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Envisioning a European Digital Building Logbook to Promote Energy Renovation: Development Approach and Case Study

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Abstract. The Digital Building Logbook (DBL) is defined in the recast of the Energy Performance of Buildings Directive (EPBD) as a common repository for all relevant building data. While the directive does not specify the exact features or structure of this tool, it is clear that its implementation will be required in the near future. For this reason, various research groups are currently working on the development of a common DBL model that can be applied across all Member States. This paper presents the approach undertaken to propose a DBL model focused on promoting the energy renovation of national building stocks. The methodology involves analysing existing initiatives, identifying the essential data fields that the model should include, and evaluating potential data sources to populate the model. As a result, a logical data model is developed and tested using a case study based on a real building located in Spain. Through the realisation of this case study, the consistency of the proposed model architecture is demonstrated, as well as its ability to fulfil the intended function of promoting energy renovation.

1. Introduction

European directives and strategies, such as the European Green Deal and the Renovation Wave, emphasise the importance of the building sector in achieving European climate goals. This is due to the fact that this sector is the largest consumer of final energy [1] and is responsible for the extraction and transformation of large quantities of materials [2], as well as accounting for 36% of energy-related GHG emissions in Europe [3].

One of the main strategies to reduce the impact of the European building stock lies in improving its energy efficiency through energy renovation. However, current renovation rates are far from what is needed to meet the established climate goals [3]. Therefore, mechanisms to accelerate these efforts are required. One such mechanism is the promotion of staged renovations, which involve renovating a building in different phases, carried out according to the technical and financial capabilities of the owners. Once all stages are completed, the result is a deep renovation of the building.

To promote this type of renovation, it is essential to have tools that enable, on the one hand, the collection of all necessary data for designing effective renovation roadmaps and, on the other hand, the storage and accessibility of information generated at each stage for use in subsequent phases. Additionally, public authorities must be able to monitor the progress of renovations to compare it against the formulated targets.

According to the new Energy Performance of Buildings Directive (EPBD), the Digital Building Logbook (DBL) is a digital repository that gathers all relevant information about buildings [3], positioning it as the ideal platform for making data available to plan renovation roadmaps. Additionally, as noted by Gómez-Gil et al. [4], it also has the potential to serve as a tool for monitoring the decarbonisation of the building stock, including tracking renovation progress. This makes the European DBL a tool capable of contributing to the increase in both the rates and quality of building renovations.

Although the DBL was officially defined in the EPBD recast [3], no common model currently exists. For this reason, in previous research, the authors worked on the development of a common DBL model for the entire European Union (EU) that would enhance its potential to serve as a driver for energy renovation. This research complemented that which was already being conducted at various levels even before the DBL was officially defined in the EPBD. This includes several H2020 and Horizon Europe research projects: IBRoad, ALDREN, X-Tendo, EUB SuperHub, and Demo-Blog, a report titled Study on the Development of a European Union Framework for Building's Digital Logbooks [5], commissioned by the European Commission, and a project named Technical Study for the Development and Implementation of Digital Building Logbooks in the EU [6], led by Ecorys, TNO, Arcadis, and Contecht.

Alongside these EU-led initiatives, independent research is being carried out, focusing on various aspects such as evaluating current DBL proposals [7-9], exploring new tool functionalities [4,10], assessing both present and potential future data sources [11-13], investigating its data structure [14], identifying connections between the DBL and building permits [15,16], as well as between the DBL and Digital Twins [17], and developing data ontologies tailored to specific functionalities [18,19].

This paper summarises all the research conducted by the authors that has led to the creation of a conceptual European DBL data model to promote energy renovation and presents, for the first time, the process that has been undertaken for its validation.

2. Previous Research: Approach to Data Model Development

The authors of this paper conducted an extensive research process over the past few years, which culminated in the proposal of a conceptual data model for the European DBL [19]. As mentioned earlier, the proposed DBL aims to enhance both the rate and quality of energy renovation. To achieve this, the following steps were taken:

1. The first step involved a literature review of the scientific literature and legislation regarding the European DBL, with the aim of understanding the origins and state of the art of the tool, thereby establishing a starting point for the rest of the research. Through this study, six existing or developing European DBL initiatives were identified, which were analysed and compared across seven parameters. A portion of this research is presented in [8].
2. From the previous analysis, it became evident that there was a significant lack of clarity regarding the functionalities of the European DBL. Therefore, the second step involved clarifying these functionalities and proposing new ones linked to the promotion of energy renovation. To support this, it was concluded that the European DBL must fulfil two primary roles: collecting the necessary information for creating tailored renovation

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roadmaps and gathering and storing data to enable the measurement of progress in decarbonising the building sector. This second functionality was explored in detail in [4].

