Next-Generation Energy Performance Certificates. What novel implementation do we need?

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Abstract. Energy performance certificates are being utilized through the European Union Member States to document and asses the energy performance of the building stock, while they are used as measures to investigate and adopt policies that would lower the final energy consumption and environmental footprint. After several years of implementation, the current EPC schemes have enlighten the domain energy efficiency in the building sector, but at the same time they have been identified with several challenges and deficiencies that deteriorate the quality of the results. This study performed under the H2020 project "Next-generation Dynamic Digital EPCs for Enhanced Quality and User Awareness (D^2EPC)", aims to analyze the quality and weaknesses of the current EPC schemes and aspires to identify the technical challenges that currently exist, setting the grounds for the next generation dynamic EPCs. The present work reveals that current EPCs schemes are based on a cradle-to-gate rationale, completing their mission after the certificate to the building user, overlooking the user's behavior and the actual energy performance of the building that might change dynamically within time. In this study, the idea of the dynamic EPCs is introduced, a certificate that will allow the monitoring of the actual performance of buildings and the users' behavior profiles on a regular basis. The introduction of novel indicators and the integration of BIM and GIS are also discussed.

Keywords. EPC, SRI, LCA, BIM, DT, GIS, human comfort, D^2EPC.

1. Introduction

Energy Performance Certificates (EPCs) are a mandatory requirement for the European Union (EU) Member States (MS) when constructing, selling, or renting a building. EPCs serve as a transparent information instrument for building owners and real estate stakeholders. They are among the most important information sources regarding energy performance in the EU's building stock. EPCs could act as a criterion for decision-making on energy efficiency property improvements by providing recommendations for cost-effective or cost-optimal upgrading of buildings. Existing procedures and tools used in assessing buildings' energy performance across Europe present several drawbacks and discrepancies.

As a promising technology in the construction industry, the building information model (BIM) concept became widespread on the market early in the 2000s. BIM is more than a three–dimensional (3D) building tool, which can become a multidimensional information model [1-2]. Well-defined semantic and geometric data for each element and the ability to enable collaboration between stakeholders during the life cycle of the facility can be referred to as a key feature of BIM [3]. According to the purpose of BIM, its application is observed throughout all stages of the asset life cycle. Architects, engineers, and constructors use BIM throughout the design and construction stage, while gaining benefits from errors reducing, improving construction efficiency, communication and data exchange, and costs and time monitoring [4-5].
The aim of the study, performed under the H2020 project "Next-generation Dynamic Digital EPCs for

Enhanced Quality and User Awareness (D^2EPC)", is to create the concept of the next generation dynamic EPCs. The aim is reached through the following steps: (i) identification of the quality and weaknesses of the current EPC schemes, (ii) identification of the novel indicators for EPC (iii) evaluation of posibilities of integration of BIM, DT and GIS in EPC, (iiii) presentation of the developed D^2EPC system architecture.

2. Methodology

Desk research was performed to identify the current status of EPCs, limitations, and information for the gaps in the existing schemes, the calculation procedures, and standards.

An overview of reports was performed to identify the current EPC schemes' challenges, needs, and opportunities, as well as the emerging future market requirements. The documented statements within the collected reports provide evidence on current practices in the EU MSs.

3. Quality and weaknesses of current EPC schemes

The main findings of the conducted study are presented below:

- At this moment, there is no obligation for MSs to use Building Information Model (BIM) software. Most EU countries do not use BIM documentation and literacy or digital logbooks for the issuance of EPCs. Furthermore, the current EPC practises in most EU MSs don't include GIS information, which could be exploited for issuing, validating, monitoring, and verifying the processes of the EPC calculation.
- Environmental/LCA-related indicators are not considered for the EPC issuance.
- The human comfort factor is combined in assessment systems, but it is not calculated in the analysis. Indoor environmental quality indicators are not covered in current EPC regimes and are not included in the calculation procedure.
- In certain countries, only parts of the building stock are examined visually or estimated according to the calculations.
- 1/3 of the EU countries do not have systematic and regular evaluation/ assessment of energy assessor's competence and skills.
- Smart metering and real-time data are not utilized in the calculation procedures of the EPC in many MSs.
- Energy-related financial indicators are not found to be included in current EPCs schemes and procedures in any EU MSs.
- There is a need for an openly accessible EPC registry of all EPCs in Europe MSs, addressed by the European Energy Performance of Properties Analysis.

