based on operational data. Penalties are rare and are mainly addressed to energy auditors, in case of gross misconduct at the EPC issuance stage.

Based on the research of this report, it was revealed that the majority of EU countries do not employ by any means BIM documentation and literacy or digital logbooks for the issuance of EPCs. Even though in some countries, there is the provision of BIM documentation and digital logbooks, these are used as a source of information for the EPC assessment procedure or energy simulations. There is no provision, national requirement, or legal obligation of a Building Management System (BMS) existence in connection with the operational EPCs. BMS data documentation is not employed as a source of relevant data, or there are no provisions or legal obligations to be used in the issuance or re-issuance of operational EPCs. Additionally, it was shown that in most of the EU Member States, information related to Geographic Information System is not included in the EPCs, and consequently, it is not exploited for issuing, validating, monitoring, and verification processes of the EPC calculation.

Analysis across the EU Member States, energy-related financial indicators are not found to be included in current EPCs schemes and procedures in any EU Member State. It appeared that, in several countries, the energy cost and the carbon dioxide emissions per m^2 are included in the EPC procedures. Apart from that, financial indicators for the proposed investments in the building retrofit and for the payback time of proposed measures, economic values of energy improvements, as well as evaluation recommendations for cost-effective measures are reported but not directly issued in the EPC procedure. Concerning the field and desk research regarding the environmental/LCA related financial indicators included in the EPC procedure, it was recognized that environmental-related financial indicators are not taken into consideration for the EPC issuance. Environmental indicators, which are present in energy certificates today, are usually linked to greenhouse gas emissions, which consequently vary from country to country depending on the energy system of each country, and in particular by the factor of the primary to final energy conversion. The conversion of final energy consumption to primary energy consumption for the production of an electric unit or thermal energy is the rationale behind the Primary Energy Conversion Factor. Although provisions for indoor environmental quality (including air quality, thermal comfort – the risk of overheating and ventilation, lighting, and acoustics) are set in EPCs, there are not covered in current EPC regimes and are not included in the calculation procedure for certification of EU countries.

EPCs constitute a significant database, where big data concerning the actual energy performance of the European building stock are gathered. Most EU Member States have developed central databases for collection, registration, and inspection of EPCs and technical building systems of existing and new buildings. By no doubt, there is no existence of a database describing the energy efficiency features of the building stock as a whole. Nevertheless, in some cases, there is available comprehensive information regarding the physical stage of the existing building stock gathered during the EPC issuance procedure. The employment of inventories, in relation to properties of building materials and building systems, is not a practice that is usually followed, but as time goes by, this kind of information and databases could be enhanced and included in the next-generation EPCs. One-third of EU countries do not have provision for systematic and regular evaluation/assessment of energy assessor's competence and skills. Intending to further improve the quality of the EPCs, experts in all Member States have to update their skills and knowledge continuously by regular training. More specifically, there is a qualification system, according to which assessors need to renew their occupational qualification certificates in a period of time, depending on their country.

The field and desk research conducted for the purposes of this report have depicted the substantial gaps in the existing European EPCs procedures, where the D^2EPC project aims to contribute in several ways. Initially, with the introduction and establishment of the dynamic EPC (dEPC) concept, as an operational certificate that will be calculated and issued on a regular basis by the establishment of the concept of dynamic EPCs, issued regularly, enabling the regular update of EU Member States reference values of their building blocks, and the regular information of building owners on the actual class of their buildings, in comparison to regional average values. Furthermore, with the definition of the drawbacks and discrepancies of the current EPC scheme, the update of EU standards on the classification requirements of buildings, as well as the development of "polluter pays" and reward policies for building users with below or exceeded expectations EPCs, are some steps towards the establishment of the dynamic EPCs.

