INFINITE
BUILDINGRENOVATION
Industrialised envelope solutions

D2.1

Building stock analysis to support industrialised deep retrofit

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About the project

Off-site prefabrication of multifunctional envelopes has been shown to be a technically viable approach to increase rate and quality of deep renovation of residential buildings. However, several barriers are still preventing a massive adoption of prefabricated solutions.

INFINITE aims at boosting the building renovation sector through the so-called "**Renovation4.0**" approach, which leverages on both digitalisation and industrialisation to offer **tailor-made solutions** with a high level of **design freedom**, **decrease retrofit costs and time** thanks to the optimisation of the value-chain and **foster the adoption of eco-compatible long-lasting products** and systems.

To do so, the INFINITE Project relies on three main pillars:

1. cross-fertilisation from digitalisation trends in other markets (i.e. Industry4.0),
2. exploitation of industrial capabilities and coupling with LC-thinking approach
3. experience gained from the 1st generation of multifunctional prefabricated envelopes

INFINITE promotes a life cycle approach that allows for comprehensive design, optimisation of the O&M and depletion of end-of-life residual value.

INFINITE partners cover the whole renovation value-chain. Together, they will develop a new generation of residential building renovation products and actions centred on the all-in-one industrialised Life-Cycle-based approach. Expected outputs include:

- a set of multi-user and **multidisciplinary design tools**,
- **process-optimised all-in-one industrialised eco envelope kits**,
- **adaptive control systems**,
- set of **demand- and industry-side matched business models** to show the Renovation4.0 market potential,
- a **structured framework of entities and knowledge** able to clearly and widely demonstrate the Renovation4.0 benefits.

INFINITE will unleash the potential of the renovation industry by increasing the market penetration of sustainable, high-quality, and long-lasting building retrofitting products and methods. This will ultimately contribute to the decarbonisation of the European building stock.

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Executive Summary

The main objective of this document is to analyse and cluster the demand-side (i.e. the building stock and the owners, investors, users) of industrialized renovation kits because of the EU building stock variability that leads to an uncertainty in the definition of the most suitable envelope solutions.

For this, in a first stage, previous experiences and initiatives at European level have been analysed to consider them as the baseline for the present work. For instance, TABULA building types are indeed the reference for most of this initiatives and projects.

Then, the key parameters of the buildings that affect the design of each of the systems have been identified (such as typologies and morphologies, regulation framework, ownership, etc.) and they have been ordered according to their importance. To do so, all the industrial partners have been involved in dedicated workshops and meetings to receive valuable feedback. This process is aimed at defining a tool that can cover the variation in the building stock and identify limiting parameters that might make the use of some of the kits unfeasible, while helping to identify different kinds of building archetypes. This will allow to understand better which buildings typologies fit better with the industrialised approach.

The following step has been to obtain the building stock characteristics to be considered. They have been grouped according to the Delphi method conclusions. As a result, a decision tree tool has been developed in excel format. It allows, by answering several questions about the building, to know what are the INFINITE kits that can be installed.

Then, different archetypes have been defined, that is, the ideal buildings whose characteristics are compatible with an INFINITE industrialised renovation.

As a final and big step, the different building parameters that are available in open data sources have been gathered, highlighting those ones of the countries within the consortium, since these ones seem the more suitable to be included in a map (linked to task 5.3). Furthermore, the ownership, tenure and age classes of residential buildings have been analysed to see where the major renovation potential is. Then, an analysis of the existing building regulations at national and European level to identify possible barriers for the industrialization approach in the renovation sector has been carried out. Finally, the current situation of the industrialization in the construction sector has been introduced, and a SWOT analysis about the industrialization has been carried out (for the countries of the project), to link them with the feasibility of installing the INFINITE kits and national conclusion have been introduced.

The activities carried out in this task have provided input for the definition of the user-centred approach and the development drivers (WP2). This work aimed also to drive the matching of the business models between demand and industry and consequently the market potential map from the demand-side perspective (WP5).

1. Introduction

The EU building stock variability leads to an uncertainty in the definition of industrialized renovation kits because of the need to exploit a critical-mass activation for maximizing the costs reduction. Consequently, there is a strong need for analysing and clustering the demand-side to configure industrialised envelope solutions supported by a sound business model.

Hence, in Task 2.1, the European building stock variability has been analysed from the perspective of the necessary requirements to carry out an industrialized renovation, in order to determine the best way to aggregate and display the information in a way that allows identifying the buildings that could be the object of an industrialized renovation, in an agile way. The Task activities have been the following.

- Analyses of existing experiences
- Identification of the characteristics of buildings that affect the design and installation of industrialized elements
- Definition and classification of the building stock features to be considered
- Development of a Decision-making aid tool
- Collection of available Information of the selected parameters
- Proposal of archetypes for each of the kits
- Collection of the parameters

2. Analyses of existing experiences

To facilitate the demand-side critical mass achievement as driver for the industry-side development, INFINITE has worked at the mapping of the EU building stock variability (different kind of building ownership, typologies and morphologies, regulation framework, social and cultural-geographic backgrounds). To map such big and fragmented picture, a vaste series of existing database has been deepened under the industrialised renovation spotlight. In the following paragraphs, the experiences that have been considered most relevant considering the specific needs of the INFINITE related technologies are reported.

2.1 TABULA

The term "building typology" refers to a systematic description of the criteria for the definition of typical buildings as well as to a set of exemplary buildings representing the building types.

In the past few decades different experiences with building typologies have been made in European countries. The idea of the IEE project TABULA was to examine them and to come to a concerted approach for the field of residential buildings. A focus was placed on the energy consumption for space heating and hot water. The overall objective was to enable an understanding of the structure and of the modernisation processes of the building sector in different countries and – in the long run – to learn from each other about successful energy saving strategies.

In the TABULA's Building Type Matrix, an overview of the national building typology is given. The columns of the matrix represent four building size classes:

- single-family houses,
- terraced houses,
- multi-family houses,
- apartment blocks.

The rows a certain number of construction year classes. The start year and end year of the construction year classes are individually defined for each country. The single cells of the matrix form the generic "Building Types" of a country.

To each generic building type of a country (cell of the classification grid) an exemplary building is assigned which is represented by a photo and the data of the thermal envelope. This building is supposed to be a typical representative of the building type, meaning that it has features which can commonly be found in houses of the respective age and size class. The envelope area and the heat transfer coefficients of the exemplary building are not necessarily representative in a statistical sense.

In addition, heat supply systems for space heating and domestic hot water are defined which can commonly be found in the housing stock differentiated by energy carrier, heat generator type and energy efficiency level.

The energy performance of buildings correlates with several parameters including:

- the year of construction,
- the building size and the neighbour situation,

- the type and age of the supply system,
- and the question of already implemented energy saving measures.

If these features are known for a given building it is possible to quickly give an estimation of its energy performance. This principle can also reduce the effort for the energy assessment of a total building portfolio (municipalities, housing companies) or a national building stock, as far as typological criteria are known [1]

2.2 FP7 Inspire

Initially, the project covered the assessment of building loads and architectural features and had the main objective to carry out a building stock survey for classification of the energy uses in the building sector over Europe. This profiling process led to the identification of primary types of reference buildings that could be standardised and developed into numerical models for simulation of energy performance of retrofit measures elaborated along with the project elaboration. Therefore, the iNSPiRe project generated initially an overview of the building stock over Europe, both residential and with respect to office buildings. The work was focused into three areas:

- Survey of the characteristics and regulations governing the existing building stock.
- Survey of the energy needs and comfort requirements of the existing building stock;
- Assessment of climatic conditions and RES availability;

The building stock analysis and data gathering exercise focused on published literature and other sources, with the aim of obtaining information about the current residential and office building stock. The types of information gathered included were:

- number and floor area of residential buildings/dwellings and office buildings
- typology
- age distribution
- construction by type and age
- façade and glazing types
- average floor area
- geometry
- number of floors
- U-value, thermal characteristic, and performance of the buildings, by age
- ownership and tenure i.e., number of social housing, owner occupied, private renting etc.
- energy consumption and demand in terms of both, total and individual end-use including space heating, domestic hot water, cooling, lighting; fuel and heating system types and comfort requirements.

The results from the building stock analysis included an EU-27 overview and country-by-country summary of:

- building typologies,
- age distribution,
- ownership profiles and
- energy use

within the residential and office buildings. It also described the reference and target buildings.

The supporting report covered policies that affect the retrofit of building and incentives that apply specifically to retrofit.

The dataset is part of an extensive survey covering databases (including Entranze, Tabula, BPIE, ODYSSEE, etc.) and single sources available in the open literature. The report presented information about the building stock in each country separately. All gathered data in terms of heating, cooling, domestic hot water (DHW), electricity demands, and consumptions have been included into a database.
Simulations were used so that the many gaps in the energy statistics could be filled, and the statistics could be critically evaluated. The data for the residential building stock was split into single family houses, small and large multifamily houses, while for offices the results were given for low- and high-rise offices with 6 or 12 office units per floor. The simulation models of such reference buildings were calibrated against the energy statistics and thus the simulation results are consistent with them. The energy consumption, per country and climatic region, was compared with the energy consumption and demand results generated from simulation using the reference buildings and appropriate input data.

The methodology resulted in a complete and consistent overview of the heating and cooling demand and consumption in residential and office buildings for seven different climate regions covering the whole of the EU and six different periods of construction, covering pre-1945 to post 2000 [2].

2.3 IEA/ECBCS Task50

The International Energy Agency (IEA) “Task 50: Advanced Lighting Solutions for Retrofitting Buildings” pursues the goal to accelerate retrofitting of daylighting and electric lighting solutions in the non-residential sector using cost - effective, best practice approaches. Their aim is to analyse the current distribution of the building stock in the non-residential sector in order to identify the most important building types. Another objective is to analyse the current average energy intensity for electric lighting for each building type as well as the characteristics of the existing lighting installations in these buildings [3].

The data used in their analysis is solely based on a review of available literature and data retrieved from:

- Building Performance Institute of Europe’s (BPIE) data hub;
- European projects (TABULA, DATAMINE, ENPER-EXIST, ETC);
- National documents (in original language) consulted by the experts involved in IEA Task 50.

Five building types should be given priority in IEA-Task 50 since they cover the largest floor space area:

- Offices,
- Educational buildings,
- Wholesale and retail trade,
- Industrial buildings,
- Agriculture buildings.

The first three building types each cover roughly 20-30% of the total floor area of the non-residential building sector. For industrial and agricultural buildings, the data is incomplete but when available, it indicates that these building types may cover a very large floor area, sometimes twice as large as the area covered by office buildings. Agriculture buildings could be excluded from the Task on the basis that these buildings mostly house animals and not human beings and thus entail different lighting issues and solutions.

Three other non-residential building types, which cover 2-10% of the total floor area, should be given a second priority within the IEA Task 50:

- Hotels and restaurants,
- Hospitals and healthcare,
- Sports buildings.

The following characteristics were further analysed per building types:

- Distribution of total floor area: percent of total floor area (%)
- Energy Intensity for electric lighting: average energy Intensity for lighting (kWh/m^{2}y)
- Typical electric lighting installations in existing buildings: fluorescent, CFL, Incandescent, halogen, LED, HID and other (%).

2.4 H2020 4RinEU

The technology development driven by 4RinEU has reached the goal of defining prototypes, and the first performance measurements are now available. Following these results, 4RinEU started the evaluation of the technologies by means of the building archetypes, with the definition of the deep renovation packages.

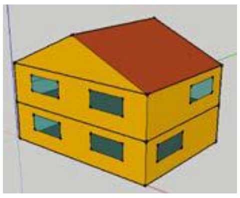
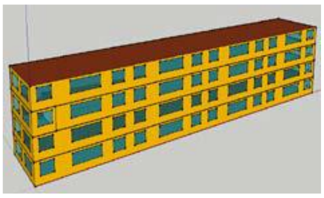
The building archetypes are representative of the building features of the European building stock. In particular, following the analysis by SINTEF, that selected 24 buildings from the DataTool of the Intelligent Energy Project TABULA, they identified 4 common geometries:

- envelope dimensions
- and opaque/transparent ratio

to be adopted as reference. Each geometry will be analysed in each Geo-Cluster, and the specific layers and building features are being implemented.

For each geo-cluster, four representative building archetypes in the respective reference country have been selected. The source for this selection was the national building typologies developed as part of the TABULA project (Institut Wohnen und Umwelt GmbH, 2018). All 4RinEU archetypes are selected among these example buildings. However, in order to keep the number of models manageable, four main geometries have been identified and used for the simulation in each geo-cluster (Table 1).

Table 1 Simulated geo-cluster geometries. Source: [4]

Building archetypes	Building characteristics
	Archetype: TERRACED HOUSE (TH) Lateral sides are set as ADIABATIC Reference floor area: 88 m^2 Floor Height: 2.8 m
	Archetype: SINGLE FAMILIY HOUSE (SFH) Reference Floor Area: 228 m^2 Floor Height: 2.5 m
	Archetype: APARTMENT BLOCK (AB) Reference Floor Area: 1330 m^2 Floor Height: 2.6 m
	Archetype: MULTIFAMILY HOUSE (MFH) Reference Floor Area: 3456 m^2 Floor Height: 2.8 m

In order to take into account, the climate conditions, the Heating Degree Days were adopted. For the building features:

- the amount of multi/single family houses,
- the construction period,
- the main used construction materials (source: FP7 project iNSPiRe),
- and the minimum value of thermal transmittance for new constructions and renovation.

Accordingly, the project 4RinEU adopts the following geo-clusters:

- Geo-cluster 1 | Northern

  Northern Europe countries with cold climate and prevalence of single-family houses – Demo-Case 1 in Norway.

- Geo-cluster 2 | North-East

Country with cold climate, large amount of multi-family houses built between 1960 and 1990, with prefabricated concrete panels that present low energy performance – Early Adopter building in Poland.

– Geo-cluster 3 | East

Continental climate, main building typology is single-family with a significant amount of multi-family houses built after the Second World War with prefabricated concrete structure – Early adopter building in Hungary.

– Geo-cluster 4 | Continental Central

This cluster includes central and West Europe. The building stock in the cluster is mainly composed by single-family houses and there is no prevailing construction period, thus the stock presents different construction features (masonry, concrete, or prefabricated structure) – Demo-Case 2 in the Netherlands.

– Geo-cluster 5 | Mediterranean

This cluster includes Mediterranean countries with warmer climate where the building stock is split almost equally in single and multi-family houses built in different construction periods mainly with masonry or concrete structures – Demo-Case 3 in Spain.

– Geo-cluster 6 | Atlantic

Focused on the UK area, with cold oceanic climate and single-family houses as the main building type – Early Adopter building in the UK.

The renovation packages are based on a set of technologies developed within the project: prefabricated wooden façade with the integration of PV, ST and ventilation devices, Plug&Play Energy Hub, comfort ceiling fans. 4RinEU results are combined with traditional technologies, completing the packages in order to fulfil the requirements in terms of energy saving. In particular, roof insulation, improvement of the efficiency of the heating plant, ground floor insulation and solutions to enhance the airtightness of the building.

Each renovation package is going to be evaluated through a set of Key Performance Indicators (KPIs), set as the outputs of the parametric study, dealing with five thematic areas: Energy, Environment, Comfort and Indoor Air Quality, Economic issues and building site management. In the following Table, the detailed list of evaluated KPIs is listed.

Table 2 Simulated geo-cluster geometries. Source: [5]

Topic and KPI name	Explanation
Energy	
Total heating demand	Yearly net energy demand for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"

Topic and KPI name	Explanation
Total cooling demand	Yearly net energy demand for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"
Heating demand per m^2	Yearly net energy demand for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Cooling demand per m^2	Yearly net energy demand for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Heating consumption [kWh/y]	Yearly final energy consumption for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Heating consumption [kWh/m^2/y]	Yearly final energy consumption for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Primary energy heating [kWh/y]	Yearly final energy consumption for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"
Primary energy heating [kWh/m^2/y]	Yearly primary energy consumption for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Cooling consumption [kWh/y]	Yearly final energy consumption for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"

Topic and KPI name	Explanation
Cooling consumption [kWh/m²/y]	Yearly final energy consumption for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
DHW demand kWh/year	Yearly energy demand for Domestic Hot Water production
Ventilation consumption [kWh/y]	Final Energy consumption for mechanical ventilation
Ceiling fan consumption [kWh/y]	Final energy consumption for the operation of the comfort ceiling fans
PV power produced [kW/y]	Yearly energy produced by the photovoltaic system (if installed during renovation)
Environment	
CO_2 emissions heating [kg/y]	Yearly CO_2 emissions for heating
CO2 emissions cooling [kg/y]	Yearly CO_2 emissions for cooling
Comfort & IAQ	
CAT_1_PPM [hours/year] (OPTIMAL)	Number of hours in comfort category I (EN ISO 15251) according to the CO_2 concentration calculated in a sample room - number of hours in optimal indoor air quality conditions
CAT_2_PPM [hours/year] (ACCEPTABLE)	Number of hours in comfort category II (EN ISO 15251) according to the CO_2 concentration calculated in a sample room - number of hours in acceptable indoor air quality conditions
CAT_I_Adpt [hours/year] (OPTIMAL)	Number of hours in comfort category I (EN ISO 15251) according to the indoor temperature and relative humidity conditions in summer period calculated in a sample room - number of hours in optimal thermal comfort conditions (evaluated in cooling period)

Topic and KPI name	Explanation
CAT_II_Adpt [hours/year] (ACCEPTABLE)	Number of hours in comfort category II (EN ISO 15251) according to the indoor temperature and relative humidity conditions in summer period calculated in a sample room – number of hours in acceptable thermal comfort conditions (evaluated in cooling period)
pmv_zone2_CatI [hours/year] (OPTIMAL)	Number of hours in comfort category I (EN ISO 15251) according to the Predicted Mean Vote of the occupants during winter period calculated in a sample room – number of hours in optimal thermal comfort conditions (evaluated in heating period)
pmv_zone2_CatII [hours/year] (ACCEPTABLE)	Number of hours in comfort category II (EN ISO 15251) according to the Predicted Mean Vote of the occupants during winter period calculated in a sample room – number of hours in acceptable thermal comfort conditions (evaluated in heating period)
Economic issues	
Total investment cost [€]	Investment costs related to technology and/or installation works and materials on building site – more details in Appendix B of Deliverable 4.2
Total investment cost, factor [€]	Investment costs related to technology and/or installation works and materials on building site; adjusted using a country-specific proportional cost factor – more details in Appendix B of Deliverable 4.2
Approximated LCC 50 years [€]	Life Cycle Cost of the building calculated for 50 years after renovation considering investment cost for the interventions, energy supply during operation and maintenance – more details in Appendix B of Deliverable 4.2
Approximated LCC 50 years, factor [€]	Life Cycle Cost of the building calculated for 50 years after renovation considering investment cost for the interventions, energy supply during operation and maintenance; adjusted using a country-specific proportional cost factor – more details in Appendix B of Deliverable 4.2

Topic and KPI name	Explanation
Building site management	
Time on building site [hours]	Number of hours needed for the installation of 4RinEU renovation packages - installation/mounting works – more details in Appendix B of Deliverable 4.2

The results of the simulation set will represent the result basis for the cost-effective rating tool [6].

2.5 H2020 MORE-CONNECT

The main goal of the MORE-CONNECT project was to develop a solution with respect to innovative, prefabricated building envelope elements for MOdular REtrofitting and smart CONNECTions. These building envelope elements contribute to the transformation of European housing towards near Energy Zero Buildings (nZEB). Point of departure is the assessment of European housing in order to determine which typologies are most suitable to be upgraded towards nZEB with prefabricated building envelope elements, i.e. a baseline assessment which determines which market segment MORE-CONNECT will focus on.

The problem considered in the project is that within the European housing sector a diversity of housing typologies can be found which are characteristic for a specific region (for example detached housing in the Netherlands) or relatively common throughout Europe (for example apartment buildings). Preliminary national and international studies already provided meaningful insights into housing typologies. The most important publication in this respect is the TABULA report (2012) which includes an assessment of the energy performance of the European housing stock. The assessment presented in the report has been built upon the Tabula report with respect to the generic building typology, the TABULA Typology Concept (Building Type Matrix). However, the TABULA report provides limited detailed information about the technological conditions of the building structure and the building envelope. This information is considered detrimental to the assessment of European housing in order to determine which housing typology is most suitable to upgrade to near energy zero applying prefabricated building envelope elements.

The "Housing typology Assessment report" includes the assessment of housing typology across Europe including Czech Republic, Denmark, Estonia, Latvia, Netherlands and Portugal (alphabetic order) based on national housing statistics. Next, based on pilot residential buildings included in the MORE-CONNECT project a detailed technical assessment will be presented. The results presented in the report are considered to be necessary to determine whether and how prefabricated nZEB retrofit elements can be applied concerning a specific building typology. These insights include in particular detailed information about:

- building geometrics,
- the structure of the building,
- and the configuration of the building envelope,

- including building service technology.

Based on these insights a decision-making tool (decision-making tree) has been developed which supports the assessment of housing in order to determine the applicability of the MORE-CONNECT retrofit concept.

The tool is designed to find the optimum configuration of a retrofit concept, from energy and cost perspective. The concept is always a 0- energy concept, that is: the demand, in any situation, is made 0 by adding as many PV panels as required to match demand [1].

2.6 PLURAL

PLURAL proposes an integrated “Plug-and-play” solution that takes into account user needs, which is hence named “Plug-and-Use” – PnU – kits. Key to achieving these goals is to understand how to select and integrate various renewable energy technologies from the many available, incorporate them in prefabricated façade components and optimise their performance for different building types, climates, and socio-economic conditions. Also, how to best manufacture them minimising energy use and material waste. All the above in the context of the BIM (Building information modelling) process.