4. The novelty of the dynamic EPC

The aforementioned shortcomings of national EPC schemes urge the development of a holistic framework that will strengthen and improve the quality and application of EPCs. The former can be achieved with the introduction of novel and cost-effective approaches for assessing the energy performance of building envelopes and systems. According to the collected information, the introduction of novel aspects in the certification process and the simplification thereof, the strengthening of its user-friendliness, as well as the conformity with national and European legislations, 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 supported their automated estimation.

4.1 New indicators

The introduction of novel aspects into the energy performance certification process includes three indicators – the smart-readiness level of the buildings (SRI), human comfort-related indicators, and environmental aspects (LCA).

Smart readiness indicator. The scheme for rating the smartness of buildings was presented in 2018 in a revision of the Energy Performance of Buildings Directive (EPBD). It was established that the smart readiness of buildings should be optionally evaluated by the smart readiness indicator (SRI) [6]. According to the EPBD, this indicator reflects the building's ability to adapt to the needs of its occupants and outdoor energy infrastructure, improving its overall energy performance.

To define the smartness of buildings' services, three main functionalities of smart readiness are introduced in the methodology:

- The ability of the building to adapt its energy consumption based on the needs in an energy-efficient way;
- The ability of the building to adapt its operation to occupant's needs;
- The building's flexibility to its overall electricity demand, as well as its ability to participate in demand-response, in relation to the grid.

The SRI scheme includes the following nine services' domains: heating, cooling, domestic hot water, controlled ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, and monitoring and control. Each domain can be evaluated with a different degree of smartness (functionality levels) and includes various impact criteria (i. e. energy savings, maintenance and fault prediction, comfort, convenience, health and wellbeing, information to occupants, grid flexibility, and storage) that can be delivered by several building services.

The functionality levels could be evaluated in ordinal numbers on a scale from 2 to 5. The higher the functionality level, the more impact the building, its occupants, or the outdoor energy infrastructure will have on the final rating. A multi-criteria assessment method, that includes the diverse domains and criteria, is used to calculate the SRI. The smart readiness score is described as a percentage of how close (or far) the building is to the maximum smart readiness that it could reach.

In a study performed by Fokaides et al. [7], SRI was calculated for a D energy efficiency class building. The total SRI score of the examined case study was relatively high and equal to 52%. Such a result demonstrates that SRI, as a methodology, does not follow the EPC class and additional attention is needed to align these two schemes.

Within the H2020 D^2EPC project, both SRI and EPC methodologies will be included in the same calculation engine allowing, where possible, to merge these two methodologies to progress the SRI to a higher level.

Human comfort. People in developed countries spend more than 90% of their time in closed environments - buildings and transport [8]. Air quality indoors is 2-5 times lower than outdoors [9]. These values can be even lower if we consider the future effects of climate change (extreme temperatures, heat waves, heavy rainfalls, air pollution). Therefore, significant attention should be paid from researchers, businesses, and standardization organizations to the field of indoor environment quality (IEQ) [10-12].

The main indicators that assess the IEQ of a building and human comfort/wellbeing can be described by an integrated multi-comfort concept that includes indoor air comfort/quality, thermal, visual, and acoustic comfort. The indoor air quality (IAQ) examines how fresh the air is in a building and the concentration in the air of certain pollutants (e.g. CO_2, VOC). Thermal comfort provides a state of satisfaction with the existing thermal environment. Visual comfort ensures that the luminance levels are within acceptable levels. Acoustic comfort creates a comfortable acoustic environment without uncomfortable noise or vibrations.