3. After studying existing European DBL models and clarifying the tool's functionalities, a specific framework of indicators -or data fields- for the European DBL to promote energy renovation was proposed [20]. These indicators supported the functionalities of collecting data to develop renovation roadmaps and collecting data to measure the progress of decarbonisation in the building sector.
4. The next phase involved studying existing data sources that could provide the necessary information to populate the new European DBL. It was found that most relevant data sources for the DBL are at a national level or below, so two specific case studies were analysed: Spain and Italy. The study is presented in [11].
5. Through the analysis of data sources, it was concluded that, at present, there are no sources that allow for the collection of all the necessary data for the European DBL. As a result, new data sources based on emerging technologies for data collection, as well as on new European frameworks aimed at promoting digitalisation and circularity in the building sector, were identified and analysed [12].
6. With all this information, a data model for the European DBL aimed at promoting energy renovation was proposed and can be consulted in [19].

3. Methodology for Data Model Validation

Once the data model for the European DBL was defined, it was necessary to validate it. Validating a model in data science involves ensuring that the usability, structure, semantics, constraints, and relationships within the model are correct and that the model supports real-world use cases, data integrity, and performance requirements. In this case, a real-world use case is utilised to verify that the model effectively fulfils its intended purpose, i.e. to guarantee its usability. Simultaneously, this serves to ensure that there are no errors or inconsistencies in the data inputted into the model, i.e., ensuring data integrity. Matters related to performance requirements are beyond the scope of this validation, as they pertain to a model in the implementation phase, which is outside the focus of this research.

The functional validation was carried out using the following methodology:

1. Case study selection and description. To test the proposed European DBL model, a real building was selected as a case study. The chosen building was preferred to meet the following criteria: to belong to a cluster of buildings sufficiently representative of the national and local context; its renovation should be feasible and practical; the building should have a renovation roadmap; and ideally, the building is being monitored.
2. Execution of the European DBL for the case study building in its pre-renovation condition, following the model proposed in [19]. This initial step is crucial for verifying whether the integrity, efficiency, and consistency of the data stored in the data model are ensured. To guarantee these aspects are functioning properly, it is essential to verify that the first three normal forms (1NF, 2NF, and 3NF) are applied in the data model. The normal forms are principles whose purpose is to structure information in databases logically and efficiently, avoiding issues such as data redundancy and loss of integrity.
3. Test of the functionality "information gathering for the design of renovation roadmaps". To execute this test, the information gathered in the *Libro del Edificio Existente* (LEEx) is utilised as a guide, as it is the official Spanish tool that contains the element most similar to a renovation roadmap. The LEEx is a document that details the current general data of

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a building, its state of conservation, its energy performance, user and maintenance manuals, the potential for improvement of the building in various aspects, and the detailed renovation roadmap.

4. Execution of the European DBL for the case study building in its post-renovation condition, following the model proposed in [19]. For this purpose, it was assumed that the case study building had already been renovated according to the renovation roadmap included in the LEEx. The renovation aimed to achieve a 50% reduction in the building's heating and cooling energy demand, as well as a reduction of approximately 46% in the consumption of non-renewable primary energy. This was carried out as a necessary preliminary step for the following stage.
5. Test of the functionality “providing data for the assessment of the decarbonisation progress of the building stock”. To this end, it was verified whether all the necessary data to collect the progress indicators of the framework proposed in [4] were present in the building's DBL in its post-renovation condition.

4. Data Model Validation Outcomes

4.1 Case study selection and description

The case study building selected for model validation is located at 19 Miguel Servet Street in Zaragoza, Spain (Figure1). Built in 1967 on a 733 m^2 plot, the building has a total built area of 5,380 m^2, comprising 52 dwellings, five offices, three commercial venues, storage rooms, and garages across eleven floors. It features a reinforced concrete structure, façades with double brick walls with an air cavity and minimal thermal insulation, and a roof with flat and sloped sections. It is equipped with a collective domestic hot water and heating system powered by a natural gas boiler. For this validation, only one dwelling, one office, and the common areas were considered, as they represent typical units within the building.