PLURAL target the following objectives:

- Near zero energy consumption of buildings renovated with PnU kits
- Cost-effective renovation
- Fast-track renovation
- Environmentally- friendlier deep renovation
- Flexibility – Adaptability

The first analysis overviewed the State of Art regarding off-site prefabrication of the PLURAL all-in-one kits and related technologies and identified:

- the preliminary requirements of the PLURAL technologies and systems for off-site prefabrication,
- The idea is to develop three different solutions: "Smart Wall", "eWHC" (**e**xternal **W**all **H**eating and **C**ooling module) and "eAHC" (an air handling unit with **A**dvanced **H**eat/**C**ool recovery system).
- the most representative residential building typologies in European countries, which are strong candidates for the implementation of the PLURAL concept. To do so, building archetypes were prosposed with the objective to identify the most representative building typology within the existing building stock in each of the regions where buildings of the demo sites are located, aiming to estimate the potential replicability of PLURAL solutions. The conducted analysis is based on data available at TABULA web tool.
- In order to define the technical penetration of the PLURAL solutions in the European building stock (candidate buildings), a geo-cluster classification and building archetype selection were performed. Regarding the geo-cluster classification, the analysis led to six (6) main geo-clusters representing 36% of the territory with a total of 324 regions. Regarding the building archetype, the analysis led to the conclusion that the most frequent building typologies are

situated from 1946 until 1980, are multifamily houses with a range of 2 up to 9 floor levels. The above conclusions were combined with the advantages and limitations of the PLURAL's solutions in order to create a "map" of the applicability of the PLURAL solutions.

- the most relevant market segments and key target countries that the PLURAL all-in-one kits.
- Scrutinizing the European building renovation market led to the identification of the PLURAL solutions penetration potential, as well as their current drawbacks. The current conditions in the European renovation market are very favourable for the PLURAL PnU kits as the renovation in the residential sector is very high and the PLURAL solutions are in line with the new renovation strategy set by EU country governments. Based on the previous analysis, the market potential of PLURAL in Spain and Germany have been identified in more detail.

2.7 Conclusion

After analysing these previous experiences, all of them took TABULA project as a baseline 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 reference for some European directives.

3. Buildings characteristics affecting the design and installation of industrialized elements

After analysing the work carried out to date in this area of expertise, the first step in grouping the demand for industrialized renovation is to identify which building characteristics affect the design and installation of the precast elements.

3.1 Delphi Method

The identification of the building characteristics has been carried out using the Delphi Method. The Delphi method is a forecasting process framework based on the results of multiple rounds of questionnaires sent to a panel of experts. Several rounds of questionnaires are sent out to the group of experts, and the anonymous responses are aggregated and shared with the group after each round. The experts are allowed to adjust their answers in subsequent rounds, based on how they interpret the "group response" that has been provided to them. Since multiple rounds of questions are asked and the panel is told what the group thinks as a whole, the Delphi method seeks to reach the correct response through consensus [7]. An example of the procedure to be followed can be found in Figure 1.

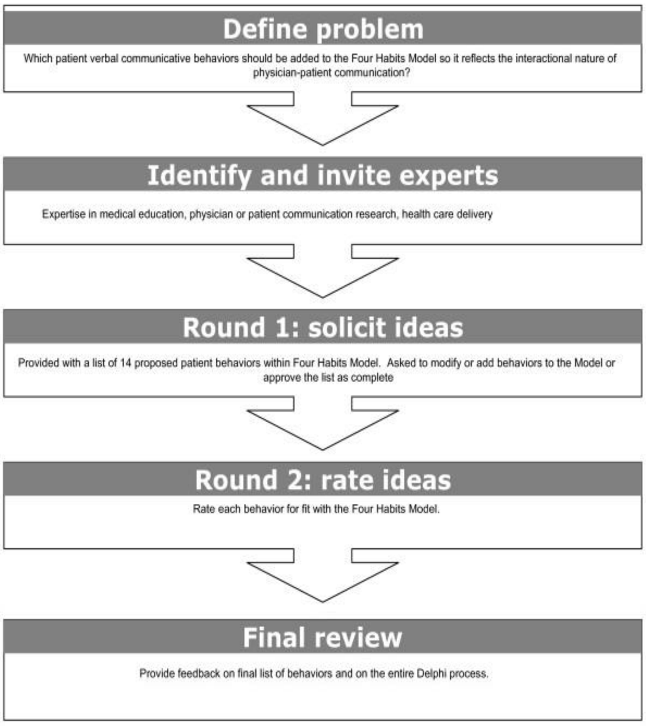


Figure 1 Example of Delphi Method application

The panel of experts has been constituted by those partners who participate in the design or exploitation of any of the 6 products involved in the INFINITE framework, as they are considered representative of the different industrialized solutions applicable to the field of building renovation.

3.1.1 Results of first round

A first round of the questionnaire was prepared to be answered online.

Partners were offered a list of the building parameters and they had to order them considering their opinion on which affected the design of the industrialised envelope kits on 1st, 2nd, 3rd, 4th, and 5th place. The summary of this first results is exposed in the following Figure:

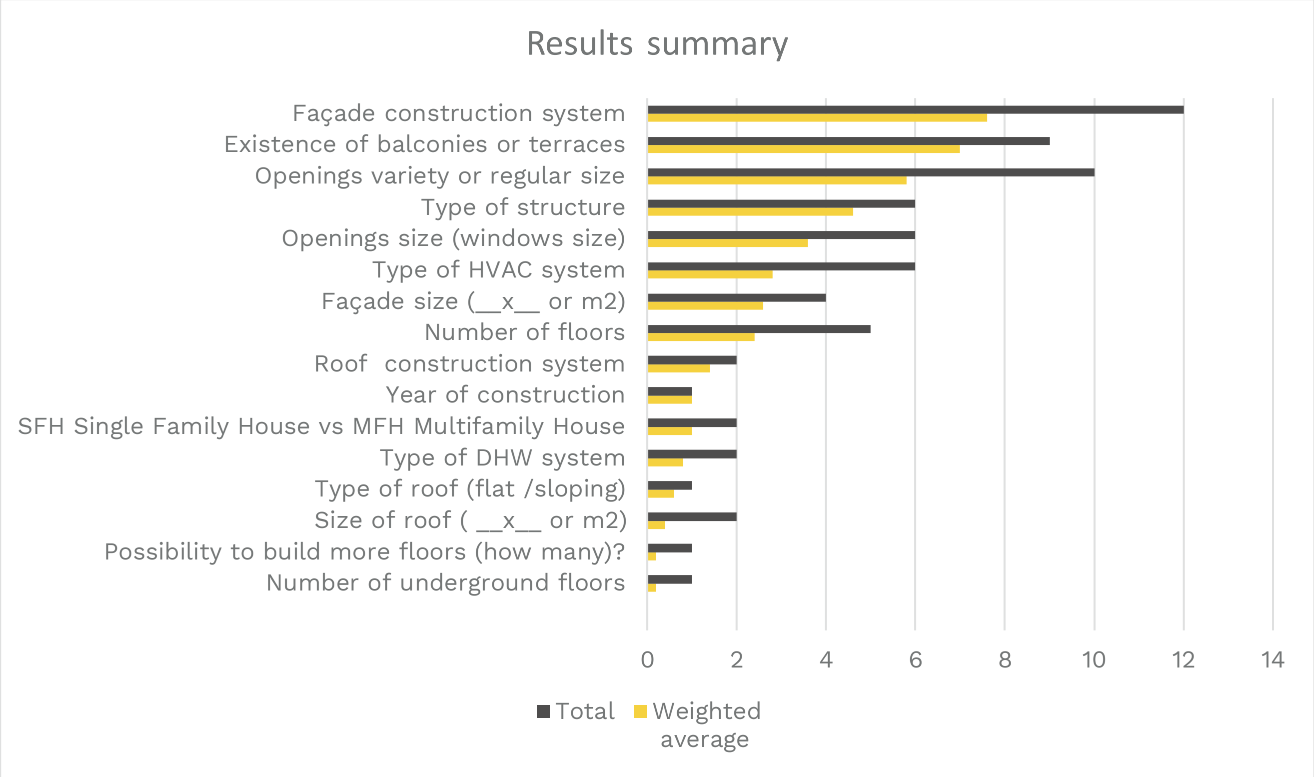


Figure 2 Summary of the results for the first round

To know what parameters (of the existing buildings) affect the design of the industrialised envelope kits, they could also add any important parameter not included previously in the list.

Table 3 Parameters proposed by the panel of experts in the 1st round

Rank	Parameter
1st / 2nd	• Size (m²) • Layout of rooms (living spaces, WC, blind premises, etc.) • Perimetral wall and openings layout (distribution)
2nd	• Height of the ceiling in each floor • Structural capacities of existing building components [i.e., reinforcement (deviations)]
3rd	• Geometric quality of existing building • Auto consumption (private or common) (onsite Renewable Energy Sources)

Rank	Parameter
4th	• Storage (thermal or electrical) • Reliability of geometry data
5th	• GDPR
Not positioned	• Fire regulation for façade material • Façade orientation • Possibility of adding cabling inside the building • Statics • Possibility of soil connection next to the façade • Cellar structure • Roof inventory (chimneys, attic, etc.) • Net- Size of the roof/wall • Type of external finish of the façade • The more regular the building, the better • The size of the technical room

During the INFINITE project kick-off meeting these results were exposed in a dedicated workshop with the panel of experts. It was exposed in the previous summary and the following results per solution.

The INFINITE results considered are:

- Process optimised all-in-one industrialised eco envelope kits and related physical interfaces, composed by:
  - Passive eco-compatible & green envelope kit
  - Energy and fresh air distribution envelope kit
  - Smart window kit
  - Energy generation BIPV kit
  - Energy generation BIST kit
- Adaptable BMS and optimized control strategies

3.1.1.1 Passive eco-compatible & green envelope kit

The first sub-result to be considered is the passive eco-compatible and green envelope kit (Figure 3).

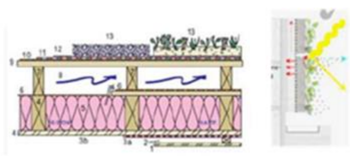


Figure 3 Passive eco-compatible and green envelope kit

The results of the first round of the questionnaire for this solution are summarised in the following Table:

Table 4 Ranking of parameters for the passive eco-compatible and green envelope kit. First round

Rank	Predefined parameters	Percentage of answers
1st	• **Type of structure** • **Façade construction system** • Number of floors • Year of construction	• **50%** • **17%** • 17% • 17%
2nd	• **Existence of balconies or terraces** • **Façade construction system** • Roof construction system • Openings variety or regular size	• **50%** • **17%** • 17% • 17%
3rd	• **Openings variety or regular size** • **Existence of balconies or terraces** • Façade construction system • Type of roof (flat /sloping)	• **33%** • **33%** • 17% • 17%
4th	• **Façade construction system** • Openings variety or regular size • Façade size (__x__ or m^2) • Type of HVAC system	• **33%** • 33% • 17% • 17%
5th	• **Façade construction system** • **Size of roof** • Openings size (windows size) • Possibility to build more floors	• **33%** • **17%** • 17% • 17%

In bold letters are marked the results that are coincident with the total results. It can be appreciated that there is not a uniform answer to consider only one parameter per position. Nevertheless, considering only the parameters with highest percentage for each position, the ranking would be as follows:

Table 5 Reduced ranking of parameters for the passive eco-compatible and green envelope kit

Rank	Predefined parameters
1st	• Type of structure
2nd	• Existence of balconies or terraces

Rank	Predefined parameters
3rd	• Openings variety or regular size • Existence of balconies or terraces
4th	• Façade construction system • Openings variety or regular size
5th	• Façade construction system

As exposed previously, the panel of experts could suggest other parameters that were not considered Initially.

Table 6 Additional parameters proposed for the passive eco-compatible and green envelope kit

Parameters
• Type of external finish of the façade • 2nd, Structural capacities of existing building components [i.e., reinforcement (deviations)] • Geometric quality of existing building / 3rd place • Fire regulation for façade material • Statics, possibility of soil connection next to the façade, cellar structure, roof inventory (chimneys, attic, etc.), net size of the roof/wall • The more regular the building, the better

3.1.1.2 Energy and fresh air distribution envelope kit

The second sub-result to be considered is the energy and fresh air distribution envelope kit (Figure 4).

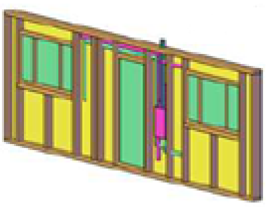


Figure 4 Energy and fresh air distribution envelope kit

The results of the first round of the questionnaire for this solution are summarised in the following Table:

Table 7 Ranking of parameters for the energy and fresh air distribution envelope kit. First round

Rank	Predefined parameters	Percentage of answers
1st	• **Type of structure** • **Façade construction system**	• **50%** • **50%**
2nd	• **Existence of balconies or terraces** • **Façade construction system**	• **50%** • **50%**
3rd	• Roof construction system • Type of HVAC system	• 50% • 50%
4th	• **Type of structure** • Number of floors	• **50%** • 50%
5th	• Number of underground floors • Type of DHW system	• 50% • 50%

In bold letters are marked the results that are coincident with the total results. It can be appreciated that there is not a unique answer to consider only one parameter per position, so further approaches will have to be carried out during the project.

The other parameters suggested by the panel of experts are:

Table 8 Additional parameters proposed for the energy and fresh air distribution envelope kit

Parameters
• The height of the ceiling in each floor, ranked 2nd • Sizes (m^2) and layout of rooms (living spaces, WC, blind premises, etc.) + perimetral wall and openings layout (distribution) >>> high rate, like 1st or 2nd.

3.1.1.3 Smart window kit

The third sub-result to be considered is the smart window kit (Figure 5).

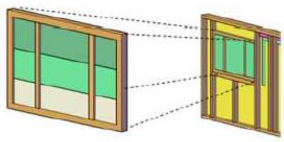


Figure 5 Smart window kit

The results of the first round of the questionnaire for this solution are summarised in the following Table:

Table 9 Ranking of parameters for the smart window kit. First round

Rank	Predefined parameters	Percentage of answers
1st	• **Façade construction system** • Openings size (windows size)	• **50%** • 50%
2nd	• **Existence of balconies or terraces** • **Façade construction system**	• **50%** • **50%**
3rd	• **Openings variety or regular size**	• **100%**
4th	• Openings size (windows size) • Façade size	• 50% • 50%
5th	• **Type of HVAC system** • **Size of roof**	• **50%** • **50%**

In bold letters are marked the results that are coincident with the total results. One more time, it can be appreciated that there is not a uniform answer to consider only one parameter per position.

In relation to other parameters suggested by the panel of experts, only two more were added:

Table 10 Additional parameters proposed for the smart window kit

Parameters
• Façade orientation • Possibility of adding cabling inside the building

3.1.1.4 Energy generation BIPV kit

The fourth sub-result to be considered is the energy generation BIPV kit (Figure 6).

Figure 6 Energy generation BIPV kit

The results of the first round of the questionnaire for this solution are summarised in the following Table:

Table 11 Ranking of parameters for the energy generation BIPV kit. First round

Rank	Predefined parameters
1st	• Openings variety or regular size
2nd	• Façade size
3rd	• **Openings size (windows size)**
4th	• **Façade construction system**
5th	• Type of structure

In bold letters are marked the results that are coincident with the total results. In this case, there was uniformity in the answers given that they were provided by one expert only.

Finally, further parameters were not suggested.

3.1.1.5 Energy generation BIST kit

The fifth sub-result to be considered is the energy generation BIST kit (Figure 7).

Figure 7 Energy generation BIST kit

The results of the first round of the questionnaire for this solution are summarised in the following Table:

Table 12 Ranking of parameters for the energy generation BIST kit. First round

Rank	Predefined parameters
1st	• Façade size
2nd	• **Existence of balconies or terraces**
3rd	• **Openings size (windows size)**
4th	• Type of HVAC system

Rank	Predefined parameters
5th	• Number of floors

In bold letters are marked the results that are coincident with the total results. In this case also, there was uniformity in the answers given that they were provided by one expert only.

Regarding other parameters suggested by the panel of experts, only one was added:

Table 13 Additional parameters proposed for the energy generation BIST kit

Parameters
• The size of the technical room

3.1.1.6 Adaptable BMS and optimized control strategies

The first sub-result to be considered is the adaptable BMS and optimized control strategies (Figure 8).

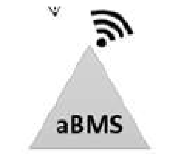


Figure 8 Adaptable BMS and optimized control strategies

The results of the first round of the questionnaire for this solution are summarised in the following Table:

Table 14 Ranking of parameters for the adaptable BMS and optimized control strategies. First round

Rank	Predefined parameters
1st	• Type of HVAC system
2nd	• **SFH Single Family House vs MFH Multi Family House**
3rd	• **Type of DHW system**
4th	• Number of floors
5th	• Openings variety or regular size

In bold letters are marked the results that are coincident with the total results. In this case also, there was uniformity in the answers given that they were provided by one expert only.

The other parameters suggested by the panel of experts are:

Table 15 Additional parameters proposed for the adaptable BMS and optimized control strategies

Parameters
• 3- Auto consumption (private or common) (onsite Renewable Energy Sources) • 4- Storage (thermal or electrical) • 5- GDPR

3.1.2 Results of second round

After the kick-off meeting, a series of online focused meetings took place. Each of these meetings were focused on each of the industrialized envelope products to better understand the different solutions. They enriched the processes, so with the feedback received, a second round of the questionnaire was sent to the panel of experts.

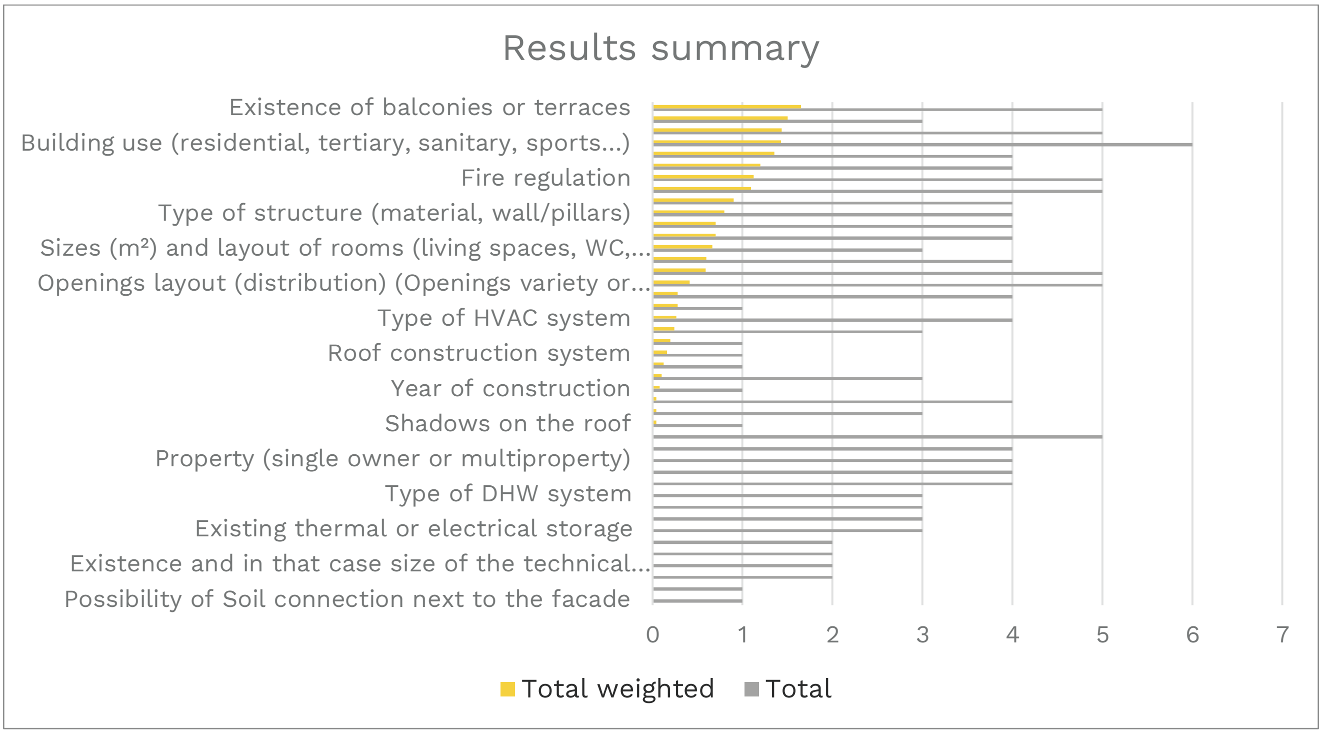


Figure 9 Summary of the results for the second round

To view in further detail, Figure 10 shows only the total weighted results.

