CODE 09

DEMAND-SIDE MAPPING TO SUPPORT BUILDINGS' INDUSTRIALISED DEEP RENOVATION THROUGH A STAKEHOLDERS' INVOLVEMENT APPROACH

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ABSTRACT

The H2020 INFINITE project aims to achieve a zero-emission and fully decarbonized EU building stock by 2050 through increased renovation rates and depth for poorly performing buildings. Industrialized all-in-one building envelope kits, including passive eco-compatible & green solutions, energy distribution systems, smart windows, and energy generation systems, are being developed under this project. This paper outlines how to support the industrialization of construction processes, a decision-making aid tool was created using the Delphi method with the industrial stakeholders, analysing the building stock features, and assisting in selecting suitable kits for renovation projects. An interactive market potential map was developed to connect demand and supply for the kits, using GIS technology to represent information at different scales. Specific INFINITE archetypes were defined for each kit to provide ideal building characteristics for optimal installation, allowing flexibility in applying the kits in different building renovation projects.

KEYWORDS: industrialised deep renovation; stakeholder's approach; demand-side mapping; industrialised envelope kits; building stock features.

1. INTRODUCTION

The revision [1] of the Energy Performance of Buildings Directive (2021) sets out how the EU can achieve a zero-emission and fully decarbonised building stock by 2050, in particular by increasing the rate and depth of renovation for the worst-performing buildings (residential and non-residential) in each EU Member State. Indeed, a BPIE report [2] shows that, in order to reach the goal of a climate-neutral Europe by 2050, the emissions of buildings should be cut by 60% by 2030.

Compared with traditional site-based construction, the industrial construction has an obvious advantage of environmental benefits, usually with a 20% reduction in energy consumption, a 35% reduction in resource depletion and a 3.47% reduction in ecosystem damage [3].

In this context, industrialized all-in one industrialised building envelope kits for the deep renovation are competitive, reliable, life-cycle-based and designed to cover near ZEB retrofit needs and are being developed under the Horizon 2020 project called INFINITE: Industrialised Durable Building Envelope Retrofitting by All-In-One Interconnected Technology Solutions. The type of technologies that are under development are passive eco-compatible & green envelope solutions, energy and fresh air distribution system, smart windows (smart glazing), building integrated photovoltaic system (BIPV) and solar-thermal generation system (BIST).

The success of industrialising the construction processes depends on the ability to combine automation and standardisation with both, a product-oriented and customer-oriented approach [4]. That is why, the European building stock variability has been analysed and aggregated into different kind of building archetypes; and to be stakeholders-accepted and follow a sustainable approach contributing to decarbonization of the EU building stock, a decision-making aid tool has been conceived in the framework of the INFINITE project following the Delphi Method.

1.1. Literature overview

To identify the specific needs for the industrialised envelope kits, the previous experiences at a European level in the characterization of the residential building stock have been investigated.

<u>Building Type Matrix. TABULA</u>
The project analyses building types and provides criteria and examples for single-family, terraced, multi-family, and apartment blocks. Energy performance estimation for building portfolios and national stocks is possible based on construction year, size, location, supply system type, and energy-saving measures, using the TABULA Building Type Matrix[5].

<u>Residential and office building stock. FP7 Inspire</u>
The project provides a comprehensive methodology to analyse demand and consumption in European residential and office buildings. It gathers data from various sources, offering insights into building typologies, ownership profiles, and energy use across EU-27 countries, with detailed analysis of heating and cooling demand in different climates and construction periods using multiple databases and simulations [6].

<u>Key Performance Indicators on specific thematic areas. H2020 4RinEU</u>
The project assessed renovation packages using KPIs for various building archetypes and regions, incorporating innovative solutions like prefabricated wooden façades with integrated PV, ST, and ventilation devices, as well as traditional methods such as roof insulation. KPIs evaluated energy, environment, comfort, indoor air quality, economics, and building management, aiming for comprehensive energy-saving renovations [7].

<u>Near energy zero applying prefabricated building envelope elements. H2020 MORE-CONNECT</u>
The MORE-CONNECT project aimed to transform European housing into energy-efficient nZEBs by developing innovative, prefabricated building envelope elements for retrofitting. A decision-making tool was created to assess housing and determine the retrofit concept's applicability, aiming for a zero-energy concept through the addition of PV panels. [8].