Many worldwide-accepted certification schemes of building energy efficiency and environmental impact are developed and applied widely. The schemes assess the impact of buildings throughout their life cycle. They include a number of factors, e.g. heating and cooling energy consumption, water consumption, operational processes, indoor environmental conditions, land use, transportation, sustainability, etc. The following parameters for human comfort/wellbeing indicators estimation or calculation are addressed in LEED [13], BREEAM [14], and WELL [15] certification systems: temperature, relative humidity, ventilation rate (rate of fresh air supply), air speed, concentrations of TVOC, formaldehyde, CO_2, CO, PM10, PM2.5, ozone, ambient noise and reverberation time, illuminance level, daylight factor, spatial daylight autonomy, PMV/PPD (WELL v2). 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). The WELL certification scheme also examines radon, benzene (same as LEVEL(s)), NO_2, CS_2, and trichloroethylene levels. The SRI scheme evaluates human comfort/wellbeing parameters indirectly via the functionality score of the technical building services (TBS) (IAQ and thermal comfort) or the climate adjustments on the domain weights used in the calculation (thermal and visual comfort). 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% and WELL gives 13%, 25%, 50% and 13%, respectively. According to the existing framework, the SRI methodology gives 26% for visual comfort, 0% for acoustics, 47% for IAQ, and 26% for thermal comfort. Currently, in the case of LEVEL(s), only two components are considered and allocated half the credits of the total IEQ credits: IAQ and thermal comfort.

Within the H2020 D^2EPC project, human comfort/wellbeing parameters will be measured and used in the calculation engine allowing dynamic input for dynamic EPCs.

Life cycle assessment. LCA indicators such as "energy savings", expressed in "embodied energy/m^2" and "carbon reductions", expressed in "carbon dioxide equivalent/m^2", will be included in the dynamic EPCs calculation engine. This will provide to the building design team the option to improve and optimize the environmental performance of the building, based on changes to be integrated at the initial design stages of the building.

In the D^2EPC project, the LCA Indicators for EPCs will allow maximizing energy saving and carbon reduction of the buildings, introducing this way the aspect of building's sustainability as part of the EPC issuance process. This could speed up the transaction into NZEBs as well as control the building's energy demand, reduce carbon emissions, and enhance public awareness.

The D^2EPC project will propose additional indicators, which will demonstrate the environmental performance of buildings, for their introduction in the next-generation EPCs.

4.2 The Introduction of BIM and Digital Twin Concepts for the Next-Generation EPCs

The use of BIM technology helps to improve the collaboration of stakeholders from the design to asset maintenance phases. Benefits can be obtained in various design and construction stages such as clash detection, scheduling, simulations during building design, as well as quality control and validation, safety management, logistic solutions during building construction and maintenance phases. While BIM delivers static data, Digital Twin (DT) focuses on linking physical objects to their respective digital replicas using periodically updated (dynamic) data flow. The key features of DT are sensing and monitoring, data linkage, Internet of Things (IoT) implementation, simulation, predictions, and controls.

As prediction and control features are concerned, the integration of the physical asset monitoring systems with the DT becomes a prerequisite feature. The rest part of the DT consist of geometrical representation of the physical objects and "attached" alphanumerical information related to various types of properties, features and attributes. A sufficient and mature BIM model can be employed as an efficient information repository. The BIM model can deliver semantically rich object-based information related to the asset and the processes involved in the asset or its part.

As far as DT is concerned for the employment in the Operation and Maintenance (O&M) management [16], the main aspects and features of DT can be linked and employed for the improvement of the EPC and its issuing procedures. Since DT enables the connection of sensing and actuating tools with the digital representation of the physical asset during the O&M phase, it can be employed for the asset and operational rating evaluation procedures. In the following are presented three use cases for the employment of DT at the EPC procedures:

1) Use of the DT to predict, visualize, and inform end-user of its behavior impact for energy consumption of the building and predict users' actions impact for EPC.

2) Employment of transformative DT to achieve and sustain the building's highest available energy efficiency class. At this point, DT's ability to take control of building appliances plays a significant role in eliminating user faults regarding energy savings. It can be utilized from the most straightforward actions such as switching off the lights to HVAC and other systems adaptation to users' behavior.