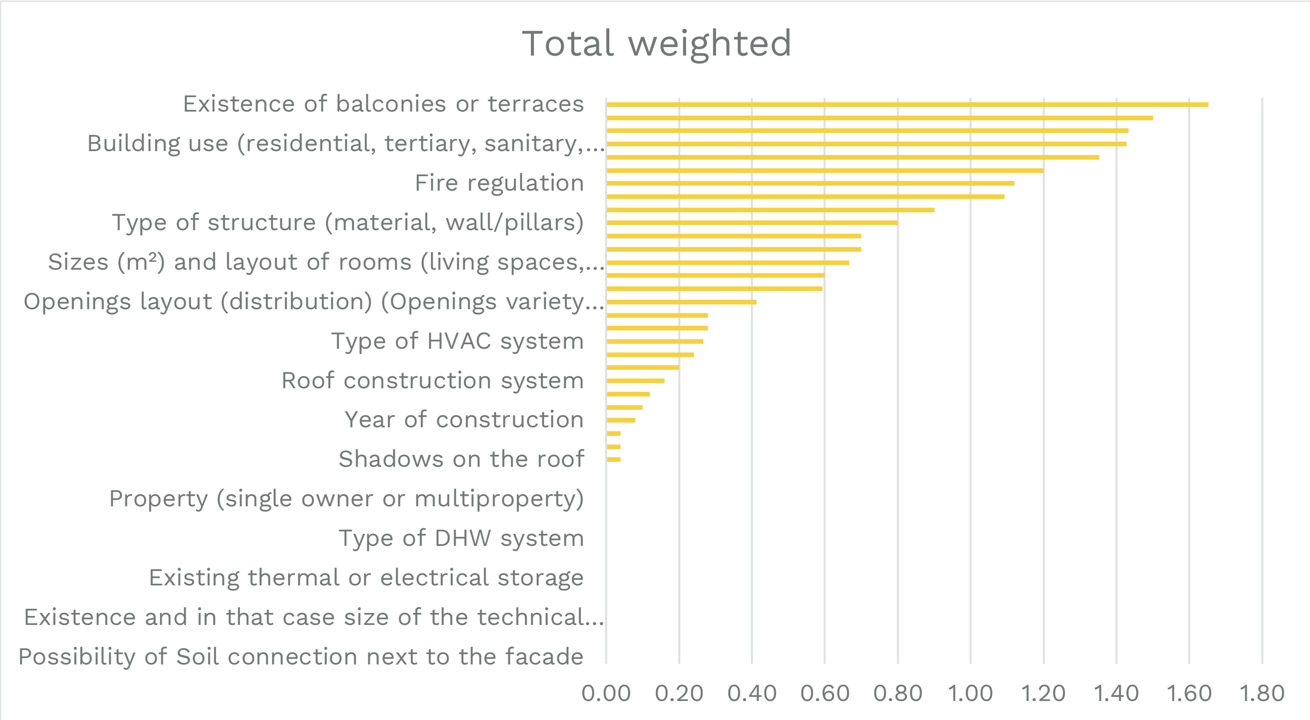


Figure 10 Total weighted results for the second round

In the following subsections, the results for each of the solutions are exposed.

3.1.2.1 Passive eco-compatible & green envelope kit

The results of the second round of the questionnaire for this solution are summarised in the following Table:

Table 16 Ranking of parameters for the passive eco-compatible and green envelope kit. Second Round

Rank	Predefined parameters	Percentage of answers
1st	• **Type of structure** (material, wall/pillars) • Size of roof (__x__ or m²) • Shadows on the façade • Façade colour restrictions	• **40%** • 20% • 20% • 20%
2nd	• **Roof construction system** • Type of roof (flat /sloping) • Openings size (windows size) • Façade size (__x__ or m²) • Building use (residential, tertiary, sanitary, sports...)	• **20%** • 20% • 20% • 20% • 20%

Rank	Predefined parameters	Percentage of answers
3rd	• Water use restrictions • Fire regulation • Façade orientation • **Façade construction system** • **Existence of balconies or terraces**	• 20% • 20% • 20% • **20%** • **20%**
4th	• Year of construction • Type of roof (flat /sloping) • Monumental protection of the building • **Openings layout** (distribution) (Openings variety or regular size) • **Façade construction system**	• 20% • 20% • 20% • **20%** • **20%**
5th	• Shadows on the roof • Possibility of crane access from the street • Presence of insulation • Type of external finish of the façade • Type of roof (flat /sloping)	• 20% • 20% • 20% • 20% • 20%

It can be appreciated that there is no uniform answer to consider the most important parameters ranked. Considering that in this round there are new parameters not included in the first round, the parameters that are coincident in position with the first round are marked in bold letters.

Furthermore, there are also parameters that are supposed to affect this solution but they have not been ranked. These type of parameters are summarised in the following list:

- Possibility of Soil connection next to the façade
- Possibility to build more floors
- Owned or rented homes
- Existing thermal or electrical storage
- Perimetral wall length
- Seismic legislation
- Existing Renewable Energies
- Free space between the façade and the façade of the opposite building
- Property (single owner or multi property)
- Structural capacities of existing building components [i.e. reinforcement(deviations)]
- The height of the ceiling in each floor
- Number of floors
- Building typology (SFH Single Family House / MFH Multi Family House)
- Energy sharing / energy community's legislation

3.1.2.2 Energy and fresh air distribution envelope kit

The results of the second round of the questionnaire for this solution are summarised in the following Table:

Table 17 Ranking of parameters for the energy and fresh air distribution envelope kit. Second round

Rank	Predefined parameters	Percentage of answers
1st	• **Façade construction system**	• **100%**
2nd	• Type of structure (material, wall/pillars) • **Existence of balconies or terraces**	• 50% • **50%**
3rd	• Sizes (m^2) and layout of rooms (living spaces, WC, blind premises, etc..)	• 50% • 50%
4th	• Openings layout (distribution) (Openings variety or regular size) • Individual or centralized heating/DHW	• 50% • 50%
5th	• Type of HVAC system • Openings size (windows size)	• 50% • 50%

Once again, it can be appreciated there is no uniform answer to consider the most important parameters ranked. Considering that in this round there are new parameters not included in the first round, the parameters that are coincident in position with the first round are marked in bold letters.

In addition, there are also parameters that are supposed to affect this solution but they have not been ranked. These type of parameters are summarised in the following list:

- Dwelling surface (m^2)
- Perimetral wall length
- Type of DHW system
- Property (single owner or multi property)
- The height of the ceiling in each floor
- Monumental protection of the building
- Façade size (__x__ or m^2)
- Fire regulation
- Building use (residential, tertiary, sanitary, sports…)

3.1.2.3 Smart window kit

The results of the second round of the questionnaire for this solution are summarised in the following Table:

Table 18 Ranking of parameters for the smart window kit. Second round

Rank	Predefined parameters	Percentage of answers
1st	• **Openings size (windows size)** • Façade size (__x__ or m²) • Shadows on the façade	• 33.3% • 33.3% • 33.3%
2nd	• Façade orientation • Shadows on the façade	• 66.7% • 33.3%
3rd	• Monumental protection of the building • Shadows on the façade • Building use (residential, tertiary, sanitary, sports...)	• 33.3% • 33.3% • 33.3%
4th	• Openings layout (distribution) (Openings variety or regular size) • Façade construction system • Existence of balconies or terraces	• 33.3% • 33.3% • 33.3%
5th	• **Type of HVAC system** • Sizes (m²) and layout of rooms (living spaces, WC, blind premises, etc..) • Building use (residential, tertiary, sanitary, sports...)	• 33.3% • 33.3% • 33.3%

Again, it can be appreciated there is no uniform answer to consider the most important parameters ranked. Considering that in this round there are new parameters not included in the first round, the parameters that are coincident in position with the first round are marked in bold letters.

Moreover, there are also parameters that are supposed to affect this solution but they have not been ranked. These type of parameters are summarised in the following list:

- Seismic legislation
- Existing Renewable Energies
- Free space between the façade and the façade of the opposite building
- Structural capacities of existing building components [i.e. reinforcement(deviations)]
- The height of the ceiling in each floor
- Possibility of crane access from the street
- Presence of insulation
- Status of the home's electrical network (circuit separation)
- Number of floors
- Individual or centralized heating/DHW
- Fire regulation

3.1.2.4 Energy generation BIPV kit

The results of the second round of the questionnaire for this solution are summarised in the following Table:

Table 19 Ranking of parameters for the energy generation BIPV kit. Second round

Rank	Predefined parameters	Percentage of answers
1st	• Energy sharing / energy community's legislation • Façade orientation	• 50% • 50%
2nd	• Fire regulation • Façade colour restrictions	• 50% • 50%
3rd	• Façade size (__x__ or m^2)	• 100%
4th	• Shadows on the façade • Façade orientation	• 50% • 50%
5th	• Façade construction system • Façade colour restrictions	• 50% • 50%

Again, it can be appreciated there is no uniform answer to consider the most important parameters ranked. Considering that in this round there are new parameters not included in the first round, any parameters are coincident in position with the first round.

Besides, there are also parameters that are supposed to affect this solution, but they have not been ranked. These types of parameters are summarised in the following list:

- Existence and in that case size of the technical room
- Existing thermal or electrical storage
- Perimetral wall length
- Type of DHW system
- Existing Renewable Energies
- Free space between the façade and the façade of the opposite building
- Property (single owner or multi property)
- Structural capacities of existing building components [i.e. reinforcement(deviations)]
- The height of the ceiling in each floor
- Presence of insulation
- Status of the home's electrical network (circuit separation)
- Type of external finish of the façade
- Type of HVAC system
- Monumental protection of the building
- Openings layout (distribution) (Openings variety or regular size)

- Openings size (windows size)
- Building typology (SFH Single Family House / MFH Multi Family House)
- Type of structure (material, wall/pillars)
- Individual or centralized heating/DHW
- Building use (residential, tertiary, sanitary, sports...)
- Existence of balconies or terraces

3.1.2.5 Energy generation BIST kit

The results of the second round of the questionnaire for this solution are summarised in the following Table:

Table 20 Ranking of parameters for the energy generation BIST kit. Second round

Rank	Predefined parameters
1st	• Existence of balconies or terraces
2nd	• Façade colour restrictions
3rd	• Fire regulation
4th	• Number of floors
5th	• Type of external finish of the façade

In this case also, there was uniformity in the answers given that they were provided by one expert only. Considering that in this round there are new parameters not included in the first round, any parameters are coincident in position with the first round.

Furthermore, there are also parameters that are supposed to affect this solution, but they have not been ranked. These types of parameters are summarised in the following list:

- Existence and in that case size of the technical room
- Number of underground floors
- Seismic legislation
- Free space between the façade and the façade of the opposite building
- Structural capacities of existing building components [i.e. reinforcement (deviations)]
- Possibility of crane access from the street
- Presence of insulation
- Openings layout (distribution) (Openings variety or regular size)
- Openings size (windows size)
- Building typology (SFH Single Family House / MFH Multi Family House)
- Energy sharing / energy community's legislation
- Type of structure (material, wall/pillars)

- Façade size (__x__ or m²)
- Shadows on the façade
- Façade orientation
- Building use (residential, tertiary, sanitary, sports...)
- Façade construction system

3.1.2.6 Adaptable BMS and optimized control strategies

The results of the second round of the questionnaire for this solution are summarised in the following Table:

Table 21 Ranking of parameters for the adaptable BMS and optimized control strategies. Second round

Rank	Predefined parameters	Percentage of answers
1st	• Building use (residential, tertiary, sanitary, sports...)	• 100%
2nd	• **Building typology** (SFH Single Family House / MFH Multi Family House) • Individual or centralized heating/DHW	• 50% • 50%
3rd	• Building typology (SFH Single Family House / MFH Multi Family House) • Individual or centralized heating/DHW	• 50% • 50%
4th	• **Number of floors** • Energy sharing / energy community's legislation	• 50% • 50%
5th	• Status of the home's electrical network (circuit separation) • Type of HVAC system	• 50% • 50%

Again, it can be appreciated there is no uniform answer to consider the most important parameters ranked. Considering that in this round there are new parameters not included in the first round, the parameters that are coincident in position with the first round are marked in bold letters.

Finally, the parameters that are supposed to affect this solution but they have not been ranked are summarised in the following list:

- Dwelling surface (m²)
- Number of underground floors
- Owned or rented homes
- Existing thermal or electrical storage
- Type of DHW system
- Existing Renewable Energies
- Property (single owner or multi property)
- The height of the ceiling in each floor

- Status of the home's electrical network (circuit separation)
- Sizes (m^2) and layout of rooms (living spaces, WC, blind premises, etc..)

3.2 Other parameters apart from the building characteristics to be considered

In addition to the characteristics inherent to the building itself, there are other parameters that can affect the design and implementation of industrialized solutions that could be included as part of a demand grouping system. In the results of the Delphi Method, as can be seen in the previous section, characteristics that are not data referring to the buildings or their immediate surroundings have been selected, but to the conditions in their design or renovation that will be considered in subsequent analysis, such as the use made of the building, the property system, or the legislation at different scales (local, regional, national, and European) that must be met.

4. Definition and classification of the building stock features

4.1 List of the building stock features

Based on the results of the Delphi method, the characteristics selected by the panel of experts have been classified in the following items, presented in the order of importance given by the panel of experts:

Physical building characteristics specific to each building

- 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 or dwellings Inside

- Sizes (m^2) and layout of rooms (living spaces, WC, blind premises, etc.)
- Status of the home's electrical network (circuit separation)
- Dwelling surface (m^2)

Characteristics related to how the building relates to its surroundings

- 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

Legislation affecting the building

- Façade colour restrictions
- Fire regulation
- Energy sharing / energy community's legislation
- Monumental protection of the building
- Water use restrictions
- Seismic legislation
- Possibility to build more floors

Characteristics of the building related to its use and ownership

- Building use (residential, tertiary, sanitary, sports...)
- Property (single owner or multi property)
- Owned or rented homes

4.2 Delphi method conclusions

Due to the type of characteristics highlighted by the panel of experts who collaborated in the study presented in previous sections, as well as to the dispersion in relation to the importance of each parameter among the different products studied, it is impossible to represent the information in a matrix format, being the matrix, the format thought as the best one before carrying out the analysis.

Based on the results obtained, three strategies have been designed to present the data obtained in a useful way for the work of the linked WPs.

On the one hand, given that the information collected includes those characteristics of the buildings and their surroundings that influence industrialized renovation systems, it is proposed to develop a decision-making aid tool (section 5) aimed at future clients that consists of an itinerary of questions that leads to an orientation regarding the type of system that is most suitable for each client, as a connection of WP2 and WP3. Figure 11 shows an example of a simple decision tree designed for deep energy refurbishment.

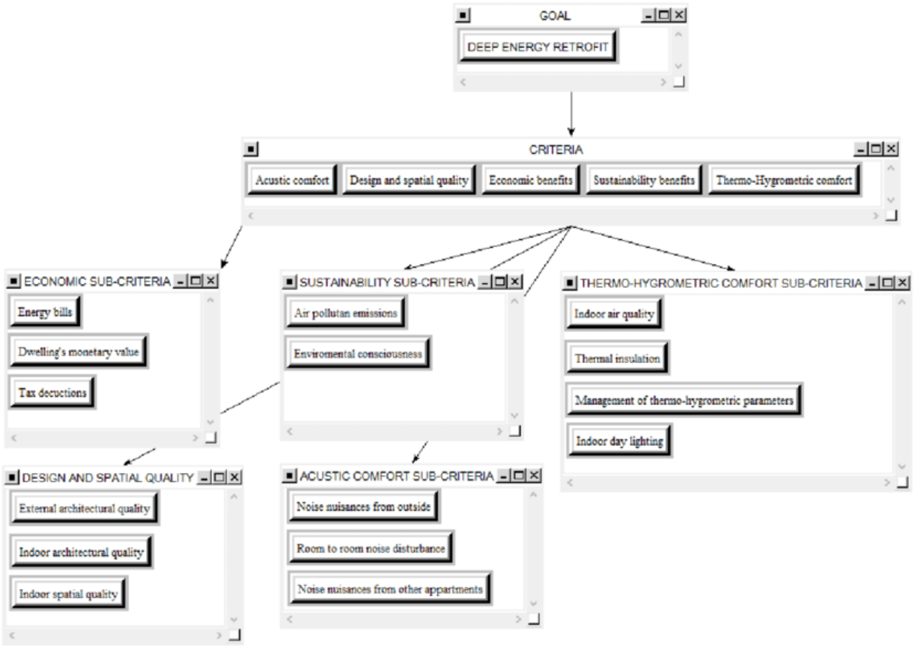


Figure 11 Decision tree of deep energy refurbishment implemented in the Super Decision software [8]

On the other hand, optimal archetypes have been defined for each of the kits proposed in the project. The aim of defining these archetypes is not to limit the use of the different kits to that single combination of parameters, but to establish a typical or ideal building for each of them (section 6).

Third, it is concluded that the representation of the different characteristics on a map using GIS technology is more adequate allowing the incorporation of the data at different scales. This conclusion is linked to task 5.3 to be undertaken within the framework of the INFINITE project which consists of the development of an interactive market potential map (R4.1) where the demand and the offer will be connected. In this regard, each of the characteristics identified are analysed in the context of T2.1 to figure out if it is possible to obtain such data at European or national level from dynamic and official sources to make incorporating such information in a GIS map feasible (section 7.2).

This demand-side mapping has been able also to provide input for the definition of the user-centred approach and the development drivers (T2.2, T2.3, T2.4), through the organization of thematic meetings with the different product providers as part of the Delphi Method process.

Finally, this Task will strongly interact with the real and virtual demo case activities (T6.1, T6.2, T6.3, T6.4) exchanging methodologies and information, iterating the analyses thanks to the INFINITE demo building experiences.

5. Decision-making aid tool

As concluded in the previous point, the development of a decision-making tool is proposed as a useful result linked to WP3 to help the demand side (users and designers) to figure out if INFINITE products are feasible for their specific situation.

The parameters identified per kit in the Delphi method will be used as a starting point.

It will be named Decision tree tool and its main objective is to be able to indicate to anyone who answers a few questions if INFINITE kits/solutions are applicable to their specific building/dwelling.

5.1 Technical questionnaires: Question and answers (Q&A)

To design the decision tree tool, a questionnaire was proposed among the industrial partners/technical providers to identify the feasibility of their solution based on the different parameters studied, to find out under what circumstances their solution would not be viable. An example for that would be a building located in an area with restrictions on the use of water. If the amount of water allowed per day were less than that necessary to maintain, for example, a green envelope, this kit would not be feasible. Another example would be the case that a façade of the building was culturally protected. In this case, for any kit that would affect that façade, it would be necessary to check the cultural legislation of the location/region to see its viability.

The steps followed to do the draft version of the tool were the following ones:

- Analysis of the parameters listed in the two previous rounds of the delphi method and elaboration of a set of questions to obtain the key information.
- Preparation of specific technical questionnaires for each kit, selecting the key questions based on the conclusions of the Delphi method.
- Specific technical questionnaires per kit and adjusted to the features of each technical system were proposed among the industrial partners/technical providers to identify the feasibility of their solutions based on the different parameters studied previously, to find out under what circumstances their solution would not be viable.

5.2 Base draft version of decision tree tool

The objective of the draft is to see what the limiting parameters and the key questions are to discard the different options in a way that shows the reality of the viable systems/kits for each specific situation.

Through a set of questions, it will show to the user which of the systems would be possible to install in their home / building / premises and put her or him in contact with suppliers / manufacturers for subsequent installation and sale.

For the development of the draft, the information needed was obtained from the answers to the questionnaires of the previous section and following the next steps:

- Analysis of the answers to better understand each of the kits and identification of the limiting parameters that prevent the viability of the system.

- Development of the draft of the tool in excel format, taking into account all the previous points.
- Sending the draft to partners for supervision and later correction of errors based on their comments.

After all the above process, tool information will be integrated into the project's web/platform in the best way that the programmers decide and a new image will be given, so that it is as simple and friendly for the users who visit it to use. This draft will be used just as a basis or starting point for programmers to adapt it.

This version is intended for end users (owners, investors, designers...etc), hence the type and specification of the questions and a language that is as simple and understandable as possible.

The draft is provided in excel format. The way to use it is to answer the questions following strictly the order proposed (from the top to the bottom), as depending on the choice, some of the questions disappear.

After answering all the questions, the possible kits to be installed are shown.

This draft is a first version that will be updated during the next months based on the needs of the project. The current image and configuration are included below.

Figure 12 show the first tool layout (not its final interface) . It represents a draft of the way of working and evaluating the different combinations and formulations of the final tool.