<u>“All-in-one” solutions. PLURAL</u>
The project analyses off-site prefabrication of Plug-and-Use (PnU) kits with renewable energy technologies for various buildings. Three solutions, "Smart Wall," "eWHC," and "eAHC," were identified and evaluated for residential typologies in geo-clusters, promoting sustainable building renovation in Europe by aligning with EU strategies [9].

<u>Conclusion</u>

After analysing these previous experiences, all of them took TABULA Typology Approach to analyse the existing building stock. Therefore, it has been taken as the baseline to map the EU building stock variability as it can be appreciated in the forthcoming sections. Indeed, it offers a wide and normalized approach for several European countries and has been used as a reference in policy making and science [10].

1.2. INFINITE project

INFINITE proposes an innovative approach to decarbonize the construction sector in Europe, utilizing prefabrication, digitalization, and adaptable Building Management Systems (BMS). The Renovation4.0 concept offers eco-friendly, cost-effective retrofit solutions with a life-cycle perspective, aiming to activate the industrialized renovation market and establish an Observatory for Industrialized Deep Retrofit (IDR) to showcase global experiences in low carbon building stock renovation, providing multi-user design tools, eco-envelope kits, and an interactive search platform [11].

2. Methodology and results

Two phases were conducted: (a) a literature review to identify existing criteria and (b) identification of building characteristics to support building renovation with industrialised kits, using the Delphi technique.

As a result of the literature review explained in section 1.1, the objective of the investigation was to obtain a similar matrix like in the TABULA [12] project, but with the building characteristics that were more relevant to apply the industrialised building envelope kits.

The idea behind was to know, with a simple structure, if a determined building had the right parameters to allocate INFINITE industrialised kits if it would be renovated, and secondarily to help the digital transformation of the construction industry, increasing its efficiency and improving its quality [13]. To do so, the following workflow was carried out (Figure 1):

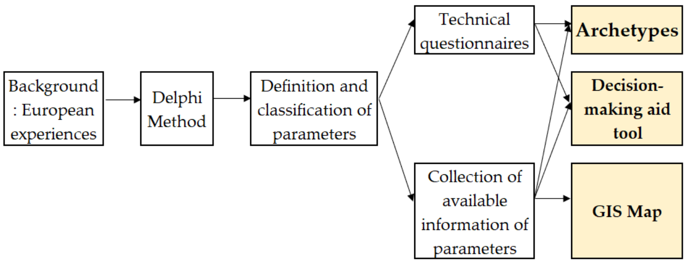

Figure 1 Workflow of the development

2.1. Delphi method

Selection of the panel of experts

As one of the objectives of the project was to support the “stakeholder-centred” approach, the Delphi method [14] was followed (Figure 2). The Delphi technique is used to reach consensus among a group of experts [15] and is particularly suitable to build consensus on issues that have limited or contradictory evidence [16]. Therefore, a panel of experts were identified from the stakeholders in the value-chain of the project. That is, the developers of the INFINITE technologies who participated in the design or exploitation of any of the products and who were engaged in the different iterative processes as they were considered representatives of the different industrialised solutions applicable to the field of building renovation.

Figure 2 Steps of the Delphi method used in this project [17]

Identification of the building characteristics affecting the design and installation of the industrialised envelope kits using the Delphi Method with a stakeholders' approach

The Delphi Method was employed to identify building parameters affecting the feasibility of industrialized building renovation. Two rounds of questionnaires were sent to a panel of experts, and their aggregated responses were shared to adjust opinions based on the total results.

The panel of experts received a list of building parameters to rank in terms of their importance in affecting the design of industrialized envelope elements. They were also given the opportunity to add other parameters not on the list that they deemed significant.

The aggregated results were shared with the experts, revealing a lack of consensus on the most important fifth parameters, and additional parameters were suggested.

Focus group meetings with technology providers were conducted, leading to the identification of additional parameters that enriched the process. The feedback obtained was used to reformulate a second round of the questionnaire, incorporating the new parameters, which influenced the design, installation, and manufacturing of the INFINITE kits.