3) DT can be adopted to monitor appliances' performance and inform the user and stakeholders about inefficient or deteriorated devices and their impact on energy uses. This feature can be utilized as well for highlighting and/or disarming inefficient appliances.

Fig. 1 represents the definition of BIM and DT concept regarding the energy efficiency of the building throughout its life cycle stages: plan and design > produce and construct > use and maintain. "Asset", "Analysis/change", and "Digital data" layers in the figure represent different types of approach.

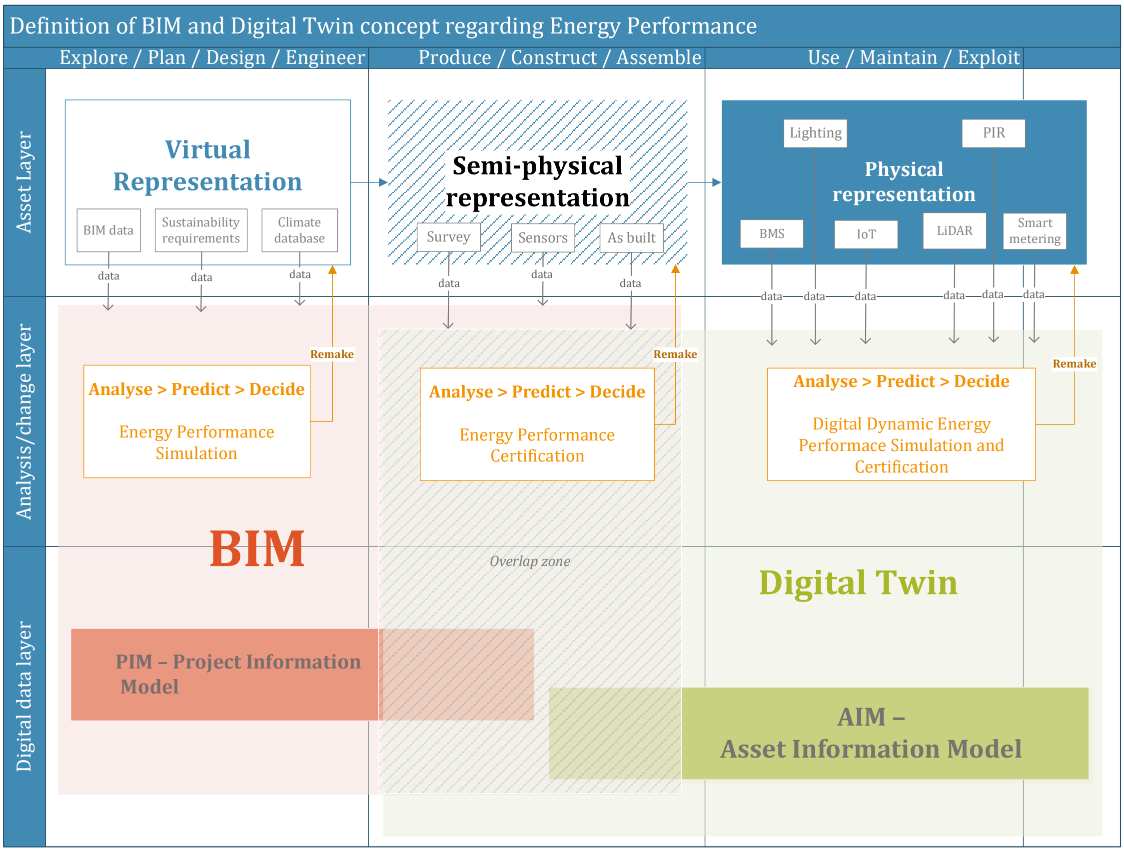

Fig. 1. Definition of BIM and DT concept regarding energy performance

Considering the "Asset layer", it delivers information on the virtual, semi-physical, and physical development of assets, including stored information such as requirements, BIM model, sensors, BMS, and other related data and documentation.

