# D$^2$EPC: Next Generation Digital and Dynamic Energy Performance Certificates

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***Abstract*—Energy performance of the building stock has been identified as one of the core challenges in the effort towards improving not only energy efficiency, but also achieving zero and positive energy buildings. With the recast of the Energy Performance of Buildings Directive, Europe has made clear that improved schemes are required for more accurate assessment of the actual energy performance, exploring in a holistic approach the factors that affect both asset and operational rating. Towards that direction, a lot of research endeavours have been denoted in order to identify the additional information required and the necessary cutting-edge digital technologies that will not only enrich the energy performance certification process, but will at the same time facilitate and accelerate related procedures while also presenting more context to the users, raising understanding, awareness, and hence actual engagement. The D$^2$EPC project presents a solution that covers the main current challenges and gaps in the assessment process, introducing a variety of improvements, in terms of information (i.e. energy, smart readiness, well-being, comfort, financial, and sustainability indicators) with the use of advanced tools (i.e., Building Information Modelling, Geographic Information Systems, etc.). The present work, introduces a high-level representation of the D$^2$EPC architecture, elaborating on individual components and their interaction, towards delivering the envisioned final enriched web-platform that will enable dynamic Energy Performance Certificates based on (near)real-time field data.**

***Index Terms*—energy performance, certification, asset rating, operational rating, building information modelling, digital twin, geographic information systems,**

## I. INTRODUCTION

In the Climate Target Plan 2030 [1], the European Commission, established ambitious commitments to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 and set a more ambitious and cost-effective path to achieving climate neutrality by 2050. The building sector, is one of the largest energy consumers in the EU responsible for approximately 40% of the final energy demand and 36% of $CO_2$ emissions. Buildings subsequently have a significant role in the EC's proposal for its energy saving goal. Indicatively, almost 75% of the EU building stock is inefficient according to current building standards, while up to 85-95% of the existing buildings will continue to be utilized in 2050 [2].To achieve the net 55% emission reduction target by 2030 as set in the Climate Target Plan 2030 [1], the EU needs to reduce buildings' energy-related greenhouse gas emissions by 60% compared to 2015 levels. In this context, the EU has proposed a set of directives and policy tools towards energy transformation of buildings. Energy Performance Certificates (EPCs) comprise an essential part of the Energy Performance of Buildings Directive (EPBD), introduced in 2002 [3] and revised in 2010 [4] and in 2018 [5]. The EPBD promotes policies that will help achieve a highly energy efficient and decarbonised building stock by 2050. In 2020, the Commission presented its 'Renovation Wave' strategy [6], requiring also the revision of the EPBD on provisions that are central to boosting building renovation, making it a critical moment for introducing new aspects and elements for dynamic EPCs (dEPCs) [7].

Nowadays, EPCs have been identified with quite a few deficits and challenges. In order to incite renovation activities and energy upgrades, customised recommendations considering occupant's needs and preferences are needed. EPCs are currently perceived as more like an administrative burden by building users and owners as they are a mandatory requirement when constructing, selling or renting a building, rather than an informative, user-friendly tool that can help them improve building's energy efficiency. Even though thermal and acoustic comfort, indoor air quality and daylighting are among the primary drivers for sustainable buildings renovation, they are not considered in current EPCs [8]. At the same time, the recommendations for energy upgrade are usually delivered by a standard list (e.g. increasing insulation, replacing windows etc.) and do not offer a user-friendly document which would motivate renovation. Although the EPC calculation process is based on a comprehensive set of standards, current practices should be extended to introduce a set of additional novel indicators, covering additional aspects of the energy and comfort performance of buildings, fulfilling also the requirement of the latest EPBD recast to integrate Smart Readiness Indicators (SRI) into the energy calculation procedure.

Despite the availability of building energy related data delivered from smart meters, sensors and IoT devices, many EPC ratings only assess the energy performance of buildings as designed and do not consider the actual energy consumption. Concurrently, for a large number of properties, there is little or no correlation between EPC ratings and actual energy performance [9]. Even though advanced design tools, such as Building Information Modelling (BIM) and building Digital Twins, are becoming a mainstream in the Industry 4.0 era, most of the EPC software tools used in EU Member States (MSs) are based on simplified architectures. In current practises, the description of the building is usually based on aggregated values (in terms of building elements' areas, thermal zones, etc.) and look-up tables (in terms of material thermal properties, infiltration rates, etc.) and do not employ the information-rich BIM files for the EPC calculation [10]. In terms of advanced design tools, a large heterogeneity is observed on the BIM uptake in EU [11], whereas DTs are still mainly being researched. Further to that, the calculation procedure is also subjected to human errors and is dependent on the competence, subjectivity and experience of the assessor.The lack of proper building documentation, in the case of existing buildings, such as architectural property drawings and other datasheets further hinders the accuracy and reliability of results [12].