The enhancement of EPCs through a novel set of indicators which cover environmental, financial, human comfort and technical aspects of new and existing buildings, aiming to simplify the understanding of buildings energy performance and to present a more comprehensive overview of the actual energy performance of buildings with the introduction of LCA and human comfort-related indicators as well as monetary indicators for the energy assessment and certification of new and existing dwellings and non-dwellings will be a contribution to this significant task. Additionally, a way to achieve the D^2EPC scheme envisions is the integration of smart readiness rationale into the building's energy performance assessment and certification with the introduction of indicators for the energy assessment and certification of new and existing residential and non-residential buildings. Last but not least, the integration of actual operational data from buildings into the EPCs using advanced data collection infrastructure integrated into BIM, as well as an intelligent operational digital platform for dynamic EPCs issuance and actual building performance monitoring and improvement, validated and demonstrated under realistic conditions with the introduction of geolocation representation of actual energy performance of buildings will eliminate the performance gap of current EPCs.

6 The Role of KPIs in the Next Generation EPCs

According to the data collected throughout this deliverable, the introduction of novel aspects of the certification process and the simplification thereof, the strengthening of its user-friendliness and conformity with national and European legislation can be accomplished using a standard collection of indicators based on a specific methodology. All upgrade needs of EPCs can be met by choosing acceptable output indicators and their automated estimation. The above would arise by taking into account considerations such as the typology of the building, use, venue, and availability of data (data storage infrastructure) whether the building is new or existing, domestic or non-domestic.

Human-centred indicators

Although thermal and acoustic comfort, indoor air quality and daylight are among the critical factors for rehabilitating buildings, current EPCs do not consider them. Simultaneously, the recommendations for energy upgrade are automatically generated by a standard list, such as increased insulation, replacing windows, and not offering a user-friendly document that could motivate renovation. By definition, EPCs are indicator-oriented documents that inform building users about their space's energy output. Adding supplemental novel indicators, it appears that this justification will be expanded, making the energy certificate into a more user-friendly and detailed document covering various aspects of buildings' energy and comfort efficiency. The assessment could be based on an established list of parameters/indicators, such as estimated annual energy use, final energy use, renewable energy consumption share, prior (climate-corrected) final energy use and energy consumption, level of comfort/well-being and level of intelligence. The deliverable analysis considers measured evidence from buildings' real condition to establish the desire for long-term enhancement in building performance to maximize comfort levels, indoor air quality, and health. These indicators, human-centred and geared towards the building's whole life cycle, will allow the holistic and cost-effective appraisal of buildings across many complementary parameters that will consider the efficiency of both the envelope and buildings' framework. The next-generation EPC would be appropriate to enable building automation and control systems to measure the building's energy efficiency, identify the inefficiency of technical building systems, and notify the person responsible for the facilities or technical building management of the possibilities enhancing energy efficiency. New elements are envisaged, including climate correction, final energy use and expenditures, comfort standards, often reflected in monetary terms, as well as value-added services that can improve EU-wide adoption and use of EPCs.

Life Cycle Assessment indicators

The need to shift to a comprehensive evaluation of buildings' environmental efficiency to extend the awareness of the building's real environmental effect as a whole comes into view. Implementing of LCA-based indicators for the energy evaluation of buildings is envisaged for this purpose. These indicators should be based on well-established databases across Europe, concerning the environmental impact of building materials (EcoInvent, BRE Greenguide), resulting in an LCA of the building's buildings and individual components (building envelope, building systems, building materials). Through this assessment, the option for building construction engineers to enhance and maximize the building's environmental efficiency, based on improvements to be implemented at the building's initial design stages could be provided. LCA allows the estimation of any system's environmental effects over its life cycle by taking into account the necessary input and related production resources of that system. Examples of LCA indicators should include "Energy savings", expressed in “Embodied energy/m^2” and “Carbon reductions”, expressed in “Carbon dioxide equivalent/m^2". The LCA indicators for EPCs could make a major contribution to optimizing energy efficiency and achieving carbon reductions in buildings. In addition, by this deliverable is ensured that the suggested strategies optimize their effect by taking their embodied energy and environmental footprint into account by integrating LCA indicators into the efficiency upgrade road-mapping method.