While the "Asset layer" is responsible for data storage and collection representation, the "Analysis/change layer" plays a significant role in optimizing energy efficiency-related actions throughout all asset life cycle stages. The "Analysis/change layer" presents a common logic of utilizing digital data received from the "Asset layer" for the energy efficiency analysis required for asset design. It can also be employed during construction and maintenance phases to achieve the best possible energy efficiency decision considering physical and operational data.

The bottom layer represents the main constituents of the BIM model according to the group of information management standards [17]. The first part is for defining concepts and principles, while the second is focused on the information delivery phase of the asset. Part 3 is based on information management during the operational phase. It is stated in the standards that a project information model (PIM) is an information model relating to the delivery phase of an asset, and an asset information model (AIM) is an information model relating to the operation of an asset. It is evident that BIM and DT overlap in the construction phase since BIM can deliver object-based data utilized for the DT.

4.3 Introduction of GIS in EPC

In the D^2EPC project and GIS context buildings are described and considered in the concept of BuildingsExtended3D, i. e. with correct geometric dimensions, proportions, scale, but not considering geolocation of a particular building. These 3D designs depict the correct building proportions and scale, but the correct geolocation is yet to be defined. To this end, several methods of geolocation can be applied, depending on the existence and availability of data: If the building under study is already correctly geo-referenced (projection information can be obtained from cadastral information and/or other spatial databases), a simple projection procedure should be applied.

In the case of not geo-referenced EPCs for buildings or lack of information, two data acquisition methods can be applied. The first is geolocating the building/parcel using a GPS/GNSS procedure to provide the best and most reliable accuracy results. The other approach is addressing geocoding method used to collect appropriate geolocation data.

In parallel with the geo-referencing procedure, it is also essential to determine the unique geographical location of each building. By adopting a common reference coordinate system for all the under-study regions/cases, a unique code can be created in many possible ways, using the coordinates of each plot of land. A simplified way to create a unique geocode for the case studies is to convert a polygon shape feature into a centroid point and extract 2D coordinates from this centroid point.

The definition of the Z - height value of a unit (building, apartment, etc.) - is as important an EPC element as the aforementioned geolocation features. Same as for geolocation, the different data acquisition scenarios may be applied: a) Floor/height information is available in official registries, spatial governmental agencies. b) If there is no known recorded and registered data, there are few options for data acquisition. The first is to use GPS/GNSS measurements taken on-site, which will give an accurate altitude. Another approach is the application of a widely agreed assumption that the height of one floor equals 3 meters; in this scenario, it is possible to identify the floor number in each building (floor = building's height / 3).

The use of geospatial technologies and accurate data location could improve the processes related to the data needed to assess the energy performance and needs of buildings and urban areas. In addition, the use of geolocation practices can increase decision-making effectiveness by different stakeholders (policymakers, technicians, citizens). Online and web-based tools that can provide near real-time data on the actual energy performance of buildings at the building or regional level could provide public authorities, governments and energy service companies with crucial regional insights. A unified scheme for monitoring and evaluating energy efficiency policies and practices, using a standard set of spatial data (dwellings, buildings, neighborhoods), could improve the synergies between existing energy initiatives and the adoption of new initiatives.

4.4 Introduction of financial schemes

Introducing financial schemes in EPC is suggested in this study. Based on the well-established principle of lifecycle costing, a set of financial indicators could be developed 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. For example, financial awards (e.g. tax reliefs) should be included if the building owner exceeds new EPC requirements and class. In the opposite case – penalties should imposed based on the "polluter pays" principle.

5. D^2EPC System Architecture

A novel methodology for dynamic EPC is being developed within the H2020 D^2EPC project, which introduces the aspects of SRI, occupant comfort, LCA, integration with DT, and GIS systems. Key functionalities of D^2EPC architecture are presented in Fig. 2.