SEQUENCE	QUESTIONS TO BE ASKED TO THE USERS (e.g.: final users)	PLEASE, SELECT AN OPTION PER QUESTION FOLLOWING STRICTLY THE SEQUENCE ORDER (ELSE, PRESS RESTART)	RESTART
FIRST	Is it residential use or another type of use: commercial, administrative, educational...?		
.	What type of user are you?		
.	What type of user are you?		
.	Are you authorized to intervene only on the façade or roof of your dwelling / premises?		
.	Does the building have any kind of patrimonial / cultural protection?		
.	Does the sun affect your facade during the day? (e.g.: rays of sun enter through the		
.	Does the sun shine on your roof / deck during the day? (e.g.: rays of sun hit directly the		
.	Are there restrictions on the use of water in your area? (e.g.: limited use of litres per day)		
.	Do you have space to bury a cistern to collect rainwater on your property?		
.	What is the approximate area of non-protected facade? (Area without any cultural		
.	Do you have individual installations in your home / premises?		
.	Can you independently measure the consumptions of each dwelling / premises and the		
.	Do you have Internet installation (Wi-fi connection) and/or do you agree to install a separate connection (new router, sim card...) to collect data?		
.	Do you have a 1.2 m x 1.2 m space under the windows? (In the areas without any cultural		
.	Do you have a balcony / terrace or similar space?		
LAST	Do you have enough space to place machines (e.g. inverter, heat pump for solar panels, tank..)? (around 4-5 sqm in a technical room or so)		

CODE	EMS THAT ARE FEASIBLE TO BE INSTALLED TAKING INTO ACCOUNT THE INFORMATION PROV	SPECIFIC COMMENTS TO BE TAKEN INTO ACCOUNT
R0	WOOD FRAME STRUCTURE	
R2.1	PASSIVE ECO-COMPATIBLE & GREEN ENVELOPE KIT	
A	GREEN FAÇADE	
B	GREEN ROOF	
R2.2	ENERGY AND FRESH AIR DISTRIBUTION ENVELOPE KIT	
R2.3	SMART WINDOW KIT	
R2.4	ENERGY GENERATION BIPV KIT	
R2.5	ENERGY GENERATION BIST KIT	
R3	ADAPTABLE BMS AND OPTIMIZED CONTROL STRATEGIES	
A	INDIVIDUAL DWELLING / PREMISES LEVEL	
B	BUILDING LEVEL	

GENERAL COMMENTS TO BE TAKEN INTO ACCOUNT
NATIONAL / LOCAL FIRE and SEISMIC LEGISLATION must

Figure 12 Decision tree tool layout

6. Archetypes

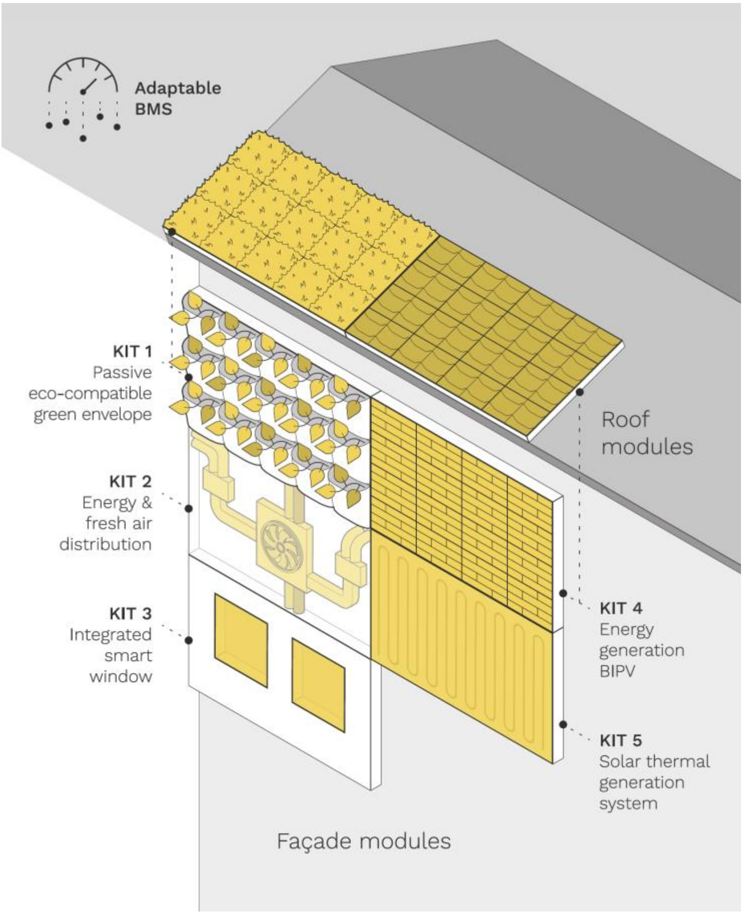
In terms of supporting the kits development in the following Work Packages and as part of the conclusion of the answers to the questionnaires, the definition of archetypes is considered useful and essential.

The aim of defining these archetypes is not to limit the use of the different kits to that single combination of parameters, but to establish a typical or ideal building for each of them.

Therefore, there will be other possible combinations, but without being so optimal for the installation of each one of the kits.

6.1 INFINITE full renovation

This would be the combination, after all the previous analysis and responses from the partners, that would allow, a priori, an optimal installation of all the kits developed at INFINITE.



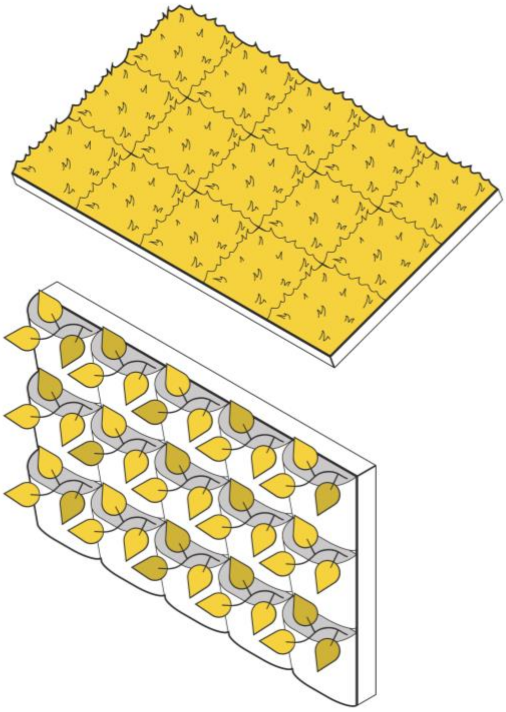
KIT
INFINITE FULL RENOVATION
Type of use
Residential
Type of user
Owner / representative of a building
Cultural Protection
No
Façade area
> 1000 sqm
Incidence of the sun
Yes
Water restrictions
No
Centralized installations
Yes
Internet connection
Yes
Space under windows
Yes
Technical room
Yes

Figure 13 Building parameters that allows the renovation with all INFINITE kits

6.2 Passive eco-compatible & green envelope kit

In order to install the green envelope, the following combination of factors would be required.

For their installation separately, green roof or green façade, the optimal combination would be the same as for the installation of both in the building.

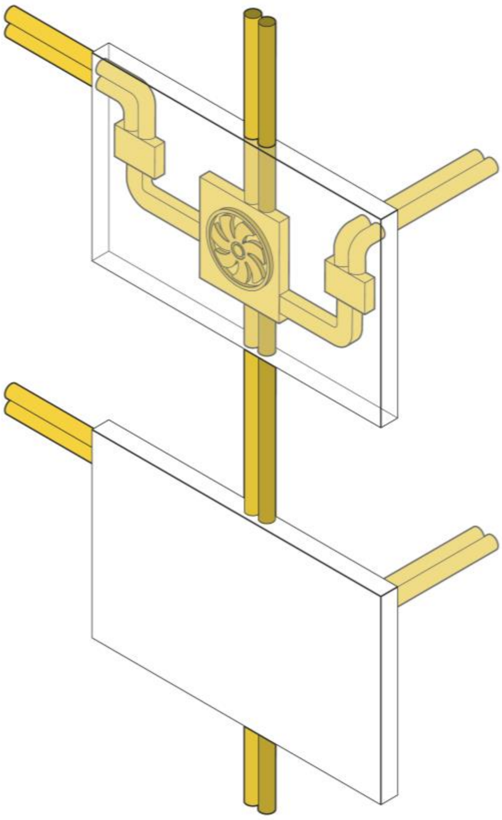


KIT
PASSIVE ECO-COMPATIBLE & GREEN ENVELOPE
Type of use
Residential
Type of user
Owner / representative of a building
Cultural Protection
No
Façade area
> 30-40 sqm
Incidence of the sun
Yes
Water restrictions
No
Centralized installations
No
Internet connection
No
Space under windows
No
Technical room
No

Figure 14 Building parameters that allows the renovation with the passive eco-compatible and green envelope kit

6.3 Energy & fresh air distribution envelope kit

In this case, the optimal parameters for the installation would be those indicated below.

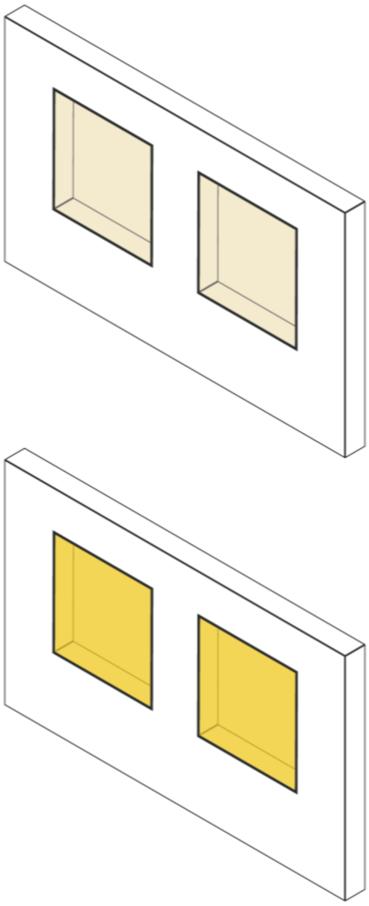


KIT
ENERGY AND FRESH AIR DISTRIBUTION ENVELOPE
Type of use
Residential
Type of user
Owner / representative of a building
Cultural Protection
No
Façade area
> 30-40 sqm
Incidence of the sun
No
Water restrictions
n/a
Centralized installations
Yes
Internet connection
No
Space under windows
Yes
Technical room
No

Figure 15 Building parameters that allows the renovation with the energy and fresh air distribution envelope kit

6.4 Smart Window kit

If the installation of this kit were chosen, the best combination of necessary parameters would be the one we see below.

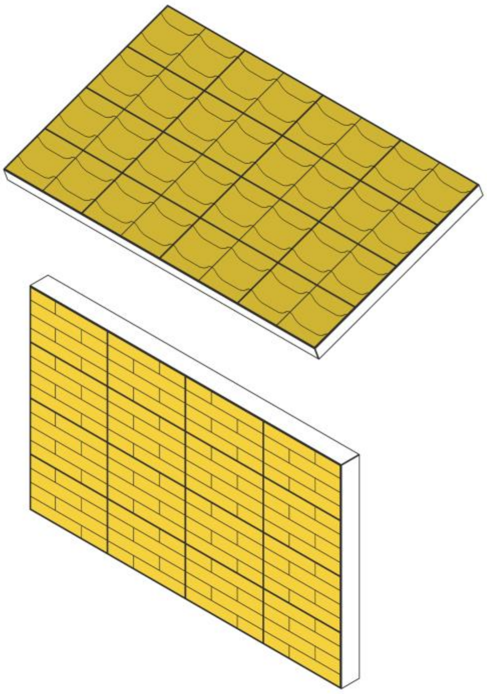


KIT
SMART WINDOW
Type of use
Residential
Type of user
Owner / representative of a building
Cultural Protection
No
Façade area
> 30-40 sqm
Incidence of the sun
Yes
Water restrictions
n/a
Centralized installations
No
Internet connection
Yes
Space under windows
No
Technical room
No

Figure 16 Building parameters that allows the renovation with the smart window kit

6.5 Energy generation BIPV kit

For the correct operation of this kit, the ideal would be to have a building with the following characteristics.

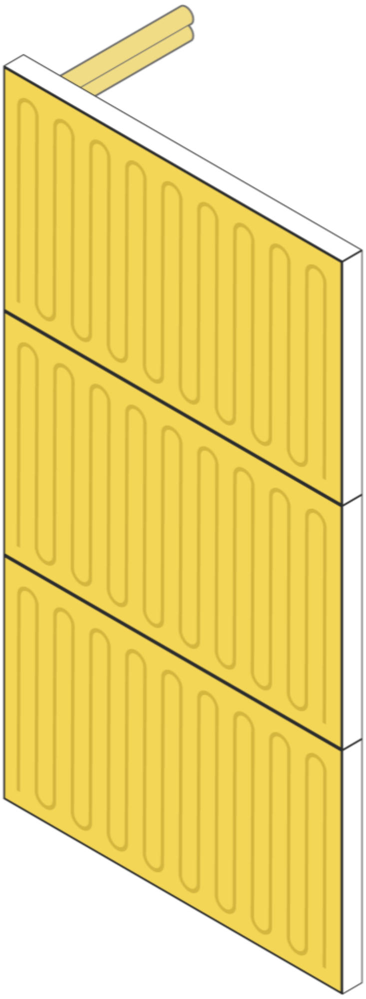


KIT
ENERGY GENERATION BIPV
Type of use
Residential
Type of user
Owner / representative of a building
Cultural Protection
No
Façade area
> 30-40 sqm
Incidence of the sun
Yes
Water restrictions
n/a
Centralized installations
Yes
Internet connection
Yes
Space under windows
No
Technical room
Yes

Figure 17 Building parameters that allows the renovation with the energy generation BIPV kit

6.6 Energy generation BIST kit

The best combination of features for the installation of this solar-thermal generation kit would be the one in the chart.

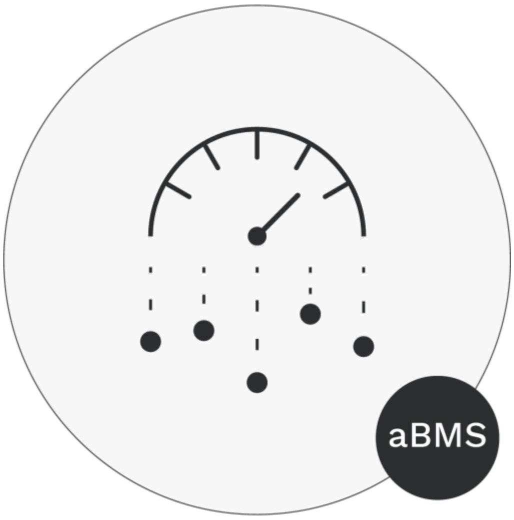


KIT
ENERGY GENERATION BIST
Type of use
Residential
Type of user
Owner / representative of a building
Cultural Protection
No
Façade area
> 30-40 sqm
Incidence of the sun
Yes
Water restrictions
n/a
Centralized installations
Yes
Internet connection
Yes
Space under windows
No
Technical room
Yes

Figure 18 Building parameters that allows the renovation with the energy generation BIST kit

6.7 Adaptable BMS (aBMS) and optimized control strategies

The optimal building for the installation of this kit would be defined below.



KIT
ADAPTABLE BMS
Type of use
Residential
Type of user
Owner / representative of a building
Cultural Protection
No
Façade area
> 30-40 sqm
Incidence of the sun
No
Water restrictions
No
Centralized installations
Yes
Internet connection
Yes
Space under windows
No
Technical room
No

Figure 19 Building parameters that allows the renovation with the aBMS

7. Collection of available information of the selected parameters

This section makes a brief introduction to the current situation of industrialization in the construction sector in Europe and explains the process of collecting the data available on the selected parameters for the development of an interactive map (T5.3). Furthermore, the data on regulations and the profile of the users, which due to their special relevance, will be developed in specific sections.

7.1 Current situation of industrialization in the construction sector in Europe

Industrialized construction initially emerged as an attempt to reduce costs and increase the speed of construction. The main strategy was to transfer a part of the construction process to the industries, and there, with more controllable conditions, to try processes of repetition, modularity, integration, standardization, and optimization.

Its general development can be placed after the Second World War, when the reconstruction of cities was necessary. It was necessary to build quickly and cheaply since there was a need for housing and economic resources were depleted in most countries by the conflict.

Prefabricated construction spread throughout Europe, but with more intensity in the most industrialized countries or in the eastern countries, and with less implantation in the warmer, less industrialized countries, and with greater cultural and historical load. As a result, a strong prefabricated construction industry was created in northern European countries, while in southern Europe, it made little progress.

Even though current technology allows all types of buildings to be made, with the highest quality, low price, and with any type of design, their implementation is being slow. The reason for this stagnation has been due, fundamentally, to social rejection.

This social rejection has a double origin. On the one hand, after the fall of the pre-war political regimes, prefabricated houses continued to be built in eastern European countries. These prefabricated houses despite having good quality, citizens associated them with the shortcomings of the previous regime.

On the other hand, the first prefabricated houses built were small, of poor quality, and with a barracks-like appearance, or similar, most of which were completely lacking in infrastructure. For this reason, the houses became simple sleeping spaces. The appearance of these buildings quickly became associated with the concept of “prefabricated housing”. For this reason, despite the enormous evolution and formal wealth of current prefabricated building systems, some citizens continue to have the same original perception of prefabricated construction.

Despite the above, we have seen that over the last five years, Europe has become a field of experimentation in which common concepts are often pushed to the limit to solve new construction challenges.

Technology has evolved a lot, and therefore prefabrication systems currently allow almost any type of building to be made, but in a cheaper, faster, and more ecological way.

The possibility of repeating production processes allows to promote the specialization of the workforce, and to adopt methods of mass production. For this reason, work on site can be gradually replaced by more effective mechanical operations carried out at the factories. This enables optimal construction results to be obtained, at times appropriate to the needs of construction programs, and in a work environment with more controllable working conditions for the workforce.

The components that come out of these production lines are taken directly to the construction site, and through a systematized assembly appropriate to the characteristics of each construction system, a final product of rapid execution is achieved, and with a good level of quality.

Today, completely flexible prefabricated systems are built, which can adapt to most building typologies, with an infinity of designs and finishes, which together with the evolution of technology, for example 3D printers or methodology BIM, allow us to develop any component of the building in the factory and then take it to work and install it, having evaluated, and corrected possible contingencies and followed a rigorous prior quality control.

However, despite this rapid technological advance, society continues to have a poor perception of prefabricated construction, which hinders its development and widespread implementation.

For this reason, looking ahead, it is important that unique examples of prefabricated architecture are disseminated as widely as possible. In this way, society will be able to realize that the results can be very attractive, functional, comfortable, and flexible, economical, fast, and sustainable. And as a result, it will stop hindering the development of the huge and attractive possibilities of prefab architecture [9].

Southern Europe vs Northern Europe and Eastern Europe

In general terms, there is a notable difference between the southern part of Europe and the northern part, including the east.

In the northern areas, the weather is more hostile, which in many cases forces to reduce the concreting in situ, such as Sweden or Finland, which makes us tend to use other types of construction systems that are more viable with the low temperatures.

Moreover, there is a culture of caring for the forest heritage and the environment and there are support measures in stable R&D by the administrations, such as the promotion of houses built with wood as a state policy in Finland, as an example [10].

In these areas, due in part to the evolution of technology and automation in wood production chains, there is a predominance of production of single-family houses in wood, built based on three-dimensional or modular elements. To cite one example, the BoKlok homes, emerged from the collaboration between IKEA and the construction company SKANSA, mainly distributed in Sweden, Norway, Finland, and the United Kingdom [11].

On the other hand, in southern European countries, with a lower degree of industrialization of the housing sector and with a stronger cultural and historical burden of traditional construction and life models in which purchase prevails over rent, experiences with industrialized systems have been rare.

Also, in general, it can be said that northern Europe tends to register more rainfall during the year and, on the other hand, fewer sunny days, unlike in the south. This directly affects the viability of some systems such as the green envelope, which can be impaired by water restrictions, or the installation of solar systems, such as BIST or BIPV kits, which will be more profitable the more days of sunshine per year they have.

7.2 Interactive map database

Based on the Delphi method result and on the needs of other Work Packages, it was agreed at consortium level to collect the information from the parameters which characterize the demand side of INFINITE products in a table format so that it can be used in an easy way for the related tasks.

So, in this section, the objective was to collect all the available data from each of the parameters at national level for all European countries.

7.2.1 Identification of sources

First step was the search and identification of different sources at European level to be able to get as much data as possible.

To achieve the above, a collaboration between INFINITE, BuiltHub (Dynamic EU building stock knowledge hub) and re-MODULEES (Flexible building renovation shared solutions) projects was set to share data bases where to find the information needed.

The final list of data sources identified were the following ones:

1. Horizon 2020 HotMaps project: Building stock analysis [12].
2. IEE TABULA project: Typology Approach for Building Stock Energy Assessment [13].
3. IEE EPISCOPE project: Focus of building stock monitoring [13].
4. IEE ZEBRA2020 project: Nearly Zero-Energy Building Strategy 2020 [14].
5. IEE ENTRANZE project: Policies to Enforce the TRAnsition to Nearly Zero Energy buildings in the EU27 [15].
6. H2020 ODYSSEE - MURE project: Comprehensive monitoring of efficiency trends and policy evaluation in the EU [16].
7. FP7 CommONEnergy Project: building stock [17].
8. JRC IDEES 2015 [18].
9. SET-Nav - Strategic Energy Roadmap [19].
10. H2020 ExcEED Project: building stock data [20].
11. FP7 iNSPiRe project: building stock analysis [21].
12. Energy consumption and energy efficiency trends in the EU-27+UK for the period 2000-2016 - FINAL REPORT [22].
13. Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU - FINAL REPORT [23].
14. EUROSTAT: Final energy consumption in households [24].
15. EUROSTAT: Final energy consumption in households by fuel [25].

16. EUROSTAT: Disaggregated final energy consumption in households [26].
17. ZENSUS 2011 [27].
18. DPE - Diagnostic de Performance Energetique [28].
19. Towards a sustainable Northern European housing stock - Sustainable Urban Areas 22 [29].
20. DEEP - De-risking Energy Efficiency Platform [30].
21. Energy consumption and efficiency technology measures in European non-residential buildings [31].
22. Dataset of the publication: Europe's Building Stock and Its Energy Demand: A Comparison Between Austria and Italy [32].
23. National Housing Census: European Statistical System [33].
24. Energy prices in 2019-Household energy prices in the EU [34].
25. EUROSTAT: GDP per capita in PPS [35].
26. EUROSTAT: Population on 1 January by age, sex and NUTS 2 region [36].
27. EUROSTAT - Cooling and heating degree days [37].
28. EDGAR (Emissions Database for Global Atmospheric Research) CO2 Emissions [38].
29. CORDEX - Regional climate model data on single levels for Europe [39].
30. PVGIS - Photovoltaic Geographical Information System [40].
31. Concerted Action EPBD [41].
32. Global Buildings Performance Network (GBPN) [42].
33. Building Performance Policy Center (formerly BuildingRating.org) [43].
34. IEA World energy balances database [44].
35. ENERFUND: Building Retrofit Potential [45].
36. Statistical pocketbook 2017 [46].
37. IRENA [47].
38. Air Quality e-Reporting (AQ e-Reporting) [48].
39. Approximated estimates for the share of gross final consumption of renewable energy sources in 2019 (EEA 2019 RES share proxies) [49].
40. Approximated estimates for the primary and final consumption of energy in 2019 (EEA 2019 proxies on primary and final energy consumption) [50].
41. Copernicus Land Monitoring Service - Urban Atlas [51].
42. INSPIRE Buildings Theme (Annex 3) Datasets [52].
43. OECD Data [53].
44. MRS ESPON [54].
45. ESPON DB [55].