This building falls within the cluster identified in the 2020 Update of the Long-term Strategy for Energy Renovation in the Building Sector in Spain as having the highest number of buildings that should be renovated in Spain. Additionally, it has a LEEx and is being monitored.

Figure 1. Case study building. Views from Miguel Servet and Salvador Madariaga streets. Own work.

4.2 Execution of the European DBL for the case study building in its pre-renovation condition

Once the case study building was selected, the DBL was developed in its original condition following the model described in [19]. Although the proposed model includes 38 tables, the DBL for the case study includes only 36 tables, as two of them are not applicable to buildings that have not been renovated. From the completion of this initial step, the following conclusions can be drawn:

The compliance with the first three normal forms was verified, and while the model generally adheres to these norms, some tables, like "Materials" and "EnvelopeLayers," do not fully comply with 1NF. This design choice was made to make the model more comprehensible for non-experts and to allow flexibility for manual data entry or data from external sources with varying formats. Although this could lead to performance issues or analysis challenges, mitigation measures, such as an autocomplete function and clear data entry guidelines, are proposed. Alternatively, independent tables could be created. For instance, within the "Materials" table, it could be considered that "MaterialType" and "MaterialSubtype" become independent tables. However, in this case, the decision has been made to retain the tables in their original state to prevent the model from becoming excessively complex.

Another limitation of the "Materials" table is that it mainly addresses the building's thermal envelope, excluding internal partitions. While this does not significantly affect energy performance, it limits the model's use for life cycle assessments (LCA). Additionally, the DBL elaboration process should be automated due to the large volume of data.

In addition, in existing buildings, some indicators cannot be collected because they pertain to elements not considered at the time of the building's construction.

4.3 Test of the functionality "information gathering for the design of renovation roadmaps"

Regarding the test of the "information gathering for renovation roadmaps" functionality, as shown in Table 1, the European DBL includes significantly more indicators (163) than the LEEx (70). Only five data fields, not gathered through the DBL or its linked sources, were identified: three in Module 1 related to urban planning regulations, and two in Module 2 concerning the building's foundations and structure.

Table 1. Summary of indicators classified by category present in the DBL and/or the LEEx.

	European DBL indicators	Of which present in LEEx	Additional LEEx indicators	Of which collectable through the DBL
Module 1	34	18	8	5
Module 2	37	14	2	0
Module 3	35	13	0	Not applicable
Module 4	43	13	1	1
Module 5	14	1	0	Not applicable
Total	163	59	11	6

Based on this comparison, it is concluded that the European DBL is well-suited as an information repository for designing energy renovation roadmaps. The indicators collected by the LEEx but not included in the European DBL could be incorporated as optional or country-specific data fields within the model.

4.4 Execution of the European DBL for the case study building in its post-renovation condition

Regarding the execution of the European DBL for the case study building in its post-renovation condition, it is possible to complete all the tables that form the DBL model proposed in [19]. It is important to note, however, that this would not be the most common scenario, as the vast majority of buildings, at least in Spain, are not renovated and/or monitored.

4.5 Test of the functionality "providing data for the assessment of the decarbonisation progress of the building stock"

After completing the DBL of the renovated building, it can be observed (Tables 2 and 3) that the data obtained directly from the DBL—either by combining them using simple mathematical operations or by aggregating the data from all buildings in Spain—makes it entirely feasible to collect the progress indicators defined in [4]. Specifically, the DBL provides data for the collection of all progress indicators, except for four that relate to issues not applicable in the context of the case study building.