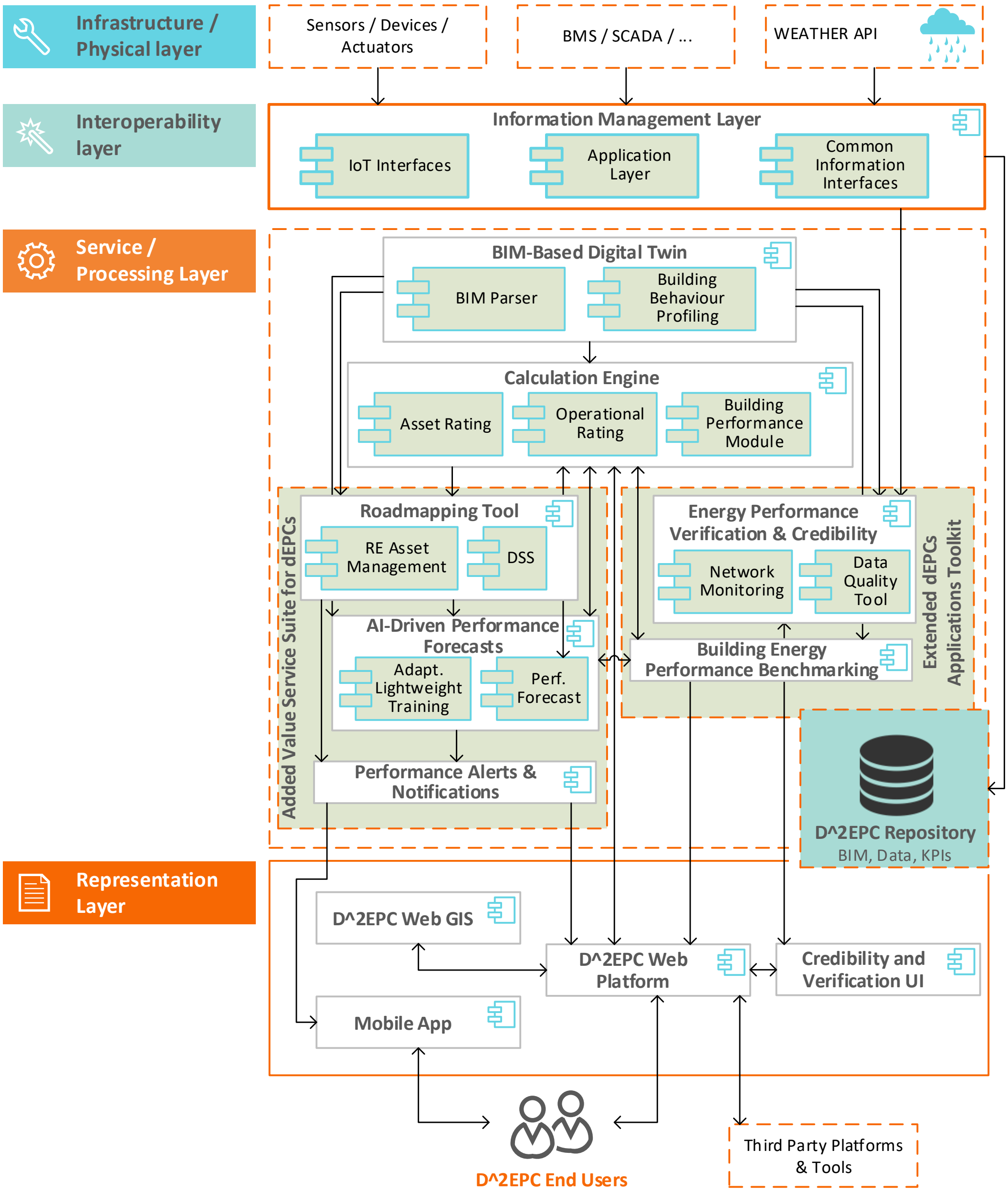

Fig. 2. D^2EPC System Architecture [18]

D^2EPC framework consists of four layers:

- Infrastructure/Physical Layer,
- Interoperability Layer,
- Service/Processing Layer, and
- Representation Layer [18].

Infrastructure/Physical Layer. All devices, sensors, actuators, and systems are included in this layer, including BMS (Building Management Systems) and SCADA (Supervisory Control and Data Acquisition), enabling dynamic EPCs. Weather data can be fed on-site or through external weather APIs from the weather stations.