7.2.2 Levels of Information

After the analysis of the different sources, the ones including information on the parameters selected were identified.

The objective was to find data at national level that allowed an analysis of demand side at that scale, but for many of the parameters identified, there was no available data at national level. Despite this, some of the parameters not included in European sources can be obtained, either through national, regional, or local sources if the address is known or as a last resort by asking the user. These three different levels of information were identified:

a. National data (Green colour)
b. Address data (Blue colour)
c. Specific data (Yellow colour)

7.2.2.1 National data

This set of parameters can be identified at the country/national level, so they are the most feasible to include in the future interactive map that will be developed in Task 5.3.

7.2.2.2 Address data

This set of parameters can be identified at building level if the user provides the address of the building, and with the use of software such as Google Earth or national cadastre websites.

7.2.2.3 Specific data

This set of parameters can only be identified nowadays asking users about some data or figures related to the building or in some cases if a test is carried out (e.g., pull-out test).

7.2.3 Parameters, codes, and levels

In the Table below, the information displayed is organized in 3 columns:

- CODE: the parameters are identified with a code to be able to be shown in the following subsections and see the link.
- Physical building characteristics specific to each building: based on the results of the Delphi method, the characteristics selected by the panel of experts have been listed,
- Feasible level: here the three levels explained above are shown in colour, indicating where they could be obtained from.

CODE	Physical building characteristics specific to each building	Feasible level
B01	Existence of balconies or terraces	Google Earth / Cadastre
B02	Façade construction system	Dweller data / Sampling
B03	Façade size (__x__ or m^2)	Google Earth / Cadastre
B04	Individual or centralized heating	Building existing sources
B05	Type of structure (material, wall/pillars)	Dweller data / Sampling
B06	Building typology (SFH Single Family House / MFH Multi Family House)	Building existing sources
B07	Number of floors	Google Earth / Cadastre
B08	Openings size (windows size)	Google Earth / Cadastre
B09	Openings layout (distribution) (Openings variety or regular size)	Google Earth / Cadastre
B10	Type of roof (flat /sloping)	Google Earth / Cadastre

CODE	Physical building characteristics specific to each building	Feasible level
B11	Type of HVAC system	Building existing sources
B12	Type of external finish of the façade	Dweller data / Google Earth?
B13	Size of roof (__x__ or m^2)	Google Earth / Cadastre
B14	Roof construction system	Dweller data / Sampling
B15	Year of construction	Building existing sources
B16	Presence of insulation	Dweller data / Sampling
B17	The height of the ceiling in each floor	Dweller data
B18	Structural capacities of existing building components	Sampling
B19	Existing Renewable Energies	Building existing sources
B20	Type of DHW system	Dweller data
B21	Perimetral wall length	Google Earth / Cadastre
B22	Existing thermal or electrical storage	Dweller data
B23	Number of underground floors	Cadastre
B24	Existence and in that case size of the technical room	Dweller data

CODE	Characteristics of the dwelling or dwellings Inside	Feasible level
D01	Sizes (m^2) and layout of rooms (living spaces, WC, blind premises, etc..)	Dweller data
D02	Status of the home's electrical network (circuit separation)	Dweller data
D03	Dwelling surface (m^2)	Building existing sources

CODE	Characteristics related to how the building relates to its surroundings	Feasible level
S01	Façade orientation	Google Earth / Cadastre
S02	Shadows on the façade	Dweller data / Google Earth?
S03	Possibility of crane access from the street	Local authorities
S04	Shadows on the roof	Dweller data / Google Earth?
S05	Free space between the façade and the façade of the opposite building	Google Earth / Cadastre
S06	Possibility of soil connection next to the façade	Local authorities

CODE	Legislation affecting the building	Feasible level
L01	Façade colour restrictions	Local authorities
L02	Fire regulation	National authorities
L03	Energy sharing / energy community's legislation	National authorities
L04	Monumental protection of the building	Local authorities
L05	Water use restrictions	Local authorities
L06	Seismic legislation	National authorities
L07	Possibility to build more floors	Local authorities

CODE	Characteristics of the building related to its use and ownership	Feasible level
O01	Building use (residential, non-residential)	Building existing sources
O02	Property (single owner or multi property)	Dweller data
O03	Owned or rented homes	Building existing sources

The following subsections show the data collected from the databases/sources identified below each table. It is highlighted in blue colour the data from the countries of the project, of which, those with the highest value in some parameters are marked in red. The data from other countries with the highest value in some parameter is marked in green.

The parameters marked in orange are the ones that coincide with those of INSPIRE (see section 7.2.5).

7.2.3.1 Individual or centralized heating (Parameter B04)

SUBCODE	B04A	B04B	B04C	B04D
PARAMETER: Individual or centralized heating	Dwellings with collective central heating	Dwellings with individual central heating	Dwellings with room heating	Share of dwellings with central heating systems (collective and individual heating)
UNIT	Thousand	Thousand	Thousand	%
YEAR	2018	2018	2018	2008
European Union 27 (EU)	n/a	n/a	n/a	n/a
European Union 28 (EU28)	n/a	n/a	n/a	n/a
Austria (AT)	3,721	722	195	95%
Belgium (BE)	n/a	n/a	n/a	n/a
Bulgaria (BG)	507	1,070	1,412	56%
Croatia (HR)	0	756	760	45%
Cyprus (CY)	n/a	156	256	38%
Czechia (CZ)	3,509	284	296	94%
Denmark (DK)	1,826	780	228	32%
Estonia (EE)	359	86	543	n/a
Finland (FI)	n/a	n/a	n/a	71%
France (FR)	n/a	n/a	n/a	98%
Germany (DE)	30,838	4,294	2,104	91%
Greece (GR)	2,188	959	976	72%
Hungary (HU)	609	2,052	1,170	54%
Ireland (IE)	n/a	1,754	25	98%
Italy (IT)	4,555	18,371	1,478	97%
Latvia (LV)	461	145	195	76%
Lithuania (LT)	n/a	n/a	n/a	91%
Luxembourg (LU)	n/a	n/a	n/a	96%
Malta (MT)	0	2	n/a	1%
Netherlands (NL)	858	6,414	126	91%

SUBCODE	B04A	B04B	B04C	B04D
Poland (PL)	n/a	n/a	n/a	87%
Portugal (PT)	n/a	n/a	n/a	n/a
Romania (RO)	n/a	n/a	n/a	42%
Slovakia (SK)	120	1,373	267	88%
Slovenia (SI)	n/a	n/a	n/a	86%
Spain (ES)	n/a	n/a	n/a	73%
Sweden (SE)	2,365	2,319	1	73%
United Kingdom (GB)	n/a	28,139	808	93%

SOURCE
ODYSSEE (B04A, B04B & B04C)

As per the statistics for the countries of the project above, it is shown that France and Italy have the highest percentage of dwelling with central heating, which allows to install for example the adaptable BMS at the building level and make the installation of the energy generation BIST kit or the energy and fresh air distribution kit more economically profitable. Other countries such as Austria, the Netherlands or Germany, also have a percentage higher than 90%, while Spain and Slovenia are slightly below.

It should be noted that the EU country with the highest percentage is Ireland, with 98%, but tied with France.

7.2.3.2 Building typology (SFH Single-Family House / MFH Multi-Family House) (Parameter B06)

SUBCODE	B06A	B06B
PARAMETER: Building typology (SFH Single Family House / MFH Multifamily House)	Number of single-family dwellings (individual residence)	Number of multi-family dwellings (collective residence)
UNIT	Thousand	Thousand
YEAR	2017	2017
European Union 27 (EU)	n/a	n/a
European Union 28 (EU28)	160,430	140,953
Austria (AT)	3,550	2,196
Belgium (BE)	730	5,659
Bulgaria (BG)	3,960	1,469
Croatia (HR)	1,720	622
Cyprus (CY)	390	99
Czechia (CZ)	3,970	1,795
Denmark (DK)	1,260	2,057
Estonia (EE)	400	435
Finland (FI)	2,910	2,910
France (FR)	12,540	26,714
Germany (DE)	28,260	20,283

SUBCODE	B06A	B06B
Greece (GR)	5,080	3,433
Hungary (HU)	3,870	1,114
Ireland (IE)	1,660	200
Italy (IT)	7,840	34,217
Latvia (LV)	270	912
Lithuania (LT)	1,100	495
Luxembourg (LU)	170	85
Malta (MT)	230	37
Netherlands (NL)	6,580	1,218
Poland (PL)	12,120	4,665
Portugal (PT)	5,590	1,443
Romania (RO)	7,710	3,003
Slovakia (SK)	1,690	681
Slovenia (SI)	710	209
Spain (ES)	20,670	14,167
Sweden (SE)	1,540	4,345
United Kingdom (GB)	23,900	6,492

SOURCE
EU Building Observatory

As per the statistics (for the countries of the INFINITE project), it is shown that France and Italy have more percentage of collective residence than the others, which implies that for the installation of certain kits like the energy generation ones or the green envelope, and especially for deep renovations of the whole building, an agreement will have to be reached between all the owners, if the building is not owned by a single owner. On the other hand, Germany and Spain have the first and second highest figure in the European Union of individual residences, so having less height and being a single owner, it is easier to apply industrialization in general and INFINITE products in particular.

7.2.3.3 Share of fuels in the final energy consumption in the residential sector for space heating (Parameter B11+B19)

SUBCODE	B11A	B11B	B11C	B11D	B11E	B19A
PARAMETER: Share of fuels in the final energy consumption in the residential sector for space heating	Electricity	Derived Heat	Gas	Solid Fuels	Oil & petroleum products	Renewables and Wastes
UNIT	%	%	%	%	%	%
YEAR	2018	2018	2018	2018	2018	2018
European Union 27 (EU)	5.2	10.6	38.0	5.1	14.1	27.0
European Union 28 (EU28)	5.4	9.3	42.9	4.6	13.3	24.5
Austria (AT)	4.8	14.5	26.2	0.4	18.6	35.5
Belgium (BE)	3.2	0.3	47.1	1.2	37.9	10.4

SUBCODE	B11A	B11B	B11C	B11D	B11E	B19A
Bulgaria (BG)	8.8	16.7	5.3	9.8	0.1	59.3
Croatia (HR)	1.8	6.5	21.9	0.1	4.7	65.0
Cyprus (CY)	13.0	0.0	0.0	0.0	63.0	24.0
Czechia (CZ)	4.7	13.5	24.8	18.0	0.8	38.1
Denmark (DK)	2.8	36.6	15.5	0.0	4.1	41.0
Estonia (EE)	5.1	37.4	5.9	0.2	0.3	51.2
Finland (FI)	24.2	29.9	0.5	0.1	5.9	39.4
France (FR)	12.7	4.0	34.8	0.1	14.7	33.8
Germany (DE)	1.8	9.1	48.1	1.3	23.6	16.1
Greece (GR)	4.8	2.2	13.6	0.2	43.0	36.2
Hungary (HU)	0.8	8.3	56.3	2.3	0.2	32.0
Ireland (IE)	4.0	0.0	25.6	17.6	50.1	2.6
Italy (IT)	0.4	5.1	58.4	0.0	7.8	28.3
Latvia (LV)	0.7	33.3	7.7	0.7	3.0	54.6
Lithuania (LT)	1.3	38.4	10.3	5.2	1.8	42.9
Luxembourg (LU)	4.2	0.0	54.6	0.1	34.0	7.2
Malta (MT)	37.4	0.0	0.0	0.0	19.0	43.5
Netherlands (NL)	2.1	3.5	86.2	0.0	0.6	7.6
Poland (PL)	0.9	20.1	14.9	44.9	0.8	18.5
Portugal (PT)	12.5	0.1	1.0	0.0	5.5	80.9
Romania (RO)	0.2	16.0	30.2	0.5	0.0	53.1
Slovakia (SK)	5.7	25.0	65.4	1.2	0.3	2.4
Slovenia (SI)	3.9	9.4	12.5	0.0	15.0	59.2
Spain (ES)	7.3	0.0	19.5	0.9	31.9	40.5
Sweden (SE)	29.3	48.7	0.6	0.0	4.0	17.4
United Kingdom (GB)	6.4	1.1	74.7	2.0	7.8	7.9

SOURCE
EUROSTAT

As per the statistics for the countries of the project above, it is shown that Slovenia despite being the fourth country in the European Union with the highest share of renewable energies with around 60% (it is still far from the almost 81% that Portugal has, the best figure in the EU), there are still almost 30% of homes that continue to use gas or petroleum products (B11C, B11E), which could be replaced by systems using renewable energies. In the rest of the countries, it can be appreciated how the majority of countries are still far from exceeding 60% of the use of renewables, having a high dependence on fossil fuels and gas (for example in the cases of Italy, the Netherlands or Germany), or having dependence on oil and petroleum products (in the case of Spain), so there is a lot of room for improvement.

7.2.3.4 Year of construction (Parameter B15)

SUBCODE	B15A	B15B	B15C	B15D	B15E	B15F	B15G	B15H
PARAMETER: Year of construction	Share of residential buildings built <1980	Number of dwellings built before 1945	Number of dwellings built between 1945 and 1969	Number of dwellings built between 1970 and 1979	Number of dwellings built between 1980 and 1989	Number of dwellings built between 1990 and 1999	Number of dwellings built between 2000 and 2010	Number of dwellings built after 2010
UNIT	%	Thousand	Thousand	Thousand	Thousand	Thousand	Thousand	Thousand
YEAR	2014	2017	2017	2017	2017	2017	2017	2017
European Union 27 (EU)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
European Union 28 (EU28)	64.9%	55,506	60,988	45,262	39,649	33,768	39,838	26,368
Austria (AT)	n/a	1,011	1,185	685	549	630	308	92
Belgium (BE)	26.4%	35	142	76	32	27	86	43
Bulgaria (BG)	44.7%	288	290	224	293	179	373	131
Croatia (HR)	47.7%	54	49	31	40	34	20	13
Cyprus (CY)	48.9%	4,117	3,703	3,406	3,845	3,796	5,165	2,529
Czechia (CZ)	49.2%	56	40	31	26	19	27	22
Denmark (DK)	51.9%	864	769	950	978	1,016	919	435
Estonia (EE)	52.2%	560	1,554	1,309	1,531	1,114	432	362
Finland (FI)	54.1%	427	683	431	543	359	390	77
France (FR)	58.3%	2,198	2,559	1,771	1,681	1,677	2,456	1,638
Germany (DE)	59.5%	1,686	1,586	997	1,040	946	727	439
Greece (GR)	59.9%	259	341	367	281	256	314	178
Hungary (HU)	60.4%	6,192	4,798	5,286	5,066	3,344	4,984	4,220
Ireland (IE)	62.0%	850	993	969	609	416	550	373
Italy (IT)	64.4%	215	137	56	50	77	75	41
Latvia (LV)	66.5%	932	1,014	652	614	479	497	283
Lithuania (LT)	67.3%	1,101	2,608	1,169	1,018	905	985	1,045
Luxembourg (LU)	67.5%	252	139	137	146	145	159	63
Malta (MT)	67.8%	908	887	542	939	382	510	252
Netherlands (NL)	68.7%	5,090	4,850	4,953	4,631	4,323	4,254	3,860
Poland (PL)	69.6%	91	349	97	68	64	115	66
Portugal (PT)	69.9%	461	400	245	316	249	259	60
Romania (RO)	70.5%	652	800	878	734	763	851	592
Slovakia (SK)	74.3%	8,810	12,444	6,269	4,421	4,340	3,135	1,761
Slovenia (SI)	75.1%	8,717	5,587	2,449	1,733	1,692	4,697	3,495
Spain (ES)	76.1%	615	544	598	301	300	318	305
Sweden (SE)	76.3%	224	266	188	188	146	151	118
United Kingdom (GB)	76.7%	928	806	800	740	633	611	544

SOURCE
EU Building Observatory

As per the statistics for the countries of the project above, it is shown that for almost all of them the percentage of residential buildings built before 1980 (generally do not have thermal insulation) is between 60% (Netherlands) and 75% (Germany), except Spain, which is slightly below 50%. From the EU Sweden is the country with the highest share. This indicates that their energy efficiency is low and with great room for improvement, so they are likely to require major renovations to meet new regulations and current comfort conditions. This parameter helps to identify the percentage of buildings on which deep renovations could be applied, using, a priori, before analysing in detail each case, practically all the INFINITE kits.

It should be noted that the EU country with the highest percentage is Sweden, with almost 77%.

7.2.3.5 Share of fuels in the final energy consumption in the residential sector for water heating (Parameter B20+B19)

SUBCODE	B20A	B20B	B20C	B20D	B20E	B19B
PARAMETER: Share of fuels in the final energy consumption in the residential sector for water heating	Electricity	Derived Heat	Gas	Solid Fuels	Oil & petroleum products	Renewables and Wastes
UNIT	%	%	%	%	%	%
YEAR	2018	2018	2018	2018	2018	2018
European Union 27 (EU)	20.5	13.1	40.6	1.8	11.3	12.6
European Union 28 (EU28)	18.5	11.2	47.1	1.6	10.7	11.0
Austria (AT)	28.5	11.7	17.6	0.1	10.3	31.8
Belgium (BE)	30.4	0.0	48.9	0.0	17.3	3.5
Bulgaria (BG)	58.7	31.5	2.7	0.5	0.1	6.5
Croatia (HR)	44.5	3.8	37.6	0.1	3.4	10.7
Cyprus (CY)	14.4	0.0	0.0	0.0	8.6	77.0
Czechia (CZ)	23.0	27.3	36.0	2.2	0.0	11.5
Denmark (DK)	4.6	63.2	17.2	0.0	8.4	6.5
Estonia (EE)	5.5	59.7	6.4	0.1	0.2	28.0
Finland (FI)	25.0	55.0	0.6	0.1	6.5	12.8
France (FR)	50.0	6.5	27.1	0.0	12.3	4.1
Germany (DE)	14.3	3.5	49.3	0.0	16.2	16.5
Greece (GR)	39.4	0.8	6.8	0.0	7.1	45.9
Hungary (HU)	39.5	16.1	38.4	0.0	1.4	4.5
Ireland (IE)	15.5	0.0	29.7	5.5	44.5	4.7
Italy (IT)	13.4	4.0	65.0	0.0	8.0	9.5
Latvia (LV)	12.6	44.5	9.9	0.4	3.7	29.0
Lithuania (LT)	9.7	51.8	13.5	2.6	4.2	18.2
Luxembourg (LU)	4.0	0.0	56.3	0.0	30.6	9.2
Malta (MT)	78.7	0.0	0.0	0.0	0.0	21.3
Netherlands (NL)	4.0	5.4	89.2	0.0	0.0	1.4
Poland (PL)	5.7	37.1	29.4	17.9	1.2	8.8
Portugal (PT)	5.4	0.0	33.2	0.0	42.2	19.2
Romania (RO)	2.0	0.0	54.5	0.7	5.9	36.8
Slovakia (SK)	20.8	25.5	47.9	2.5	1.0	2.4

SUBCODE	B20A	B20B	B20C	B20D	B20E	B19B
Slovenia (SI)	29.5	7.5	12.5	0.0	9.1	41.5
Spain (ES)	18.7	0.0	45.6	0.2	23.9	11.6
Sweden (SE)	32.8	54.7	0.6	0.0	3.2	8.6
United Kingdom (GB)	6.4	0.0	84.4	0.3	7.1	1.8

SOURCE
EUROSTAT

As per the statistics for the countries of the project above, it is shown that Slovenia, despite being the third in the European Union with the highest consumption of renewable energies with around 42%, is still far from the 77% that Cyprus has, the best figure in the EU. There are still almost 1 of each 4 homes that continue to use gas or petroleum products (B20C, B20E), which could be replaced by systems using renewable energies. In the rest of the countries, it can be appreciated how the majority of countries are still far from exceeding 77% of the use of renewables, having a high dependence on fossil fuels and gas (for example in the cases of Italy and the Netherlands), or having dependence on oil and petroleum products (in the case of Spain), so there is a lot of room for improvement.

7.2.3.6 Dwelling surface (m^2) (Parameter D03)

SUBCODE	D03A	D03B	D03C	D03D
PARAMETER: Dwelling surface (m^2)	Floor area of dwellings (average)	Floor area of new dwellings (average)	Average number of rooms per person (Rooms per person)	Average household size (Average number of persons)
UNIT	m^2	m^2	no	%
YEAR	2018	2018	2019	2019
European Union 27 (EU)	90.06	99.99	1.6	2.3
European Union 28 (EU28)	n/a	n/a	n/a	n/a
Austria (AT)	100.10	n/a	1.6	2.2
Belgium (BE)	n/a	n/a	2.1	2.3
Bulgaria (BG)	73.27	92.35	1.2	2.4
Croatia (HR)	85.80	n/a	1.1	2.7
Cyprus (CY)	148.38	215.83	2.0	2.7
Czechia (CZ)	80.40	n/a	1.5	2.3
Denmark (DK)	118.40	122.04	1.9	2.0
Estonia (EE)	61.51	90.00	1.7	2.1
Finland (FI)	101.56	85.30	1.9	2.0
France (FR)	90.38	n/a	1.9	2.1
Germany (DE)	91.84	102.06	1.8	2.0
Greece (GR)	88.00	124.50	1.2	2.6
Hungary (HU)	83.00	97.00	1.5	2.3
Ireland (IE)	119.34	135.96	2.1	2.6

SUBCODE	D03A	D03B	D03C	D03D
Italy (IT)	94.18	86.50	1.4	2.3
Latvia (LV)	69.84	n/a	1.2	2.3
Lithuania (LT)	68.90	106.40	1.6	2.2
Luxembourg (LU)	133.00	n/a	2.0	2.3
Malta (MT)	141.03	n/a	2.2	2.5
Netherlands (NL)	119.00	114.00	2.0	2.1
Poland (PL)	74.20	90.30	1.1	2.8
Portugal (PT)	96.85	98.66	1.7	2.5
Romania (RO)	47.61	n/a	1.1	2.6
Slovakia (SK)	86.75	112.30	1.2	2.9
Slovenia (SI)	82.84	148.20	1.6	2.4
Spain (ES)	92.27	134.69	1.9	2.5
Sweden (SE)	106.93	n/a	1.8	2.0
United Kingdom (GB)	94.25	n/a	2.1	2.3

SOURCE
Odyssee (D03A & D03B)
EUROSTAT (D03C & D03D)

As per the statistics for the countries of the project above, it is shown that for almost all of them the floor area of dwelling (average) is around 90 m^2 that is the average for the whole European Union, therefore, when applying INFINITE products, regarding this parameter, the same conditions are used. Highlight the cases of the Netherlands, with an average of almost 120 m^2 per home, and that of Slovenia, with about 82 m^2. In the second case, the data is very close to the average, but some of the systems may require more power, like the energy and fresh air distribution kit or need space for machinery, as in the case of energy generation kits. A further case-by-case study will be required.