This study presents introduces the architecture of an advanced EPC calculation tool, which will be developed in terms of the H2020 D$^2$EPC project [1]. D$^2$EPC aspires to deliver the next-generation of dynamic EPCs for the operational and regular assessment of buildings energy performance through a set of cutting-edge digital design and monitoring tools and services. The architecture of the envisioned framework is presented in detail, highlighting key functionalities and interactions, that can introduce an improved user-experience for all involved stakeholders (e.g. engineers, facility managers, building owners, tenants, public bodies, policy makers, etc.) and lead the assessment of buildings efficiency into a new digital era.

## II. D$^2$EPC FRAMEWORK ARCHITECTURE

The architecture of the D$^2$EPC framework is divided into four layers, according to its physical deployment as can be observed in Fig. 1: 1) Infrastructure or Physical Layer; 2) Interoperability Layer; 3) Service or Processing Layer; and 4) Representation Layer. High level information for each of these layers, including details on individual components and modules, is included in each one of these layers. An overview of the D$^2$EPC components is listed below:

### A. *Infrastructure / Physical Layer*

This layer consists of one of the core layers for dynamic EPCs, especially for the operational rating. Within this layer, all devices, sensors, actuators, and systems (i.e. Building Management System – BMS, Energy Management System – EMS, or even Supervisory control and Data Acquisition - SCADA) are included for collecting the necessary building information for all succeeding layers. As weather data are also required, in the absence of accessible weather stations on site, external weather APIs will be used to retrieve the necessary information.

### B. *Interoperability Layer*

The Interoperability layer is also presented as the Information Management Layer. As a component, this layer is responsible for communicating with the building assets from the physical layer, retrieving the necessary information, translating it to a commonly accepted format and streaming it to the D$^2$EPC repository to be then accessible by other D$^2$EPC components.

As current IoT solutions, either already available on site or to be 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. Therefore, a variety of protocols, standards, and interfaces should be taken into account towards ensuring such robust (near)real-time data acquisition from the building's ecosystem. To facilitate this endeavour, D$^2$EPC aims to present an information model that extends current standards (e.g. IFC4) and incorporates all required aspects for delivering both asset and operational assessment.

### C. *Service / Processing / Decision Making Layer*

This layer introduces all components that present either processing or decision-making functionalities. By incorporating numerous state-of-the-art digital technologies, this layer presents a cutting edge arsenal for evaluating the quality and credibility of incoming data, mapping static and dynamic building (near) real-time information, while calculating a wide variety of metrics and indicators. In this layer, optimal recommendations for cost-effective building upgrades, and finally benchmarking findings towards evidence-based results are introduced. The main components that constitute this layer are briefly explained below:

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[1] https://www.d2epc.eu

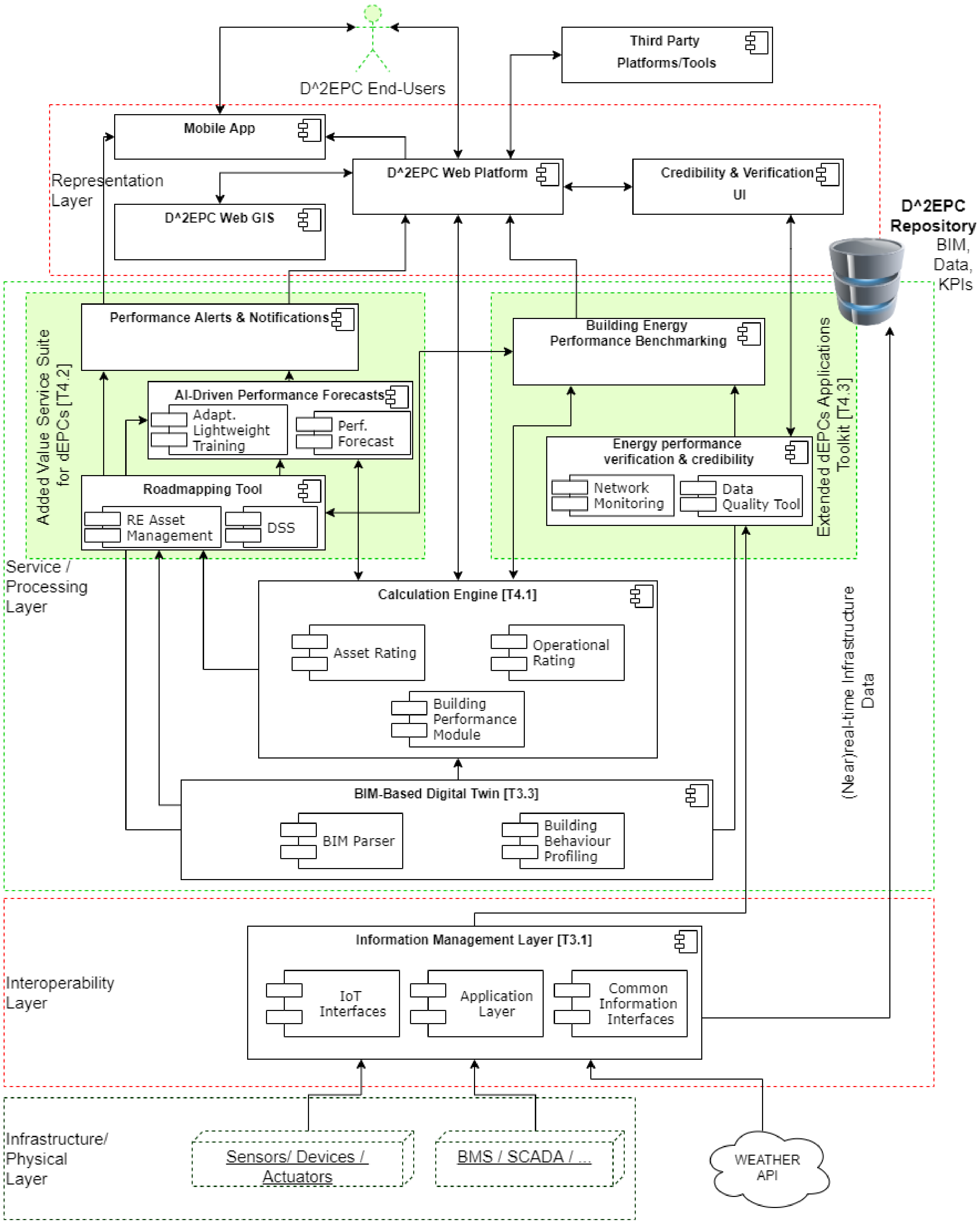

Fig. 1. D$^2$EPC System Architecture

*1) BIM-based Digital Twin:* Within D$^2$EPC, BIM-based performance assessment is expected, towards minimizing the effort and complexity of the overall process. Level 3 BIM practices will enable dynamic energy (re-)assessment, given that the BIM model has been updated and sustained correctly. In more detail, to leverage the full potential of BIM technologies, the 4th (time), 5th (cost), and 6th (sustainability) dimensions will be explored, for presenting a more thorough and automated assessment (all information required as input for the assessment process will be extracted from the building's BIM model).

Going a step beyond BIM representation, which currently does not include operational data, D$^2$EPC will also employ the concept of Digital Twins, in order to present a complete digital representation in (near)real-life operation. The BIM model will be further enriched with real-life building data, resulting in the Building's Digital Twin (BDT). All other D$^2$EPC components, besides the *Credibility Tool*, will retrieve required information concerning the building envelope, the design and materials, as well as the building systems, and their real-life, (near)real-time data through the BDT. By incorporating such digital representation, the assessment process will not only be completely automated (constantly updating the digital model), but it will also be highly dynamic allowing for ad-hoc certificate issuing, monitoring and verification.

The digital model will also allow the introduction of various behavioural characteristics to the BIM-based BDT, while its dynamic nature, based on the continuous collection of operational data, will allow regular adaptation of the digital model to reflect more accurately the buildings' current real-life status. By properly identifying the correlation between static and dynamic information originating from the various systems, an alive digital ecosystem becomes available for delivering the necessary level of information for dynamically extracting the building's holistic performance.

*2) Calculation Engine:* This engine is one of the main components of the presented architecture. This component is responsible for performing all the necessary calculations for accurately assessing both asset and operational performance. As these require different input parameters, two separate modules have been designed. In addition, a dedicated module (i.e. *Building Performance Module*) has been identified with the sole purpose of performing the necessary calculations for a wide variety of indicators that will enrich the EPC procedure (e.g. smart readiness, comfort and well-being, financial, life-cycle assessment, etc.).