Interoperability Layer. This layer is responsible both for the managementt of the received information from the Infrastructure/Physical Layer and the interoperability of the various interconnected devices. It retrieves the necessary information and streams it into the D^2EPC repository in the proper data format. As current IoT solutions, either available on-site or installed, are quite diverse in terms of communication protocols, data acquisition, etc., interoperability is considered one of the most cumbersome challenges when deploying and integrating a digital solution for dynamic EPCs [18]. D^2EPC will employ IFC4 standard to ensure data interoperability".

Service/Processing Layer. Processing and decision-making functionalities are included in this layer of D^2EPC architecture. State-of-the-art methodologies allow the evaluation of incoming data's quality and credibility, the mapping of static and dynamic building (near) real-time information, as well as the calculation of a wide variety of metrics and indicators. Furthermore, recommendations for cost-effective building upgrades and benchmarking are also introduced here. This layer employs the BIM-based Digital Twin concept, which means operational data are collected, represented, and used for analytics, and in turn, the assessment process is automatic.

One of the main components of the D^2EPC architecture is the Calculation Engine. It consists of three modules which deal with the Asset and Operational Rating schemes, while the third sub-module is related with the calculation of certain KPIs related to the overall performance of a building. A variety of indicators are calculated relevant smart readiness, comfort and wellbeing, financial and life cycle assessment aspects, to enrich the EPC procedure.

The Roadmapping Tool for performance upgrade will enable novel decision support algorithms for strategic scenarios generation, enabling user-centered suggestions on building performance and upgrades.

The module AI Driven Performance Forecasts utilizes artificial intelligence algorithms to train dedicated models. These models will be used for forecasting the future energy performance of the building taking into account the both the data streams as received from the building, as well as outside parameters that affect the building's energy performance. A lightweight approach will be employed to reduce the need for the processing power and the actual forecasting should only be used when needed.

The actual performance of the building is monitored through the Performance Alerts & Notifications component, which will also enable the occupants to personalize their indoor environment settings.

An automatic and continuous verification process will be enabled with the Energy Performance and Credibility component, which analyses the IoT data streams and performs a constant check on sensor's health and data quality.

The classification and comparison of the particular building data with reference to certain metrics will be carried out through the Building Energy Performance Benchmarking component, which is linked to the Roadmapping tool for increasing the building performance.

Representation Layer. The representation layer enables the D^2EPC platform interaction with the end-users and third-party platforms. The Web Platform will enable the representation of different KPIs and provide dashboards and analytics results, while the Web-GIS module will provide geospatial information using maps and 3D models.

6. Conclusions

The following new indicators are suggested to be included in the dynamic EPC: SRI, human comfort-related indicators, LCA, and financial schemes.

By integrating BIM into the EPC scheme, it is possible to obtain object-based information related to a particular asset (e. g. class, related properties and processes, aggregation, etc.). A semantically rich BIM model can be considered the basis for a digital twin, which can be used for energy performance modelling from the design to the maintenance phases of the asset. Complemented by sensors/BMS/IoT and other data, the DT can visualize and inform the users about the impact of their behavior on EPC. As DT can take management action to eliminate user culpability, it can be used to achieve the highest possible energy performance class for a building. In addition, the sensing and monitoring functions of DT can be used to prevent inefficient energy impacts of the appliance through smart assets or the IoT.

Correctly locating the geographic location of the dynamic EPC will provide a better understanding of the energy performance status of each dwelling/building over a given monitoring period. In addition, the EPC can be tailored to spatially and visually relate the exact location of the building to other relevant climatic factors (climate change indicators, the greenness of the neighborhood, incoming sunlight, etc.). At the same time, it will help to explore innovative geolocation practices to overcome the lack of existing cadastral data.

New technologies that didn't existed at the time when the current EPCs schemes were developed, enable new approaches towards building energy certification. D^2EPC platform aims to integrate IoT, AI, and other novel technologies to enhance end-user awareness and facilitate a more sustainable life cycle of buildings. Nevertheless, integrating these technologies into a coherent unified tool is still a challenging task. D^2EPC aims to provide a demonstrator platform that will help increase the understanding of European building stock's EPCs.

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Data Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.