It should be noted that the EU country with the highest average is Cyprus, with more than 148 m^2.

7.2.3.7 Building use (residential, non-residential) (Parameter O01)

SUBCODE	O01A	O01B
PARAMETER: Building use (residential, non-residential)	Total number of residential dwellings	Number of non-residential buildings
UNIT	Thousand	Thousand
YEAR	2016	2017
European Union 27 (EU)	n/a	n/a
European Union 28 (EU28)	215,330.54	46,296.98
Austria (AT)	3,864.80	649.23
Belgium (BE)	5,360.73	1,173.44
Bulgaria (BG)	3,943.99	587.37
Croatia (HR)	1,750.18	505.14
Cyprus (CY)	448.00	309.34
Czechia (CZ)	4,327.08	701.35

SUBCODE	O01A	O01B
Denmark (DK)	3,013.59	758.12
Estonia (EE)	670.55	770.03
Finland (FI)	2,968.20	761.71
France (FR)	35,944.00	6,130.32
Germany (DE)	41,703.35	11,886.97
Greece (GR)	6,433.80	1,192.52
Hungary (HU)	4,405.00	407.31
Ireland (IE)	1,758.19	426.48
Italy (IT)	32,100.62	2,990.05
Latvia (LV)	1,045.58	135.51
Lithuania (LT)	1,392.00	204.28
Luxembourg (LU)	233.85	30.20
Malta (MT)	263.46	39.36
Netherlands (NL)	7,686.18	1,299.70
Poland (PL)	14,272.00	2,646.16
Portugal (PT)	5,932.70	935.70
Romania (RO)	8,929.17	879.44
Slovakia (SK)	2,007.30	94.98
Slovenia (SI)	849.98	232.50
Spain (ES)	25,541.66	2,975.44
Sweden (SE)	5,258.00	459.19
United Kingdom (GB)	28,469.17	7,106.13

SOURCE
EU Building Observatory

This parameter must be interpreted from two related points of view.

In the first place, in a general way, it is necessary to see the number of buildings for residential use with respect to the total of the EU that each of the countries represents. It is seen that the largest amount of EU housing stock belongs to Germany, which represents around 19% of the European stock, followed by France with almost 17%. These two countries, together with Italy and Spain, represent more than 60% of the buildings for residential use. This is where the potential in quantity of each country is seen if it is read together with the parameter Year of construction (B15), since looking at the total number of buildings for residential use and the % of those that are prior to 1980 and, a priori less efficient Energetically, without taking into account other limitations, in terms of volume, you can see the largest amount of stock on which to act.

Second, the percentage of buildings for residential use within each of the countries must be considered. According to the previous statistics of the project countries, Italy has the best data with around 91% of its building stock for residential use, the best figure in the EU being that of Slovakia with close to 95%. The rest of the project countries see how they are between 78% of Germany and 90% of Spain. This data, less relevant than the first, should be studied together with the type of aid or funds that each of the members of the European Union makes available to people and companies for the renovation of buildings, since if a priori, all the kits of INFINITE, with the exception of some characteristics of the aBMS, could be applied to buildings for other uses, in general, the aid or funds are intended for dwellings or buildings for residential use.

7.2.3.8 Owned or rented homes (Parameter O03)

SUBCODE	O03A	O03B	O03C	O03D	O03E
PARAMETER: Owned or rented homes	Owner-occupied	Tenant, rent	Owner occupied - dwellings/units	Private rented - dwelling/units	Social housing - dwelling/units
UNIT	%	%	Mil.	Mil.	Mil.
YEAR	2019	2019	2016	2016	2016
European Union 27 (EU)	69.8%	30.2%	n/a	n/a	n/a
European Union 28 (EU28)	69.2%	30.8%	211.64	56.30	33.44
Austria (AT)	55.2%	44.8%	2.55	1.21	0.70
Belgium (BE)	71.3%	28.7%	3.79	1.02	0.46
Bulgaria (BG)	84.1%	15.9%	3.77	0.12	0.59
Croatia (HR)	89.7%	10.3%	1.79	0.04	0.17
Cyprus (CY)	67.9%	32.1%	0.32	0.05	0.07
Czechia (CZ)	78.6%	21.4%	3.76	0.79	0.21
Denmark (DK)	60.8%	39.2%	1.89	1.09	0.00
Estonia (EE)	81.7%	18.3%	0.53	0.03	0.09
Finland (FI)	71.1%	28.9%	2.13	0.32	0.46
France (FR)	64.1%	35.9%	22.03	6.54	5.32
Germany (DE)	51.1%	48.9%	21.62	16.31	3.25
Greece (GR)	75.4%	24.6%	5.08	1.37	0.41
Hungary (HU)	91.7%	8.3%	3.90	0.17	0.35
Ireland (IE)	68.7%	31.3%	1.22	0.29	0.27
Italy (IT)	72.4%	27.6%	23.36	4.57	4.03
Latvia (LV)	80.2%	19.8%	0.84	0.09	0.11
Lithuania (LT)	90.3%	9.7%	1.15	0.02	0.11
Luxembourg (LU)	70.9%	29.1%	0.16	0.05	0.01
Malta (MT)	79.8%	20.2%	0.19	0.01	0.04
Netherlands (NL)	68.9%	31.1%	4.97	2.42	0.03
Poland (PL)	84.2%	15.8%	11.67	0.60	1.71
Portugal (PT)	73.9%	26.1%	4.44	0.74	0.75
Romania (RO)	95.8%	4.2%	8.49	0.06	0.28
Slovakia (SK)	90.9%	9.1%	1.80	0.16	0.04
Slovenia (SI)	74.8%	25.2%	0.65	0.05	0.15
Spain (ES)	76.2%	23.8%	20.93	3.21	2.42
Sweden (SE)	63.6%	36.4%	3.51	1.54	0.02
United Kingdom (GB)	65.2%	34.8%	18.38	4.85	5.13

SUBCODE	O03A	O03B	O03C	O03D	O03E
SOURCE					
EUROSTAT (O03A & O03B)					
Horizon 2020 HotMaps project (O03C, O03D & O03E)					

As per the statistics for the countries of the project above, it is shown that in relation to total housing, Slovenia is the one with the highest percentage of social housing in the whole EU, with almost 18% of the building stock (as in the United Kingdom), followed closely by France and Austria with almost 16%. On the other hand, there is the Netherlands, with only 0.4% of the total. In general, this type of building has a single owner, which will facilitate the deep renovation of the whole building and the dwellings using, a prior, all the INFINITE kits.

7.2.3.9 Other parameters

Considering other parameters that influence industrialization (that have not been identified by the technical partners), and in relation to the countries where project partners belong, the following topics can be highlighted:

- The high levels of solar radiation, like most southern European countries, indicate a high photovoltaic potential and therefore the generation of solar energy will be more profitable.
- Due to cultural reasons, in southern countries, it is common not to try to prevent the entry of daily light through the openings in the façade, and therefore to prefer other options different from the automatic darkening of the windowpanes, to which they are not as used as in countries located more to the north.
- Even though some areas of the countries, according to the Water Risk Atlas and indicators [56], are at risk of water stress *(Baseline water stress measures the ratio of total water withdrawals to available renewable surface and groundwater supplies. Water withdrawals include domestic, industrial, irrigation, and livestock consumptive and no consumptive use. Available renewable water supplies include the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users)* only restrictions on the use of water have been established:
- occasionally in the Canary Islands in Spain,
- occasionally in Rome (Italy), on the use of water in public fountains,
- very punctually due to the heat wave in 2019, the authorities of the German cities of Loehne and Bad Oeynhausen (center-west) imposed restrictions on the consumption of drinking water. Its use was limited to "vital needs".

7.2.4 INFINITE archetypes versus TABULA typologies

Once the INFINITE archetypes have been defined for the use of the set of kits and to be used individually, and the data has been analysed, a link with TABULA project typologies has been tried so to provide the INFINITE consortium with example buildings where to energy simulate the installation of the kits.

TABULA typology matrix is built on 2 main building characteristics, the building size and the year of construction. As the characteristics important for the industrialized renovation identified in this deliverable are not directly related with any of these 2 parameters, all the building types could be used for energy modelling purpose. A set of advice applicable to any of the cases in the different EU countries as described below for the choice of building types from TABULA matrices:

- According to parameter B06 (Building typology), in the European Union global, the individual residence number and the collective residence number are quite similar, so both types can be considered. In cases where the façade area needs to have more than 1000 m^2, we will focus on Apartment Blocks (AB) and Multi Family Houses (MFH), but if it would not be necessary for the installation of some kits, Single Family Houses (SFH) and Terraced Houses (TH) will also be considered. Despite the above, it should be remembered that from a production point of view and to achieve greater effectiveness during the industrialization process, it is more advisable to install the kits on large façade surfaces.

- According to parameter B15 (Year of construction), the majority of houses in the European Union as a whole were built before 1980, more specifically between 1945 and 1969. So even though this period could be taken as a priority, with the aim of improving energy efficiency in the EU building stock, any building with poor or without insulation could be considered.

7.2.5 INSPIRE data (Infrastructure for Spatial Information in Europe)

Once the data that were available for each of the parameters has been obtained, for a possible future standardization (using a data model and a standard vocabulary defined and agreed for the whole EU), it is checked whether any parameter is defined by the INSPIRE directive.

The parameters in the Table below have been extracted from the document "D2.8.III.2 INSPIRE Data Specification on Buildings – Technical Guidelines" (published by European Commission Joint Research Centre) [57].

The data specification is based on a common template used for all data specifications, which has been harmonised using the experience from the development of the Annex I, II and III data specifications [58].

The document provides guidelines for the implementation of the provisions laid down in the draft Implementing Rule for spatial data sets and services of the INSPIRE Directive. It also includes additional requirements and recommendations that, although not included in the Implementing Rule, are relevant to guarantee or to increase data interoperability.

Interoperability in INSPIRE means the possibility to combine spatial data and services from different sources across the European Community in a consistent way without involving specific efforts of humans or machines. It is important to note that "interoperability" is understood as providing access to spatial data sets through network services, typically via the Internet. Interoperability may be achieved by either changing (harmonising) and storing existing data sets or transforming them via services for publication in the INSPIRE infrastructure. It is expected that users will spend less time and effort on understanding and integrating data when they build their applications based on data delivered in accordance with INSPIRE.

Therefore, the parameters in orange are the ones that coincide with those of INSPIRE, for possible harmonization in the future.

INSPIRE Parameter	INFINITE Parameter	Location	Application Schema	Code List
Residential	B15A, O01A	Annex C (normative)	BuildingsBase	CurrentUseValue
Individual Residence	B06A	Annex C (normative)	BuildingsBase	CurrentUseValue
Collective Residence	B06B	Annex C (normative)	BuildingsBase	CurrentUseValue
Electricity	B11A, B20A	Annex C (normative)	BuildingsExtendedBase	HeatingSourceValue
Solid Fuels	B11D, B20D	Annex C (normative)	BuildingsExtendedBase	HeatingSourceValue
Central Heating	B04A, B04B, B04D	Annex C (normative)	BuildingsExtendedBase	HeatingSourceValue

7.2.6 Data collection conclusions and next steps

As a general conclusion to the previous data collection and analysis, the data from the two lower levels (address & specific) should be collected in the international standardized procedures to facilitate industrialization and prefabrication in the construction sector.

As an example, a way to improve the study and data collection would be using current technical guidelines to promote standardization, such as the INSPIRE directive, as a good practice for a better harmonization and identification of data in the future and related European projects.

7.3 Building owner profiles

The ownership of buildings is related to the rate at which renovations are undertaken and the depth of the energy savings measures that may be included in renovation projects [115], impacting therefore in the use of the INFINITE kits.

Building ownership is context specific, but the overall renovation progress and energy performance of buildings in different types of ownership groups can be described using official and publicly accessible databases [116].

At a general level, in the following Figure it can be appreciated that the ownership of residential buildings is mainly private for all the countries in Europe:

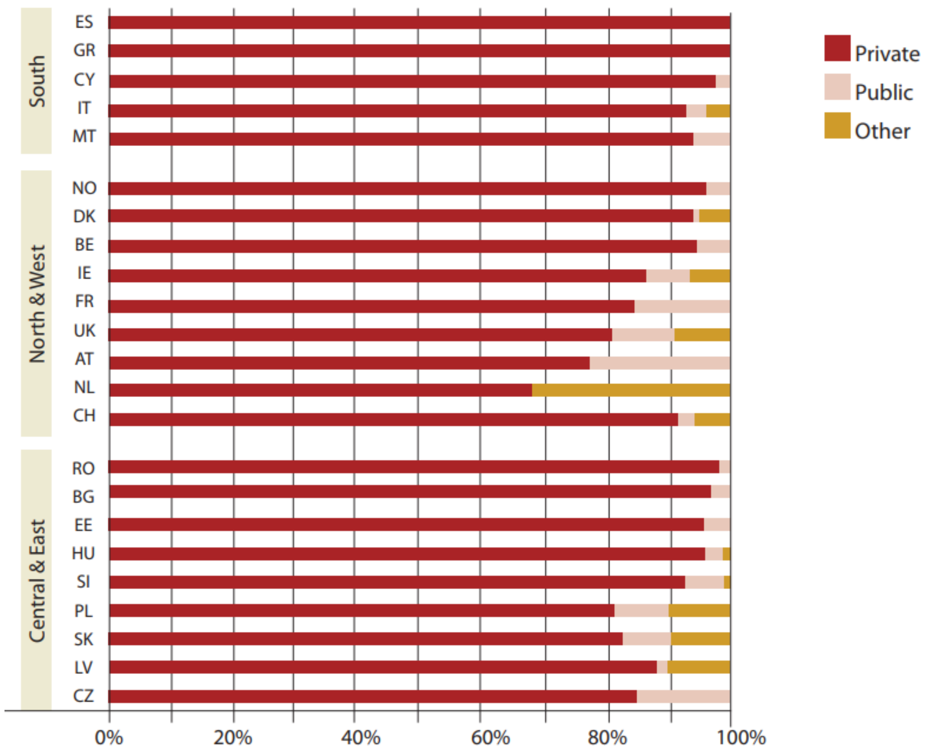


Figure 20 Ownership of residential buildings in Europe. Source: [115]

In this sense, a study in Gothenburg, reveals that municipally owned real estate companies face challenges in the renovation of building in socio-economically disadvantaged areas [116]. This is an aspect that can happen in other specific contexts, reason why it cannot be generalised at EU level, but it must be considered.

Considering the tenure at EU level, it is mainly owner-occupied, at least 50% of residential buildings are occupied by the owner in all countries [115] as it can be appreciated in the following Figure:

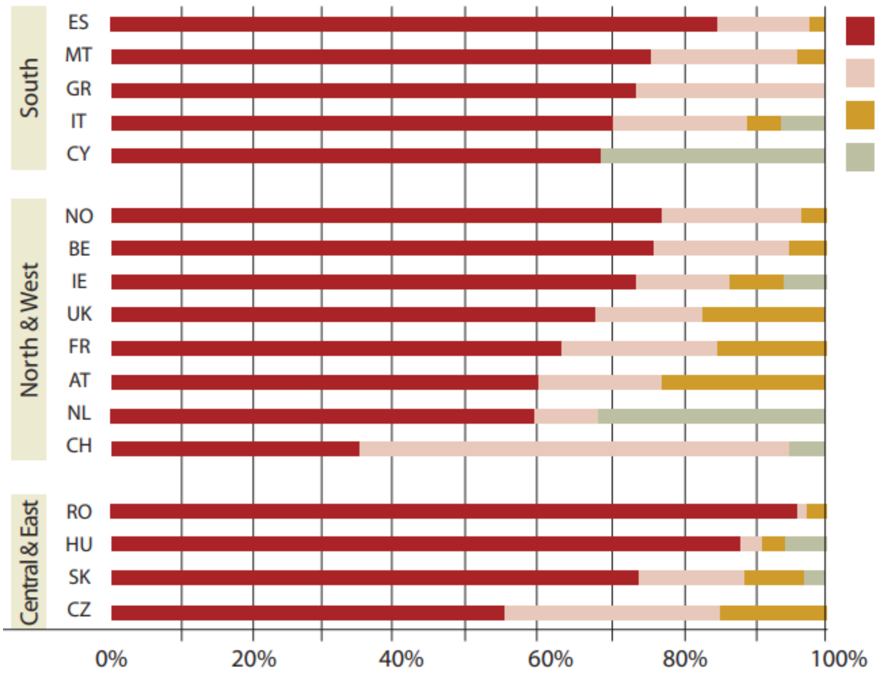


Figure 21 Tenure of residential buildings in Europe. Source: [115]

Considering the distribution of tenure status (%) indicated in section 7.2.3.8 for the countries representing INFINITE project, it can be appreciated that the owner-occupied profile is the dominant too (Figure 22). Nevertheless, going into details, Germany has the most balanced profile (51% owner-occupied vs 49% tenant, rent) and Spain has the most differentiated one (76% owner-occupied vs 24% tenant, rent) as it can be appreciated in the following Figure:

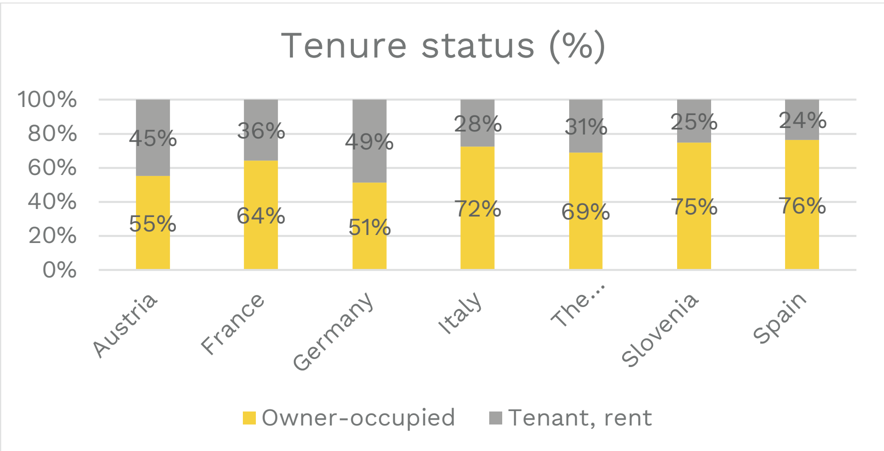


Figure 22 Distribution of tenure status of homes (2019). Source: section 7.2.3.8

Considering a range (45-55%) where ownership is balanced between owner-occupied or tenant, rented homes, Austria and Germany could be grouped into one profile, and the rest of the countries into another one where the owner-occupied dwellings prevail.

In addition, if the distribution of the population is taken into account considering their age (Figure 23, Figure 24, Figure 25), it can be appreciated that the balance of tenure (considering a range 45-55%) is in the following countries for the following range of ages:

- Austria (55 or over)
- France (18-54 years)
- Germany (65 or over)
- Italy (55-64 years)

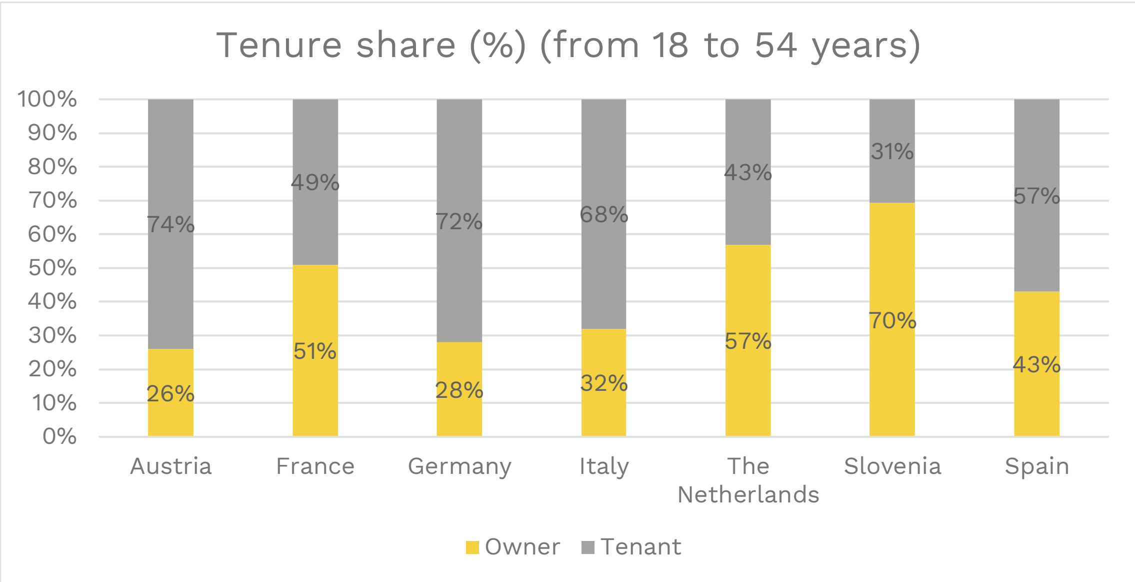


Figure 23 Distribution of population by broad group tenure status for population from 18 to 54 years (2019/2020). Source: EUROSTAT.