*3) Roadmapping tool for Performance Upgrade:* This component will allow the post-analysis of dEPC data and provision of building-specific recommendations and user-centred suggestions, that will further enhance the building's energy performance and upgrade its EPC classification within an indicative timeframe. In order to be able to deliver such recommendations, the roadmapping tool will exploit novel decision support algorithms and multiple strategic scenarios generation, hence exploring and deciding from a large pool of potential solutions, delivering the most cost-effective under certain considerations. The tool will be built upon the evaluation and assessment of building as a whole, including all information introduced through the D$^2$EPC framework. Based on the identified optimal scenarios, which will be mainly focusing on the building's infrastructure, this tool will also feed the *AI-Driven performance Forecasting* counterpart towards evaluating additional data-related aspects for delivering optimal solutions for the operational aspects of the infrastructure.

*4) AI-Driven performance Forecasting:* This component acts complementary to the *Roadmapping Tool* by analysing in detail operational information extracted from the building. State-of-the-art AI algorithms will be employed to train dedicated models and forecast building operating conditions and their impact in building's energy efficiency/ performance. The goal will be to coordinate operation of building's assets in the optimal comfort and energy efficient manner and proactively indicate any patterns that if not pointed out and modified, might affect negatively the energy performance certification class of the building. The component will consist of two modules, the first is used to train the required models regularly in an adaptive way, using a lightweight approach to avoid stressing the system, whereas the second will perform the actual forecasting when needed.

*5) Performance Alerts & Notifications:* As the D$^2$EPC web platform aims towards presenting not only the recommendations during the process of issuing an EPC (as notifications), but also during the actual operation of the building, it is proposed to develop a dedicated component that will provide the users the flexibility to personalize their indoor environment, in order to avoid a performance downgrade in theirs building operation. According to the Article 11 of the EPBD [5], recommendations to users are mandatory in EPCs. To this end, this tool will be able to cover a wider range of recommendations, both in terms of processes and end-users, during the EPC issuance and the (near)real time building's operation. One of the most interesting functionalities thought, is expected to be the support provided to property owners with accurate and customised recommendations for daily operations, maintenance, and even renovations. The notifications provided will be semantically enriched based on information dynamically extracted by the various D$^2$EPC components, to optimally pinpoint the challenging issue and the appropriate user-response.

*6) Energy Performance and Credibility:* The Energy Performance Verification & Credibility will be a cloud-based tool that aims to facilitate the verification process concerning the credibility of collected data streams through the locally installed IoT infrastructure/ equipment towards ensuring the reliability of the collected data. It will introduce an automatic and continuous checking process of specific features related to data quality, sensors health, availability, etc.

*7) Building Energy Performance Benchmarking:* This component will deliver for the classification / comparison of buildings with reference to certain metrics, regarding both infrastructure and temporal characteristics. As quite a few new metrics are expected to be introduced to the EPC scheme, this component will lead their benchmarking, presenting the necessary reference values. Furthermore, through the detailed analysis of the information deriving from the issuing process, this tool will also act as a classification engine. This classification will indicate the potential paths for performance improvements and can provide valuable insight to the *Roadmapping Tool* and building renovation passports.

### *D. Representation Layer*

This layer constitutes the web-based environment that is offered for interaction with the end-users (engineers, building owners, registries, etc.) or third-party platforms / tools (i.e. b-logbooks, BIM desing tools, etc.). Within this layer, three D$^2$EPC components are included, namely:

*1) D$^2$EPC Web Platform:* The role of the Web platform will be to facilitate the presentation of the results from the various components and sub-components, such as the EPCs, the KPIs, recommendations and notifications, etc. The D$^2$EPC Web Platform, as part of the presentation layer will be querying information from the D$^2$EPC repository while also coupled with the repository for extracting and updating information. Employing visual analytics, the platform will deliver a user-friendly, information rich environment for the D$^2$EPC end-users to interact with. Given the dynamic aspects introduced by D$^2$EPC, through the web-platform, the user will be able not only to adjust and configure certain components (e.g. roadmapping tool) but also to request directly the execution of certain processes ad-hoc, for updating the EPC results.

*2) D$^2$EPC Web-GIS:* A GIS component will integrate enriched data and information in the D$^2$EPC framework. This module will analyze the buildings energy consumption information spatially and will deliver layers of information into visualizations using maps and 3D scenes. With this unique capability, the Web-GIS tool will allow to reveal deeper insights into data, such as energy performance patterns, supporting experts, practitioners and authorities to take informed decisions, while helping users in general to understand complex spatial phenomena.