Table 2. Data collected through the DBL that enable the measurement of progress indicators regarding the decarbonisation of the building stock. Level 1 indicators

	Goal ID	Progress indicators	Data from the European DBL
L1	E1	-ME1A_Annual operational greenhouse gas emission reduction per building type	18.40 kgCO2eq/(m²·y) + Collective residence
		-ME1B_Annual operational greenhouse gas emissions per building type	30.20 kgCO2eq/(m²·y) + Collective residence
	E2	-ME2A_Share of renewable energy in the building sector (thermal energy) for different uses/on-site/off-site	0%
		-ME2B_Share of renewable energy in the building sector (electric energy) for different uses/on-site/off-site	18,144 kWh generated On-site
	E3	-ME3A_Primary and final annual energy consumption (ktoe) per building type/end use	DHW system: 36.82 kWh/m²·y Heating system: 78.12 kWh/m²·y Cooling system: not applicable Ventilation: not applicable Lighting: not applicable + Energy factors + 5,380 m² + Collective residence
		-ME3B_Energy savings (ktoe) per building type/public buildings	Energy savings: 103.82 kWh/m²·y + Energy factors + 5,380 m² + Collective residence
		-SE3A_Energy savings from deep renovations	Not applicable
		-SE3B_Reduction of annual energy consumption per end use/per building type	Reduction energy consumption: DHW system: 0 kWh/m²·y Heating system: 103.82 kWh/m²·y Cooling system: not applicable Ventilation: not applicable Lighting: not applicable + Collective residence
	E4	-ME4A_Annual reno. rates: no. and total floor area per building type/to nearly zero-energy and to zero-emission building/per reno. depth/deep reno./public buildings	5,380 m² + Medium renovation
	E5	-SE5A_No. of buildings equipped with building water + BEMSs or similar smart systems per building type	0
	S3	-SS3A_No. of households renovating/willing to undergo energy renovation in their dwellings	52

Table 3. Data collected through the DBL that enable the measurement of progress indicators regarding the decarbonisation of the building stock. Level 2 and 3 indicators.

	Goal ID	Progress indicators	Data from the European DBL
L2	E6	-ME6A_ Lifecycle GWP in new buildings per building type	Not applicable
	E7	-ME7A_No. energ communities/citizen-led reno. initiatives	0
	E8	-SE8A_Amount and % of reduction in water consumption from public supply network achieved through deep reno.	Not applicable
	E9	-ME9A_Number of buildings: NZEBs	0
		-ME9B_Total floor area (m2): NZEBs	0
	E10	-SE10A_Ratio of number of dwellings to number of charging points	52 Dwellings
			+ 2 Charging points
	E11	-ME11A_Number of EPCs per building type (including public buildings)/per energy performance class	1 EPC
			+ Collective residence
			+ E class
	E12	-ME12_No. of buildings and total floor area (m^2) per worst-performing buildings (including a definition)/the 43 % worst-performing residential buildings	1 Building
			+ 5,380 m^2
			+ E class
			+ Collective residence
	E13	-SE13A_No. of buildings/dwellings that have obtained an efficiency certification	0
	E14	-SE14A_Ratio of number of dwellings to number of bike parking slots	52 Dwellings
			+ 8 Bike parking slots
	S6	-SS6A_Average/aggregate IAQIs and TCI	Real data from monitoring
	S7	-SS7A_% of multifamily buildings with barriers for persons with disabilities	1 Multifamily building with barriers
	S9	-SS9A_No. of refurbishment-related reinforcements	0
	F1	-SF1A_Total investment in energy renovation	***Protected data***
	F3	-SF3A_Ratio of sustainable financing products to conventional financing products used for renovation	1 to 0
	F4	-SF4A_Public and private investments in deep renovations	Public funds: ***Protected data***
			Private funds: ***Protected data***
	F6	-SF6A_Public incentives for deep renovation	Not applicable
	F7	-SF7A_% of renovation/energy efficiency works funded through public-private partnerships	0
L3	F8	-SF8A_Direct savings associated to energy renovation	***Protected data***

5. Discussion and conclusions

This paper outlines the process of proposing and validating a data model for the European DBL, focused on promoting energy renovation, through a real case study. The case study confirmed that the model largely meets its objectives of collecting data for renovation roadmaps and tracking the progress of building stock decarbonisation. Additionally, five potential indicators specific to Spain were identified, related to urban planning regulations and a more detailed characterisation of building foundations and structure.

The case study also demonstrated the feasibility of the database architecture, allowing for proper data entry without issues like duplication. However, it was noted that the architecture could be improved, particularly in terms of database performance, which will need further refinement in future implementation.

The study's limitations include testing the model on only few units of one building due to limited data access and the impracticality of manually creating DBLs for multiple buildings. Future research should focus on developing more case studies and optimising the model for better data management efficiency.

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