The tenancy prevails (>55%) in the profile of younger people, 18-54 years, in the following countries:

- Austria
- Germany
- Italy
- Spain

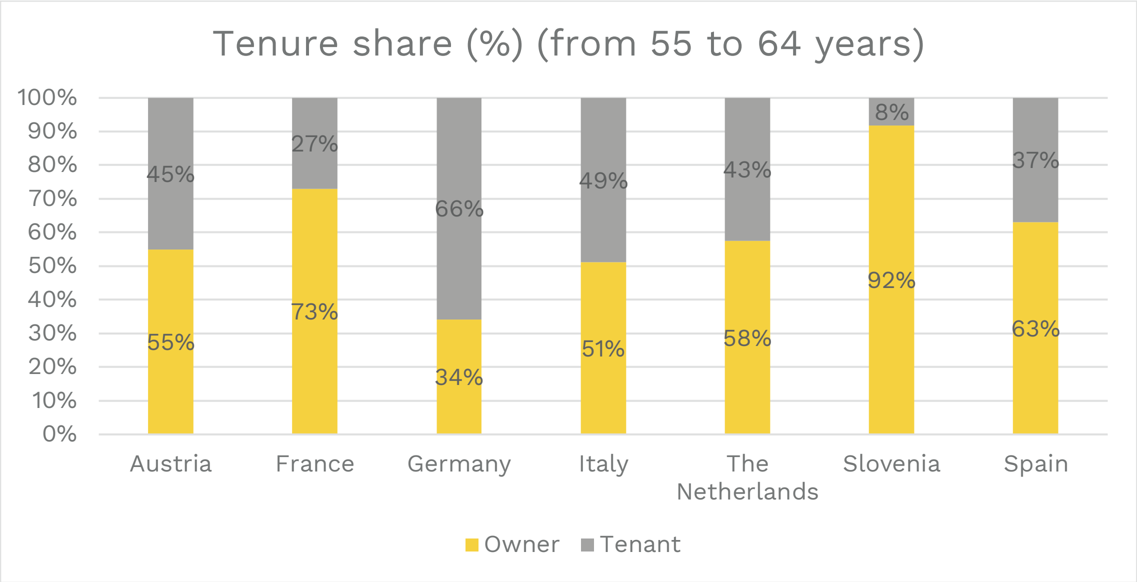


Figure 24 Distribution of population by broad group tenure status for population from 55 to 64 years (2019/2020). Source: EUROSTAT.

And the ownership prevails (>55%) in the following profiles:

- France (55 or over)
- Italy (65 or over)
- The Netherlands (all ranges of age)
- Slovenia (all ranges of age)
- Spain (55 or over)

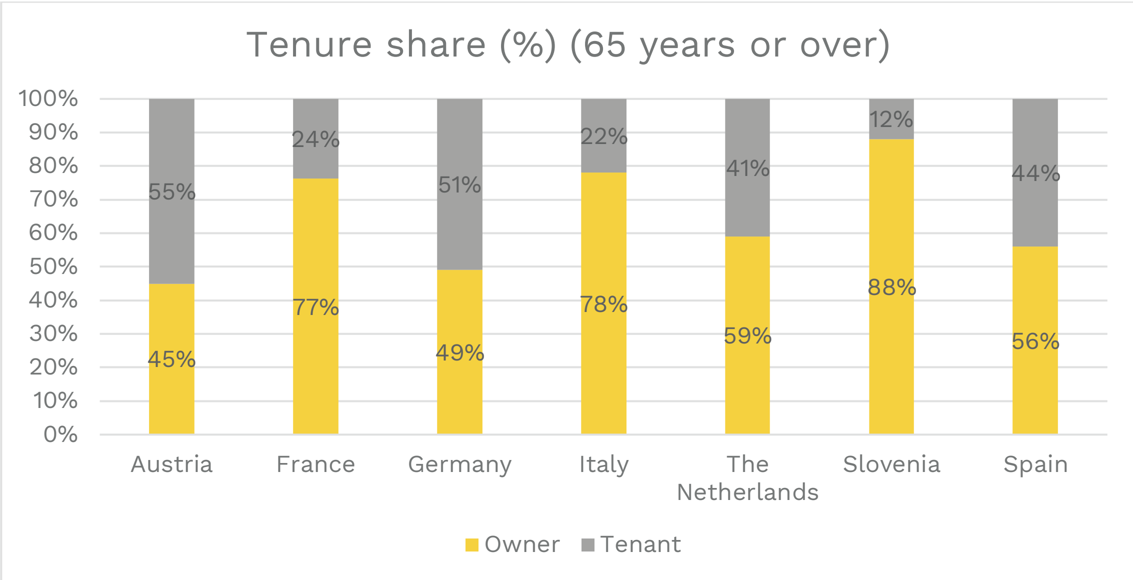


Figure 25 Distribution of population by broad group tenure status for population from 65 years or over (2019/2020). Source: EUROSTAT.

Putting together the age class with the tenure share (Table 22) it can be appreciated that The Netherlands and Slovenia have a more stable profile independently of age (ownership prevails at all ages), France and Spain have another type of profile where ownership prevails from 55 on. In Austria and Germany prevails the tenancy or it is balanced. And in Italy, the tenancy gradually goes to ownership with age.

Table 22 Tenure share linked to the age class

Age	Austria	France	Germany	Italy	The Netherlands	Slovenia	Spain
18-54							
55-64							
>65							

Legend:

- Tenancy > 55%
- Balanced tenancy 45-55%
- Ownership > 55%

Putting the focus in the number of dwellings, Germany, France, Italy, and Spain are the ones with a higher number of dwellings and possibly the higher potential to be renovated. And as generally seen, their tenure is mainly owner-occupied:

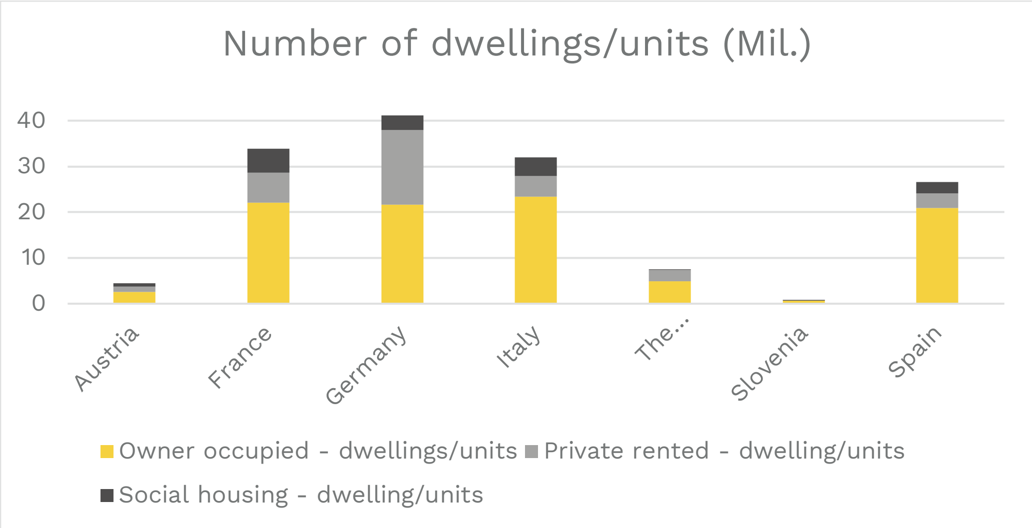


Figure 26 Number of dwelling/units per tenure (2016). Source: section 7.2.3.8.

Nevertheless, if the distribution of units is considered within each country, Slovenia has the higher share of social housing-dwellings (18%) and The Netherlands the least.

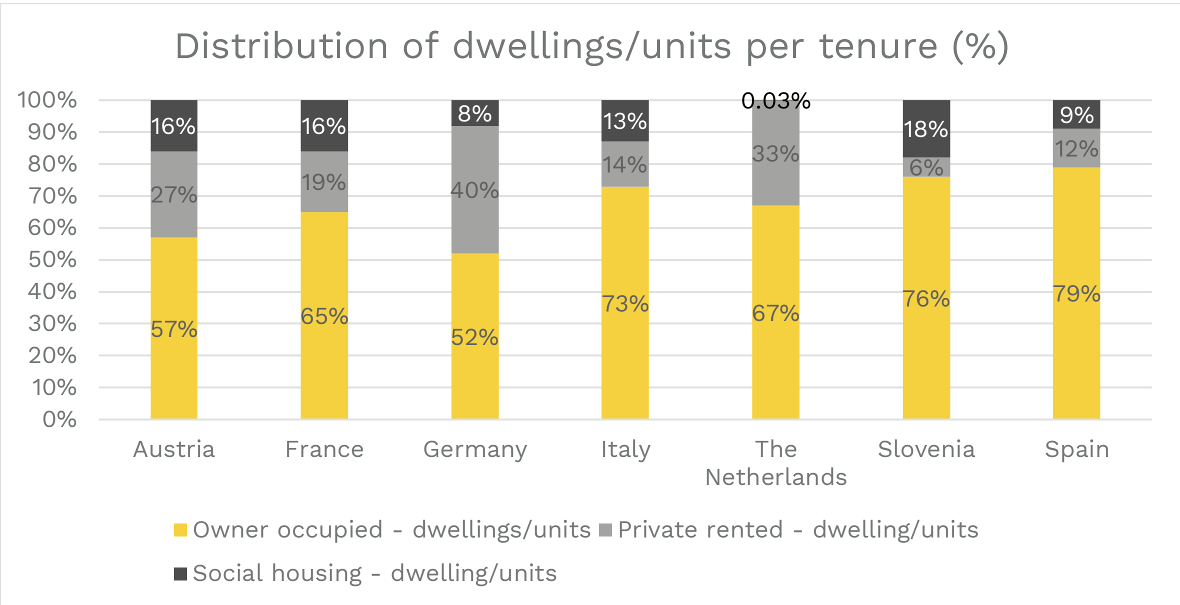


Figure 27 Distribution of dwellings/units (%) per tenure (2016). Source: section 7.2.3.8.

So, considering a share for social housing of 10%-20% Slovenia, Austria, France, and Italy can have a common profile; Spain and Germany another one (5-10%); and the Netherlands a different one.

Slovenian demo case

On national level in Slovenia half of residential building stock premises are owned by pensioners (poor ownership issues) owned by employees (48%) and pensioners (43%). The housing cost overburden rate is ~4,1% (percentage of persons living in households where the total housing costs (net of housing allowances) represent more than 40% of the total disposable household income (net of housing allowances).) Due to high ownerships shares, the real-estate presents the main asset in and significant share of households (poor ownerships issues) [117].

The main part of the data in this subsection was obtained by using ethnographic qualitative approaches (focus groups, semi-structured interviews, observations) in the Slovenian real demo case.

The data should be read as a level of data obtained by interviewing end-users, i.e., residents and building managers, and as complementary to data obtained from other sources.

The demo building included in the INFINITE project is a four-storey apartment block (built in 1982) located on the edge of the city centre. There are 69 residential units, and the ownership of these apartments is threefold:

- The Housing company L.L.C. is the owner of 34 apartments (2nd and 4th floor apartments).
- The local entrepreneur is the owner of 34 apartments (apartments on the 1st and 3rd floor).
- Only 1 apartment is privately owned by the tenant.

Therefore, most of the 81 residents do not own the apartments in which they live. There is some variation in the fluctuation of residents depending on who owns the apartments. In general, the apartments are "transient" for many residents, with higher turnover for privately owned apartments (i.e., 10 or more per year) compared to the apartments owned by the Housing company (i.e., 5 or less per year). The apartments are fairly small (20-25 m^2), as the building used to be a so-called "home for single people" and many residents are (former) workers in a local steel factory and immigrants from countries of former Yugoslavia.

According to the information gathered during the interviews and focus groups, the housing company takes better care of the maintenance of the apartments and strives to keep its tenants for a longer period of time. Apartments owned by other entities are maintained less well and with less care. However, the housing company is also more interested in cooperating in the renovation process, partly because STAN is also an INFINITE project partner, and partly because its main profession is property maintenance and management, compared to other main income of the local entrepreneur.

7.4 Regulation framework

In the consideration of the building stock variability for the demand-side mapping and aggregation, the regulation framework has been analysed. Its consideration is at building level, to see how it impacts the industrialized renovation approach. That is, an analysis of the existing building regulations at national and European level to identify possible barriers for the industrialization approach in the renovation sector including a review of the existing regulation and an assessment of policy options and their potential for boosting the energy efficient renovation of buildings in Europe using industrialized enveloped products has been done. As starting point, the buildings considered for INFINITE project are existing residential buildings.

To carry out the analyses at national level, a questionnaire has been filled in per country where project partners of INFINITE belong to, that is Austria, France, Germany, Italy, Slovenia, Spain, Switzerland, and The Netherlands. First, questions were addressed to get an overview of the general framework, then, questions were addressed to detect possible barriers or drivers for the installation of INFINITE kits. In general terms, the answers provided by Austria refer to the passive eco-compatible & green envelope kit; France answers are related to Adaptable BMS and optimized control strategies; Germany, to timber frame elements; Italy, to all kits; Slovenia refers to all the kits except the energy generation BIST kit; Switzerland refers to Energy generation BIPV kit.

A first overview has been considered to see which authorities set the technical building regulations (Table 23).

Table 23 Authorities who set the technical building regulations per country.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
National/ Central	X	X	X	X	X	X	X	X
Regional	X	-	X	X	-	X	X	X
Local	-	-	X	X	-(*)	X	X	X

(*) Unless a building permit is needed, it is not needed just for energy retrofit.

Even if national authorities are who set the technical building regulation in all countries, some considerations provided by [118] are interesting for the countries where regional and local authorities also set them. Starting with Austria, regional authorities set the technical building regulations with functional requirements and refer to the central guidelines for technical requirements. In Germany, central authorities set a model of technical building regulations that is adapted by regional authorities. In Italy and Spain, central authorities set technical building regulations, and regional and local authorities also set additional building regulations subordinated to national ones.

Furthermore, at regional level, in Austria it must be considered that there are 9 federal provinces in which, regarding regulations, there are often differences.

The second approach at general level was to identify the topics included in the building regulations. The study carried out by [118] showed that in most EU countries all main requirements are included in the technical building regulations, what has been confirmed now (Table 24). Nevertheless, some nuances must be considered. For instance, in Spain building and plot regulations are covered by municipal regulations.

Table 24 Subjects included in technical building regulations per country.

Subjects / Country	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
Building and plot	X	X	X	X	-	- (e)	X	-
Safety (structural and seismic safety)	X	X	X	X	X	X	X	X
Practicability (a)	X	X	X	X	-	X	X	X
Energy saving	X	X	X	X	X	X	X	X
Environmental Protection	X(b)	X	X	X	-	- (f)	X	-
Health. What does it include? (Acoustics, air quality, humidity, etc.)	X (c)	X	X	X	X	X (g)	X	X
Other:	X (d)					X (h)		X (i)

Legend:

(a) E.g., dimensions of rooms, ceiling height, accessibility, number of shower/basin/toilets.

(b) Hygiene, fire protection, health, and preservation of the environment [119].

(c) Included into OIB regulation 3: Sanitary facilities, precipitation, wastewater and other runoff, waste, exhaust gases from fireplaces, protection against moisture, drinking water and service water, protection against hazardous immissions, lighting and illumination, ventilation and heating, level, and height of rooms.

(d) Accessibility, fire regulations, detailed list of building materials. In Austria, the OIB Institute sets the national technical building regulations (for more information, it can be consulted OIB Guidelines | OIB).

(e) They are included in municipal regulations.

(f) Indirectly included. Directly regulated by other laws.

(g) Noise protection, protection against moisture, waste management, indoor air quality, water supply and evacuation, protection against radon exposure.

(h) Safety of use and accessibility.

(i) 1- The Dutch Building Reg's are 'performance based' so only (basic performances, no prescriptions in following way 1- functional requirement, 2. Performance requirement, 3. Way of verification (i.e., reference to standards).

2 - The Dutch Building Reg's have included the Equivalent Principle, i.e., if your product cannot be assessed by the Building Regs& Standard than you have the right to prove the equivalent performances (for example by lab testing. Simulations etc.) and that you fulfil the functional requirements.

Once the general framework has been fixed, since INFINITE is focused on the renovation of existing buildings, the questions addressed to know whether there are technical building regulations specific for existing buildings in each country.

Table 25 Existence of building regulations specific for existing buildings.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
Yes	X		X	X			X	X
No		X			X	X		

It must be highlighted the changes from the research by [118] until now. For example, in 2010 only in Italy and Slovenia there were specific regulations for existing buildings. Now, in Austria (national plan), Germany and Switzerland are also included.

To summarize the type of approach they follow in each country:

- General building regulations apply to all construction works, but for existing buildings relaxations of the provisions are possible: Germany and Slovenia.
- General building regulations apply to new buildings, and to reconstruction, extension, extensive renovation or change in use of existing buildings. Small renovations and maintenance works are usually excluded from complying with building regulations for new buildings. In these situations, it is not necessary to raise the standard, only to avoid making it worse: Austria, France, Spain, Switzerland, and The Netherlands.

In Italy both approaches are followed. In Spain, application criteria have been included for some of the subjects.

The authorities who set the regulations for buildings to be renovated (Table 26) are basically at national/central level with slight differences in relation to the authorities who set the technical building regulations (Table 23).

Table 26 Authorities who set the regulations that apply to residential buildings that are going to be renovated per country.

	Austria	France	German y	Italy	Slovenia (a)	Spain	Switzerland	The Netherlands
National/ Central	X	X	X	X	X	X	X	X
Regional	X	-	X	X	-	-	-	-
Local	-	-	X	X	X	-	-	X

Legend:

(a) Laws by the state, permits local community.

To know the different regulations that can be consulted online the following Table compile them.

Table 27 Regulations that apply to residential buildings that are going to be renovated.

Country	Regulations and public link with the conditions
Austria	Depending on the type of renovation, there are minimum energy performance requirements – regulations for new construction, major renovation, and single component renovation. Projektgruppe 3: Energieeinsparung und Wärmeschutz (oib.or.at): https://www.oib.or.at/sites/default/files/nationaler_plan_20.02.18_0.pdf
France	Just to increase the energy performance of the building
Germany	Gebäudeenergiegesetz (GEG). https://www.febs.de/gesetze-normen/gebaeudeenergiegesetz-geg/geg-2020
Italy	It is the same regulation for new buildings
Slovenia	The following essential requirements for facilities must be considered when obtaining a building permit: 1. mechanical resistance and stability, 2. fire safety, 3. hygienic and health protection and environmental protection, 4. safety in use, 5. noise protection, 6. energy saving and heat conservation, 7. universal construction and use of facilities, 8. sustainable use of natural resources. The National authorities publish rules and technical guidelines to meet these essential requirements. In addition to the essential requirements, it is necessary to consider local urban requirements, when renovate and reconstruction take place, for example, such as: the appearance of the façade and roof, the installation of devices on the outer envelope of the building. For façade, windows replacement, new heat source, PV power plant, not permits are needed. https://www.gov.si/teme/sprejemanje-predpisov/

Country	Regulations and public link with the conditions
Spain	Technical Building Code https://www.codigotecnico.org/DocumentosCTE/DocumentosCTE.html
Switzerland	RUEn regulations, Minergie construction standard, SIA 380 standard https://m3.ti.ch/CAN/RLeggi/public/index.php/raccolta-leggi/pdfatto/atto/526 https://www.minergie.ch/media/20170515_flyer_baustandard_minergie_it_rgb_1.pdf https://www4.ti.ch/fileadmin/DT/temi/risparmio_energetico/documenti/schede_incarto_energia/EN02_Isolamento_termico_edifici.pdf
The Netherlands	For existing buildings there are basic requirements, lower than for new buildings and considering thee 'level obtained by law'. However, for high level or deep renovation (> 25% of the envelope is renovated) requirements for news building is applicable https://www.bouwbesluitonline.nl/

The following questions are dedicated to get to know direct restrictions to INFINITE kits affected by regulations. Fire safety, seismic hazard, the level of heritage protection (in case it applies), and the increase of the thickness of the façade to the walkway side, seem to be the regulations that can prevent the different kits to be installed in a building that is going to be renovated.

Table 28 Type of restriction for the building envelope imposed by building regulations.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
Fire safety in residential homes [(a)]	X	X	X	X	X	X	X	-
Seismic hazard	X	X	-	X	-	X	X	-
Level of heritage protection	X	X	X	X	X[(f)]	X	X	X
Sharing energy	- [(b)]	X	-	-	-[(g)]	X	X	-
Increase the thickness of the façade to the walkway side	X	X	X	-	X	X	X	-
Watering	X[(c)]	-	-	-	-	-	X	-
Water-treatment	X[(d)]	-	-	-	-	-	X	-
Multi-property or condominiums	X[(e)]	-	-	-	-	X	X	-
Other:	-	-	-	-	[(h)]	-	-	-

Legend:

(a) Including new and existing dwellings.