The introduction of LCA indicators within the scheme explained in the deliverable could integrate all midpoint, and endpoint environmental impact assessment categories and the use of renewable energy sources with deficient LCA emission factors. An additional reduction of greenhouse gases could be further expected.

Financial indicators

A set of financial indicators could be developed, based on the well-established principle of life-cycle costing, to allow the individual elements of buildings' energy efficiency to be interpreted into standardized numerical values. The delivery of such indicators could allow the use of EPCs for the financial evaluation of energy upgrading measures for buildings. Additionally, it could allow the exploitation of the information produced by EPCs by energy audit processes, bridging the gap between the energy-related directives of EPBD and the energy efficiency. These should provide the ability to produce several strategic scenarios and encourage substantiated decision-making based on several indicators, as described above, such as financial indicators, energy indicators, condition of building elements, renovation time, and level of comfort.

Smart indicators

The exploitation of the overall amount and granularity of energy consumption data available from smart meters and other connected home devices, such as smart thermostats, could enhance EPCs for existing buildings. It appears from the deliverable that the innovative indicators of a building's environmental impact and smartness could be integrated. Real-time energy-related data from smart devices and sensors, addressing issues resulting from incorrect data due to improvements made during the design process could be considered. The SRI should be viewed as an extension of the generally agreed EPC system, either optional or obligatory, in such a manner as to ensure the multiplication of the SRI's behaviour. SRIs could be used, in compliance with Directive (EU) 2018/844, to (iii) assess the ability of buildings to employ information and communication technology and electronic networks, (ii) adjust the functioning of buildings to the demands of inhabitants and the system, (iii) enhance energy performance and the total operation of the system. The implementation role of EPCs is mainly applicable to the SRI, but it also has analytical significance. A building's environmental efficiency should be viewed in line with its potential to lower its environmental footprint dynamically. SRIs could promote awareness of intelligent buildings' advantages and design, especially from an energy aspect, and make their upgrades more accessible to building occupants, owners, residents, and distributors of innovative technologies. Moreover, they could encourage consumers to increase developments in smart construction innovations and promote the implementation of technological advancement in the construction industry. Consequently, it would be possible to classify a selection of SRIs that can be derived depending on the input information of the EPC and to establish the methods for their estimation.

Classification in the certification

As it is depicted in the deliverable, it would be appropriate proving real-time access by suitable user interfaces to EPC information. The information's quality and durability are favoured by following a dynamic approach, allowing homeowners or tenants to adjust the building's operating mode in response to their needs, retaining safe indoor environments and thermal comfort. Further to that, certification helps landlords and building users to become more aware of the impact of building performance on running costs and comfort and the necessity to rationalize energy usage in buildings. The use of monetary indicators for the different solutions applied within a building, both in terms of its envelope (e.g. insulation) and mechanical structures (e.g. heating), provides the occupants with a clear view of the energy behaviour of their buildings relevant to their indoor behaviours. In addition, it converts into monetary value the elusive definition of energy conservation, which is more comprehensible to non-experts.

All novel indicators to be delivered could be categorized into building shell and building system-oriented indicators to address the building shell criteria and build a system-oriented approach. This approach could also allow additional indicators, such as the share of renewable energy used, to be extracted. Another classification of indicators could include the energy indicators according to the building type (dwelling, non-dwelling) or the buildings' age (new, existing). As depicted in the deliverable, an additional assessment could be based on comparative indicators (level of improvement) in the latter case. As the proposed system holistically values buildings by implementing new performance indicators and real, regularly updated measured data, it could improve buildings' energy performance and ensure sustainable energy savings on a daily basis, thus resulting in lower energy costs for all citizens. In this respect, when making decisions on energy improvements, land acquisitions or leases on either new or existing properties, dEPCs will be a helpful piece of knowledge. The project's road mapping tool and efficiency benchmarking could be an invaluable source of advice for building owners on prices, payback times and advantages of building improvements to achieve a better rating.

The appropriate actions to determine criteria for achieving indicators’ certification based on EPC results' association would be very beneficial. The evaluation might be connected to digital resources to notify consumers and access tracking the indicator's components.