Apart from the building's inherent characteristics, there are additional parameters that can influence the design and implementation of industrialized solutions and could be integrated into a demand grouping system. The Delphi Method results highlighted non-building-related characteristics that will be considered in further analysis, such as building usage, property system, and compliance with various legislation at different scales (local, regional, national, and European) related to the building's design or renovation process.

2.2. Definition and classification of the building stock features to be considered

According to the results of the Delphi method, the building's characteristics have been classified (Table 1) and presented in the order of importance according to the selection and the order provided by the group of experts.

Table 1 Final building stock features

Group	Parameters	
General data	· Building use (residential, tertiary, sanitary, sports…)	· Type of property (single owner or multi property)
	· Type of tenure (owned or rented homes)	
Regulations	· Façade colour restrictions	· Water use restrictions
	· Fire regulation	· Seismic legislation
	· Energy sharing / energy community's legislation	· Possibility to build more floors
		· Monumental protection of the building

Urban data	· Façade orientation · Shadows on the façade · Possibility of crane access from the street · Shadows on the roof	· Free space between the façade and the façade of the opposite building · Possibility of soil connection next to the façade
Physical building characteristics	· Existence of balconies or terraces · Façade construction system · Façade size (__x__ or m^2) · Individual or centralized heating/DHW · Type of structure (material, wall/pillars) · Building typology (SFH Single Family House / MFH Multi Family House) · Number of floors · Openings size (windows size) · Openings layout (distribution) (Openings variety or regular size) · Type of roof (flat /sloping) · Type of HVAC system · Type of external finish of the façade	· Size of roof (__x__ or m^2) · Roof construction system · Year of construction · Presence of insulation · The height of the ceiling in each floor · Structural capacities of existing building components · Existing Renewable Energies · Type of DHW system · Perimetral wall length · Existing thermal or electrical storage · Number of underground floors · Existence and in that case size of the technical room
Characteristics of the dwelling	· Sizes (m²) and layout of rooms (living spaces, WC, blind premises, etc.)	· Dwelling area (m^2) · Status of the home's electrical network (circuit separation)

The number of parameters (variables) was reduced by elaborating another final questionnaire that was specifically tailored to each of the technologies. The objective was to find out under what circumstances their solution/kit would not be viable. For instance, if the building is in an area where there are restrictions on the use of water, and the amount of water needed to maintain the green envelope is higher than the amount of water that is allowed per day, then this kit is not feasible to be installed in that building. As a result, the kits in which some of the characteristics were not relevant, such as, for example, to mention one parameter, the incidence of the sun, the questions related to this aspect were not included, so the answers were more specific or natural to the kit to be developed.
According to the results obtained, three strategies were designed to present the data obtained in a useful way, according to the following three sections: The decision-making aid tool; Interactive market potential map; INFINITE archetypes.

2.3. Decision-making aid tool

The development of the tool was intended as a useful result to help the demand side (users and designers) to figure out if industrialised solutions are feasible for their specific situation.

The summary of the steps carried out to develop the tool, according to the previous sections are:

- Analysis of the parameters identified by the stakeholders using the Delphi method (two rounds).
- Analysis of the key parameters preventing the installation of the solution in the building.
- Development of the tool, reviewed by the stakeholders.

The tool is available online [18], at the building level tab (Figure 3).

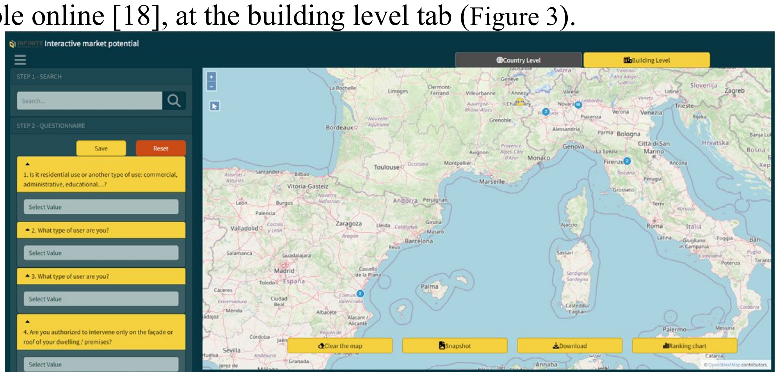

Figure 3 Decision-making aid tool

This tool is intended to be used by end users (owners, investors, designers...). By answering the questions, following strictly the order proposed, from the top to the bottom (left part of the image). Some of the questions might disappear depending on the answer provided.
After answering all the questions that come up, the possible kits to be installed are shown.