The D$^2$EPC Web-GIS Tool will be an additional system on top of which energy quality data and dEPC information will be presented in a GIS environment. The plan is to enhance the D$^2$EPC Web-GIS tool by additional dimensions, regarding time (4$^{\text{th}}$ Dimension) and level of details (5$^{\text{th}}$ Dimension). The time aspect (4D) will give each object the crucial time reference, making it easier to identify the energy needs of each building, as well as to harmonize with present or future national and European energy legislation. The level of details (5D) will concern the amount of information embedded to the platform and will eventually describe the energy capacity of each building.

*3) Credibility UI:* To support the credibility assessment process, an additional user-friendly interface will be employed, for producing more technical alerts to report equipment malfunction and communication disruptions at the IoT devices network installed at the D$^2$EPC pilot sites. This interface will enable a more detailed analysis of the errors and alerts, allowing for a thorough investigation of the alerts generated. Additionally, notifications will be provided to the end-users in case of problems identified in the collected data, so that immediate actions will be taken by the building tenants.

## III. DEMONSTRATION CASES

The D$^2$EPC scheme will be applied, demonstrated and validated in operational environment at six demonstration buildings. D$^2$EPC has formulated the demonstration cases having as focal point of addressing the different needs of Certification of different types (residential, tertiary, and industrial) and classes (Class A to Class E) of buildings. Moreover, in order to identify common issues in different locations and conditions, the Demonstration Cases include variations, as there are buildings within the same region but with different class and type, but also diversity in location and climate conditions (Central-North Europe – Germany, Central-South Europe – Greece and South Europe – Cyprus).

- **nZEB Smart House**: A 316 $m^2$, two-floor, rapid prototyping demonstration infrastructure shaped as a real residential household at the premises of CERTH/ITI, in Thessaloniki, Greece. The building is representative of a mixed type facility (residential and tertiary) and is already equipped with many IoT, smart home solutions that provide a lot of information about its operational characteristics, including also among others highly diverse consumption, generation, and storage assets.
- **Multi-family Residential Building**: A three storey building that consists of six apartments in Velten, Germany. A central oil-fired boiler is utilised to cover the building's needs in heating and Domestic Hot Water (DHW).
- **Industrial Building**: The building has a total area of 2235 $m^2$ and houses a metalworking company in Berlin, Germany. This demonstrator will focus on the production halls, presenting the industrial requirements for dEPCs, whereas additional spaces like offices will also be examined.
- **Educational Building**: Frederick's University new wing building, a three storey, mixed type, concrete framed building constructed in 2007 with a total area of 2100 with a total area of 2100 $m^2$. The building, equipped with a BMS and a central HVAC unit hosts, auditoriums, offices, and a restaurant.
- **Multi-family Residential Building**: A classical multi-family building with a total area of 1685 $m^2$, located in the centre of Berlin, Germany. The four storey building was initially constructed in 1900, consists of 16 apartments and is currently equipped with a solar thermal system and a PV system.
- **Multi-family Residential Building**: It is a historical building constructed in 1911, located in the centre of Berlin, Germany. It consists of 4 floors, and overall there are 12 apartments hosting 36 occupants.The facades are constructed out of brickwork and wooden windows. The

building is equipped with smart devices which monitor its energy performance.

As seen in the above high-level description, the buildings introduce different challenges and energy performance requirements, presenting the ideal demonstration environment for deploying, evaluating, and validating the D$^2$EPC framework.

## IV. CONCLUSION & FUTURE WORK

This study introduced a technical proposal for a new system architecture that will enable easy and fast issuing of a context-rich, comprehensive, reliable and highly dynamic EPC. Covering a robust pipeline from the building infrastructure to the end-users, the proposed framework incorporated four distinct layers that provide for solutions that address the challenges and gaps currently identified in the existing processes. Special emphasis will be given in the interconnection between the asset and operational rating methodologies, as the first can give usefully insights regarding the building design whereas the later provides the building's stakeholders with an accurate evaluation of the building's actual energy performance and the opportunity to identify energy behavioural patterns, in order to make near future energy performance predictions.

The presented architecture will be evaluated and validated through the six diverse demonstration cases, allowing for quantified results and evidence-based findings that will leverage the utmost of the technologies introduced. It is also expected, that through the benchmarking process, it will be feasible to present the necessary recommendations towards not only leading future policy making, but also fuelling standardisation activities for unified approaches for both asset and operational rating across Europe.

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