7 Conclusions

Current EPC schemes are based on a cradle to site rationale, completing their mission after the delivery of the certificate to the building user, overlooking the user's behaviour and the actual energy performance of the building that might change dynamically within time. The dynamic EPCs will allow for the monitoring of the actual performance of building users on a regular basis and the introduction of intelligent financial schemes associated with output-based assessment. These schemes will either be based on financial awards (e.g., tax reliefs) for those building owners who exceed EPC expectations or on penalties for the "unconscious" users, not meeting the EPC expected class, based on the "polluter pays" principle.

The research on potential standards or methodologies at the European level which are based on real-time data for the calculation of EPCs showed, that based on the feedback received from the CEN/TCS, current approaches include mostly in-situ measurements or data which are periodically updated and therefore are not dynamically calculated. These approaches, to our knowledge, are not explicitly dealing with real-time data to be applied in EPC calculations. From the perspective of light and lighting EN 15193-1 standard of CEN/TC 169, there is no procedure for the dynamic simulation of lighting, and we do not see there is a direct application to the dynamic approach for EPC. In order, though, to satisfy the need for integration of real-time measured data into the calculation procedure, D^2EPC will need to identify and communicate to CEN and ISO revision needs for the current set of used standards.

The Smart Readiness Indicator characterizes various operations of building technical systems ranging from default/established market control systems to cutting-edge innovative control solutions. Based on the research of this report, the SRI score is expressed as a percentage (%) representing the ratio between the smart readiness of the building or building unit against the maximum achievable smart readiness. The calculation is based on pre-determined weighting variables, the value of which is affected by weather and other relevant factors. Based on the degree of complexity of the SRI definition, three potential SRI assessment types have been identified by the technical studies: a simplified version with less services assessed (Method A), a more detailed version (Method B) and metered/measured method (Method C) based on the actual performance data of in-use buildings. Taking further steps towards future implementation, a third SRI technical support team was contracted by the EC in Spring 2021 aiming to support and facilitate the necessary processes of exchange experiences among Member States and provide technical assistance for the first phases of testing and implementation of the SRI. According to the work performed under the D^2EPC SRI dedicated task, T2.1, the information contained within each functionality level may be modelled or documented up to a certain degree when Building Information modelling (BIM) is concerned, however, the capacity of BIM models to define higher functionality levels (representing complex BACS systems and sophisticated solutions) becomes challenging. In addition, according to the analysis under this task, the current state of data for EPC assessment precludes the performance of the SRI assessment. While some screening information for the SRI can be recovered, this information is insufficient to determine the building's SRI score.

Analysis of green building certification systems showed that LEED and BREEAM aim to determine overall sustainability based on factors including design, construction, maintenance and operation. The WELL certification heavily focusses on the factors affecting occupant needs and comfort from IEQ to nourishment, fitness and state of mind. LEVEL(s) is a common European performance-based framework for the sustainability of the buildings, which emphasizes important aspects like - health and comfort - related to the building's performance enabling the assessment of them via suitable indicators.

LEED, BREEAM, and WELL examine a set of common parameters (PMV, PPD, temperature, relative humidity, air speed, ventilation rate (outdoor air supply rate), TVOC concentrations, CO, CO_2, PM_{10}, $PM_{2.5}$, ozone, formaldehyde, ambient noise and reverberation time, illuminance level, daylight factor, and spatial daylight autonomy). WELL, is even more extensive on the examined factors - governing the well-being of the occupant- taking into account radon, benzene, NO_2, CS_2 and trichloroethylene levels. The contribution of IEQ to the total number of credits of the schemes is 15% for LEED, 12% for BREEAM, 20% for LEED, 18% for the SRI and 17% for LEVEL(s). Among the IEQ components, the most significant for LEED, WELL, and SRI schemes is the indoor air quality (~50% contribution to the total IEQ credits), while visual comfort is the most credited for the BREEAM certification (33%). IAQ and Thermal comfort are credited equally for the LEVEL(s). The comparative assessment performed on those well-established certification schemes and frameworks governing the human comfort has shed light on the domains of indoor environmental quality selected to be examined within the project. The IEQ pillars considered correspond to the thermal comfort, the visual comfort and the IAQ.