2.4. Interactive market potential map

Another conclusion was that the representation of the information on a map using GIS technology would be more adequate allowing the incorporation of the data at different scales.
The objective was to develop an interactive market potential map where the demand and the offer would be connected. In this regard, the characteristics that were possible to be obtained at European or national level from dynamic and official sources, were incorporated on a GIS map. For instance, the number of buildings according to their age of construction can be compared across countries (Figure 4).

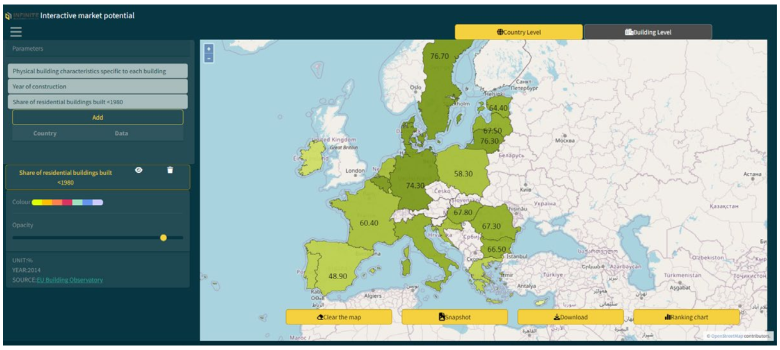

Figure 4 Interactive market potential map

2.5. INFINITE Archetypes

After analysing the responses to the questionnaires, one building archetype has been defined for each kit. The establishment of archetypes is considered crucial to create a standard representation of an ideal building for each kit. However, this does not mean that the use of different kits is limited solely to those specific parameters. Other combinations of parameters are indeed possible, but they may not offer the optimal installation for each kit.

Table 2 INFINITE archetypes per kit

Questions	ALL kits	Green envelope kit	Energy & fresh air distribution envelope kit	Smart Window kit	Energy generation BIPV kit	Energy generation BIST kit	aBMS and optimized control strategies kit
Type of use	Residential	Residential	Residential	Residential	Residential	Residential	Residential
Type of user	Owner / representative of a building	Owner / representative of a building	Owner / representative of a building	Owner / representative of a building	Owner / representative of a building	Owner / representative of a building	Owner / representative of a building
Cultural Protection	No	No	No	No	No	No	No
Façade area	> 1000 m2	> 30-40 m2	> 30-40 m2	> 30-40 m2	> 30-40 m2	> 30-40 m2	> 30-40 m2
Incidence of the sun	Yes	Yes	No	Yes	Yes	Yes	No
Water restrictions	No	No	N/A	N/A	N/A	N/A	No
Centralized installations	Yes	No	Yes	No	Yes	Yes	Yes
Internet connection	Yes	No	No	Yes	Yes	Yes	Yes
Space under the window	Yes	No	Yes	No	No	No	No
Technical room	Yes	No	No	No	Yes	Yes	No

3. Conclusions

The INFINITE project aims to achieve a zero-emission and fully decarbonized EU building stock by 2050 through industrialized all-in-one building envelope kits, encompassing eco-compatible solutions, energy systems, smart windows, and energy generation.

The success of industrializing construction processes depends on combining automation and standardization with a product-oriented and customer-oriented approach. The building stock variability in Europe has been analysed and aggregated into different building archetypes. The suitability of using prefabricated systems in renovating existing buildings, as opposed to new constructions or other forms of energy-efficient renovations, relies on a wide range of parameters. Given that the extensive range of features makes it challenging to create a functional closed matrix, a decision-making aid tool has been developed using the Delphi method to assist in selecting suitable kits for renovation projects.

An interactive market potential map has also been created to connect demand and supply for the industrialized kits. This map utilizes GIS technology to represent information at different scales, such as the number of buildings according to their age of construction across different countries.

Finally, the project defines specific INFINITE archetypes for each kit, providing typical or ideal building characteristics for optimal installation. However, the use of other combinations of parameters is also possible, allowing flexibility in applying the kits in various building renovation projects.

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