The rapid change in our way of life due to technological advancement and extraordinary circumstances (pandemic) increases the need for better living conditions into closed spaces. Nowadays, there is a plethora of green building certifications, highlighting the importance of indoor environmental quality for the comfort and well-being of the occupants. The green building certification aspects related to human comfort might be introduced in dynamic EPCs.

D^2EPC project also aims to propose additional indicators, which demonstrate the environmental performance of buildings, for their introduction in the next- generation EPCs. For the development of the environmental indicators, LCA methodologies and tools can be introduced to the dynamic EPC scheme for the efficient energy design of buildings and for enabling the parameterization of its embodied energy and primary energy demand, to be included in dynamic EPCs. According to the applicable criteria, LCA may help to recognize opportunities to enhance the environmental performance of the product or service under review, to inform decision-makers in business, government or non-governmental organizations to choose specific environmental performance metrics and to market goods or services.

The D^2EPC WebGIS (Web Geographic Information System) application is a dynamic tool for EPC documentation proposed for covering the requirements of BS C “Evaluation and Benchmarking of more certificates for policy making/ marketing / business purposes”. The main functionalities of the application cover the generation of anonymised statistics per region and the visualisation on a map, the provision of analysis tools such as the comparison and querying of regional dEPC statistics and the provision of operational rating visualisation tools for pilot case buildings and the 3D visualisation for demonstration purposes. The potential end users for the application include several D^2EPC stakeholders namely, authorities/ registries/ public bodies, Energy Service Companies (ESCOs), Real Estate agencies, the Building services industry, researches and academia, environmental organisations and standardisation bodies..

The research showed that since the intimate connection between BIM and DT are observed, it is crucial to implement best practices on BIM legislations and standards to define the use of DT. Also, the importance to continuously propose and develop BIM as a reliable source of semantics for DT still exists. Data acquisition and processing still requires improvements and novel insights when it comes to cyber-security and an enormous amount of data. On the other hand, DT implementation in the construction sector is promising since it can be implemented from the early construction phase throughout all building lifecycle. Implementation can cover various aspects, including building energy performance simulations, predictions and at the highest level of implementation transformative decisions. The main challenge related to D^2EPC project in the context of energy performance is to consolidate all digital data of the asset distributed within different kind of sources, devices and formats. It is important to make the process as much machine-readable as possible, take into account data from the whole life cycle of the building, and implement the possibility to stream real-time data. Regarding digital and dynamic energy performance certification programme, it's significant to analyse maturity levels of digital data related to energy performance within the whole life cycle.

In the context of EPC, BIM is a promising technology that has the potential to simplify procedures, particularly when it comes to data collection. However, no standards related to BIM standards for EPC have been identified. D^2EPC will also aim to establish the required procedures required for the implementation of EPCs based on BIM. Given that BIM is rapidly gaining prominence in many European countries, particularly regarding the energy performance of building assessment, a BIM-based EPC standard will shed light to further possibilities and expand the usefulness of such tools.

The appropriate management of big data concerning the actual energy performance of the European building stock can drive the developments in the field of policy-making in the EU. Should the appropriate buildings' energy monitoring infrastructure be developed, EPC registries have the potential to become the EU monitoring database of the actual energy consumption of the European building stock.

Under the policy implication rationale, the D^2EPC project intends to deliver a framework of proposals concerning the required upgrade of standards to enable the integration of the dynamic certificate concept into the existing standards.

On the basis of the findings of the D^2EPC, the project will lead to the transition from the EPC to a systemic instrument that recognizes the whole life cycle of a building as a structure and will encourage best practices in the field of resource performance, a core policy concern for the European Union. In this sense, it is expected that the next EPC generation envisaged by the D^2EPC project will provide guidance and decision-making on matters related to the sustainable management of natural resources.

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