(b) There is a new legislation called "Erneuerbaren-Ausbau-Gesetz (EAG)", the goal is to form energy-sharing communities (Renewable Energy Communities /Erneuerbare-Energie-Gemeinschaft (EEG), but it has not been fully defined yet.

(c) Referring to water management (Water Rights Act: Wasserrechtsgesetz 1959 (WRG 1959), bmlrt.gv.at) and water-treatment.

(d) RIS - AEV Wasseraufbereitung - Bundesrecht konsolidiert, Fassung vom 29.03.2021 (bka.gv.at).

(e) Rental Property Law (Mieteigentumsgesetz) – full consent of all parties required, Wohnungsgemeinnützigkeitsgesetz, Wohnungssanierungsgesetz.

(f) There are several levels of cultural protection. On the highest (historical buildings in Ljubljana center) even the insides are protected.

Register kulturne dediščine RKD https://gisportal.gov.si/portal/apps/webappviewer/index.html?id=df5b0c8a300145fda417eda6b0c2b52b

(g) Citizen energy communities defined and are starting now: http://www.pisrs.si/Pis.web/pregledPredpisa?id=ZAKO8141

(h) Efficient energy use in buildings tech guide:

http://www.arhiv.mop.gov.si/fileadmin/mop.gov.si/pageuploads/zakonodaja/prostor/graditev/TSG-01-004_2010.pdf

Low Voltage installations tech guide:

https://www.gov.si/assets/ministrstva/MOP/Dokumenti/Graditev/tsg_N_002_2013_nizkonapetosne_el_instalacije.pdf

After this general overview, partners were asked to foresee how these regulations can affect INFINITE results.

In France, the fire safety regulation can affect the installation of photovoltaic panels / insulation material. In relation to seismic hazard, the mechanical design, and properties of the attached façade. For heritage protection, in the perimeter of the “protection du patrimoine”, it will affect the choice the materials, appearance, etc. Finally, for sharing energy, if the renovated building will be connected to the grid, INFINITE kits cannot cover the private consumption.

In Germany, the planning has to consider the specific requirements marked in Table6. Each topic has to be considered as follows:

- Fire safety: dependent on the building class requirements are given for materials, fire resistance, fire aprons etc. of façades (GER: height is an important characteristic for grouping into a building class; class 1-3: <= 7 m, class 4: <= 13 m, class 5: <= 22 m; It is the main basis for the definition of fire requirements; In Germany and with regard to fire requirements "building height" is used meaning the level of the very upper floor (with rooms where people are regularly) above ground surface).
- Accordingly, components and composition as well as the arrangement needs to meet the rules for the specific purpose and application.
- Heritage protection: In case of a listed building the specific terms for that building needs to be taken into account. The appearance could be one of the protected characteristics which might need to be left unchanged. This needs to be checked case by case.
- Walkway side: If thermal insulation is going to be increased in a renovation and therefore using space over a walkway this must be discussed and agreed on with the local authorities. This issue is handled differently from federal state to federal state. The tendency seems to

be changing towards allowing it. Be aware that adjoining properties need to be respected as well.

In Italy, fire regulation applies depending on the height of the building. For instance, it does not apply for the Italian demo case. Also, heritage protection regulations are not applicable to it. Finally, the sharing of energy is not allowed for the moment.

In Slovenia, it is necessary to anticipate the right type of thermal insulation and the appearance of the building façade. For instance, the planned intervention of de demo case represents an additional significant load on the existing load-bearing structure of the building, it is necessary to make a static and seismic recalculation, which proves that the static and seismic resistance of the building will not be decreased.

In Spain, some kits could not be installed, depending on the conditions.

In Switzerland, every restriction and regulation for the building envelope has its own guidelines and specifications. certain materials with different technical and aesthetic specifications may be required depending on regulations.

In the Netherlands, concerning public law, in principle, because of the equivalence principle, it could be possible to apply any kind of innovative products in the Netherlands. Yet, getting an equivalence declaration is quite difficult (and can be costly). Concerning private law/standards, main barrier for innovations is quality labels (like KOMO), and certification.

In general, in all the countries a building permit is mandatory when renovation works will be carried out to change the building envelope (Table 29). In most of them, except the Netherlands, local regulations apply. In Austria and France also applies the national and regional ones. In Slovenia also the national/central ones and in Switzerland also the regional level. The Netherlands is the only country where national/central regulation only apply. When available, the link to the different regulations is provided at the bottom of Table 29. Finally, Italy is the only country where the building permit is not affected by alterations to the building design and floor plan (increase of floor space).

Table 29 Countries where a building permit is mandatory to change the building envelope (placing a prefabricated façade or roof of a property), the level of regulation that apply, and where the alterations to the building design and floor plan (increase of floor space) affect.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
Building permit (BP) mandatory	Yes (a)	Yes (b)	Yes (c)	Yes	Yes (d)	Yes (e)	Yes (f)	Yes
National/ Central	X	X	-	-	X	-	-	X
Regional	X	X	-	-	-	-	X	-
Local	X	X	X	X	X	X	X	-
BP affected by alterations to the building design and floor plan	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes (g)

Legend:

(a) In Austria, different instruments and specifications are available for the implementation of green buildings. Provincial laws form the legal basis for supra-local and local spatial planning. According to the Federal Constitutional Law, the enforcement of local spatial planning falls within the municipalities' own sphere of action. The respective specifications apply at the level of the zoning plans, which are defined by ordinances. Subsidies are often granted in the form of grants at the federal, state, but also municipal level.

Some cities, for example, stipulate green roofs in the zoning and development plan; likewise, there may be a requirement on an area-by-area basis not only to green the areas, but also to equip them with energy generation systems.

By means of urban development contracts, agreements under private law can be concluded between local authorities and property owners, which realize the goal of greening. It is important to maintain the public character of the project, which applies to street-side facade greening or publicly accessible roof greening.

On a national level, there are currently two programs for building greening that address consulting costs and investment costs, respectively:

An independent expert consultation for companies on green roofs and facades is subsidized by the Austrian Federal Economic Chamber to 100% within the framework of the ecological business consultation: https://www.wko.at/site/OekologischeBetriebsberatung/start.html.

Investment costs for roof and facade greening are subsidized by the Federal Environmental Promotion Agency (KPC) within the framework of the subsidy program for new buildings in energy-efficient construction with up to € 150/m² for new buildings used by companies in energy-efficient *construction or for existing buildings in the course of thermal building renovation. Companies and municipalities are eligible for funding: https://www.umweltfoerderung.at/betriebe/neubau-in-energieeffizienter-bauweise/navigator/gebaeude/neubau-in-energieeffizienter-bauweise-2.*

In the current city survey of the GREENMARKETREPORT in AUSTRIA on the topic of building greening, questions were also asked about funding incentives at the municipal level. It was found in the study that certain factors were considered very essential by the responsible parties surveyed, in particular the completion of a mandatory

The study showed that certain factors were regarded as very important by those responsible, in particular the completion of a binding consultation, standard-compliant execution by specialist companies, orientation on the runoff coefficient and the degree of sealing, as well as a minimum height of the substrate layer in green roofs.

(b) https://www.legifrance.gouv.fr/affichCode.do;jsessionid=BED4D2049F118AA122DD14A8C8137FE2.tplgfr32s_2?idSectionTA=LEGISCTA000031721322&cidTexte=LEGITEXT000006074075&dateTexte=20190329

(c) As a tendency; but it may depend on several specific aspects and regional obligations.

(d) When planned intervention represents an additional significant load on the existing load-bearing structure of the building. https://www.zaps.si/index.php?m_id=strokovna_predpisi

(e) For the virtual demo: https://www.alicante.es/sites/default/files/documentos/202008/bop-ordenanza-municipal-licencias-urbanisticas-y-ambientales-y-figuras-afines.pdf.

(f) https://www.are.admin.ch/are/it/home/sviluppo-e-pianificazione-del-territorio/strategia-e-pianificazione/concezioni-e-piani-settoriali/piani-settoriali-della-confederazione.html

(g) Not always, it depends.

In relation to historical / monumental characteristics that need to be taken into account when considering a retrofitting, the following Table gathers each of them per country. For any of the demo pilots apply.

Table 30 Historical / monumental characteristics

Country	Historical / monumental characteristics and public link with the conditions
Austria	Denkmalschutzgesetz, heritage protection law RIS - Denkmalschutzgesetz - Bundesrecht konsolidiert, Fassung vom 25.03.2021 (bka.gv.at)
	UNESCO heritage UNESCO-Welterbe in Österreich - Österreichische UNESCO-Kommission
France	-
Germany	In case of a listed building the specific terms for that building needs to be taken into account. Appearance might be one of the characteristics. http://www.denkmalliste.org/denkmalschutzgesetze.html
Italy	In the Italian DEMO there is no historical characteristic.
Slovenia	In the Slo DEMO site there is no historical characteristic: https://gisportal.gov.si/portal/apps/webappviewer/index.html?id=403a54629867466e940983d70a16ad9e&extent=497729.4074%2C155160.2522%2C498107.2332%2C155416.1048%2C3912
Spain	In a first step, it must be determined if the building is included in the regulations for the protection of cultural heritage. https://www.culturaydeporte.gob.es/cultura/patrimonio/bienes-culturales-protegidos/niveles-de-proteccion/regimen-general.html Then, it must be considered the building protection level. Then, the local regulations say the type of renovation works that can be carried out or not. For some, it is not possible to modify the outer envelope of the building. Regional regulation of the demo site: https://www.boe.es/buscar/pdf/2014/BOE-A-2014-9625-consolidado.pdf Local regulation of the demo site: https://www.alicante.es/sites/default/files/documentos/202008/bop-ordenanza-municipal-licencias-urbanisticas-y-ambientales-y-figuras-afines.pdf
Switzerland	Approval of project by national cultural heritage office. https://m3.ti.ch/CAN/RLeggi/public/index.php/raccolta-leggi/legge/num/557
The Netherlands	So called Monuments (National, Province, Local) have a special status and have separate rules and obligations.

Partners have also been asked about the aesthetic characteristics that need to be taken into account when considering a retrofitting (Table 31). In general terms it also depends on where the building is located.

Table 31 Aesthetic characteristics.

Country	Aesthetic characteristics and public link with the conditions
Austria	Also depending on the federal region where the building is located in. In some municipalities, the overall picture of the city/town centre has to be protected (For example in Salzburg, which is an old city with multiple buildings from the Middle Ages/Baroque Ensemble protection). Some Countries do have regulation about % of Timber façade. Ortsbildgesetz, naturschutzrechtliche Bewilligung, Umweltverträglichkeitsprüfung UVD, Vorschreibung Fassaden Ortsbild, Ensembleschutz proHolz Austria: Alles über Holz, Baustoff und Rohstoff
France	If the building is in the perimeter of “des architects de France”, it has to be taken into consideration the aesthetics appearance. On the other hand, it must be checked the PLU “Local Plan urbanism”.
Germany	Guidelines of the local development plan might contain limitations for cladding or roofing materials and colours.
Italy	-
Slovenia	Urbanistic, most of the requirements relate to the appearance of the building https://www.ravne.si/act/21302
Spain	It depends on local regulations. Maximum height of the building, cornice height, terraces. Compositional elements: cornices, eaves and integrated canopies plaster materials and colours. For the virtual demo: https://www.alicante.es/es/normativa/normas-urbanisticas-texto-refundido-no-6
Switzerland	It depends on the area in which the project is located. You need to check the zoning plan and the zoning master plan. https://map.geo.ti.ch/?lang=it&baselayer_ref=Carta%20Nazionale%20(bianco%20e%20nero)&tree_groups=Piano%20Registro%20Fondiario%20-%20SIFTI%2CPiani%20regolatori%2CPiani%20di%20utilizzazione%20cantonali
The Netherlands	The so called ‘welstandcommissie’, a local board assessing the aesthetics

When considering how the recast Directive 2018/2001/EU on the promotion of the use of energy from renewable sources has been applied in relation to self-consumption of renewable energy, in the different countries, it can be concluded in general terms that in multifamily buildings, PV panels con supply energy to common and private areas. Nevertheless, in Austria and France, PV panels can supply energy only to common consumption (centralised heat pump, centralised DHW, lighting of common areas and parking, centralised ventilation). And, in The Netherlands, it is not still clear.

Table 32 How the recast Directive 2018/2001/EU on the promotion of the use of energy from renewable sources has been applied.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
In Multifamily Buildings, PV panels can supply energy only to common consumption (centralised heat pump, centralised DHW, lighting of common areas and parking, centralised ventilation)	X [(a)]	-	-	-	-	-	-	-
In Multifamily Buildings, PV panels con supply energy to common and private areas	-	X	X	X	X [(b)]	X	X	-
Only to single houses	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	X [(c)]

Legend:

(a) EU countries' 2018 cost-optimal reports | Energy (europa.eu) OIB document for verification of the cost optimality of the requirements of OIB Guideline 6 and of the National Plan pursuant to Article 5 of Directive 2010/31/EU, Article 5(2) of the EPBD (2010) – Directive 2010/31/EU – obliges the Member States to calculate cost-optimal levels of minimum energy performance requirements using the comparative methodology framework established in accordance with Article 5(1) and relevant parameters and to compare the results of this calculation with the minimum. Austria has the National Plan.

Due to the similarity of the results for new builds and larger-scale renovation for residential buildings, service buildings and 'minor renovations' or 'renovation of elements', the previous results are considered to have been confirmed by way of reasoning by analogy

(b) Decree on the self-supply of electricity from renewable energy sources ad.5 http://www.pisrs.si/Pis.web/pregledPredpisa?id=URED7867

There is new regulation being drafted, and it is foreseen to be valid in this year. More in NRG2PEERS inquiry.

(c) This is the official status of the renewable energy directive in the Netherlands (in practice it is still a grey domain NL).

In relation to CE marking and to understand the different options (Table 33), it has to be reminded that the existing technologies that are already available will result in the following kits, to be developed during the project duration:

- Green façade/roof KIT.
- Fresh Air and distribution KIT

- Smart window KIT
- BIPV KIT
- BIST KIT
- aBMS

It also has to be reminded that that the answers provided by Austria refer to the passive eco-compatible & green envelope kit; France answers are related to Adaptable BMS and optimized control strategies; Germany, to timber frame elements; Italy, to all kits; Slovenia refers to all the kits except the energy generation BIST kit; Switzerland refers to Energy generation BIPV kit; and Slovenia, Spain and the Netherlands do not refer to any product.

Table 33 CE marking applicable to INFINITE kits.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
The current product has CE marking	X	-	- [(a)]	X	N/A	N/A	X	N/A
The resulting kits will have CE marking	X	-	- [(b)]	X	N/A	N/A	X	N/A

Legend:

(a) Timber frame elements are not subject to European product standards or European technical rules currently. Consequently, there is no CE marking possible. This will change in the future probably (Note: national rules apply that set requirements for production and production control)

(b) To our understanding "kits" as used in a building-authority point of view are subject to national regulation and therefore there will be no CE-marking. If "kit" in this environment would be classified as a building product CE-marking would be mandatory.

In general, regarding GDPR, the type of approach that the products have to follow to be installed in a building is to get an informed consent by each tenant (data to be stored, where it will be stored, who has access to the data, how long the data is stored). For the timber frame elements, any special GDPR rule must be followed (Germany).

Table 34 GDPR approach of the different products to be installed in a building.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
None	-	-	X	-	-	-	-	-
Informed consent by each tenant (data to be stored, where it will be stored, who has access to the data, how long the data is stored)	X	X	-	X	X	X	X	-
IT security aspects in the development of the product (in case of smart home applications)	X	-	-	X	-	-	-	-
Other	-	-	-	-	-	-	X [(a)]	-

Legend:

(a) Informed consent by the manufacturer.

Finally, in addition to investigating the barriers that legislation can affect the installation of INFINITE kits, we must also investigate what can promote them, such as financial instruments. According to [120] financial instruments supporting building energy renovations list, in INFINITE countries the following instruments have been found:

Table 35 Financial instruments that could apply to INFINITE solutions.

	Austria	France	Germany	Italy	Slovenia	Spain	Switzerland	The Netherlands
Grants/subsidies/funds	X [(a)]	-	X	-	X	X	-	X
Loans	X [(b)]	-	X	-	X	-	-	-
Tax/VAT incentives	X	-	X	X [(d)]	-	X	X	-
Energy supplier obligations (white certificates)	- [(c)]	-	-	-	-	-	-	-
Third Party Financing/Energy Performance Contracting	X	-	-	-	X [(e)]	-	-	-
Levies	-	-	-	-	-	-	-	-

Legend:

(a) Wohnbauförderung in each country.

(b) KPC Sanierungsoffensive: Umweltförderung Kommunalkredit Public Consulting (umweltfoerderung.at))

(c) Energy supplier obligations [121] and Renewable Energy Expansion Act (EAG) and the obligation to connect to and use district heating is governed by environmental regulations.

(d) It must be checked in detail; they are not added to EU financing usually.

(e) "Celovita prenova večstanovanjske stavbe: Subvencija Subvencija Pilotni razpis energetsko pogodbeništvo" (eng. "Complete renovation of a multi-apartment building: Subsidy Pilot tender Energy Contracting")

https://ekosklad.si/prebivalstvo/pridobite-spodbudo/seznam-spodbud/celovita-prenova-vestanovanjske-stavbe-3/celovita-prenova-vecstanovanjske-stavbe-subvencija-428

To see more details about them the following Table can be consulted, where the name, details, type, and link to the information that is available.

Table 36 Financial instruments that could apply to INFINITE solutions.

Country	Type (*)	Name, and description and public link with the conditions
Austria	N, R, L	In Austria, those grants are different in the 9 federal provinces, so there are a lot of options, depending on the province. Some of them are provided: HELP.gv.at: Grants and Financing https://www.help.gv.at/Portal.Node/hlpd/public/content/138/Seite.1380002.html Förderungen - GRÜNSTATTGRAU (gruenstattgrau.at): https://gruenstattgrau.at/urban-greening/foerderungen/
France	-	-

Country	Type (*)	Name, and description and public link with the conditions
Germany	N, R, L	Grants: Bundesförderung für effiziente Gebäude (BEG): Project to unify the grant programms from the the national state; organized in 3 parts of the program. 1st part Start 2021 Single measures - Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA): https://www.bafa.de/beg 2nd and 3rd part will follow til the end of 2022 Energieeffizient Sanieren – Investitionszuschuss: grant for total restoration to gain a certain energy-level (KfW) https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilie/F%C3%B6rderprodukte/F%C3%B6rderprodukte-f%C3%BCr-Bestandsimmobilien.html Energieeffizient Bauen und Sanieren: Zuschuss Baubegleitung: grant for engaging an expert for energy efficiency for planning and construction consultancy (KfW) Loans: Energieeffizient Sanieren – Kredit: promotional loan for total restoration as well as for single measures to gain a certain energy-level (KfW). Energieeffizient Sanieren – Ergänzungskredit: promotional loan for conversion of heating to renewable energies (KfW) Erneuerbare Energien – Standard: promotional loan for facilities for using renewable energies as e.g. PV (KfW) Tax: Energetische Sanierungsmaßnahmen-Verordnung – EsanMV in §35c EStG: costs of energy-level aiming restoration can be set off against tax liability (heat insulation of façade or roof, new windows or doors, new or renewing air ventilation, renewing heating, digital systems for energy efficiency) (BMF): https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Klimaschutz/2020-02-07-steuerliche-foerderung-energetischer-gebaeudesanierungen.html
Italy	N	GSE – Gestore servizi energetici / Superbonus (it expires in June 2022): https://www.gse.it/
Slovenia	N	Eco Fund, Slovenian Environmental Public Fund (Eco Fund). Its main purpose is to promote development in the field of environmental protection by offering financial incentives such as soft loans and grants for different environmental investment projects: https://www.ekosklad.si/english
Spain	N	PREE: BUILDING ENERGY RENOVATION PROGRAM: Aid plan of € 300 million for the energy renovation of buildings for: 1. The thermal envelope. 2. Use of renewable energies in thermal installations for heating, air conditioning, refrigeration, ventilation, and sanitary hot water.

Country	Type (*)	Name, and description and public link with the conditions	
		3. Lighting installations. https://www.idae.es/ayudas-y-financiacion/para-la-rehabilitacion-de-edificios/programa-pree-rehabilitacion-energetica-de	
	R	Plan Renove: Boilers and aerothermal: http://planrenove.ivace.es/es/	
	R	TAX DEDUCTIONS: Tax deductions in income tax for self-consumption and renewable energies: https://www.ivace.es/index.php/es/ayudas/energia/deducciones-fiscales-en-irpf-para-autoconsumo-y-energias-renovables/6816-deducciones-fiscales-en-el-irpf-para-autoconsumo-y-energias-renovables	
	N, R	Conservation and accessibility: Aid for the conservation and accessibility of residential buildings: https://calab.es/ayudas-economicas/	
Switzerland	N, R, L	Remuneration for PV: In Switzerland, Pronovo is in charge of promoting photovoltaics on a federal level. Some cantons, towns and energy suppliers have additional subsidy programmes: https://www.swissolar.ch/it/temi-principali/incentivi-fv/#:~:text=In%20Svizzera%20il%20fotovoltaico%20%C3%A8%20incentivato%20a%20livello%20federale%20da%20Pronovo.&text=La%20distribuzione%20dell'incentivo%20avviene,messa%20in%20servizio%20dell'impianto. https://pronovo.ch/it/	
The Netherlands	R	-	-

Legend:

(*) N: national level; R: regional level; L: local level.

7.5 Current situation of industrialization in INFINITE countries and specific conclusions

In this section, first the context of the specific country is introduced. Then a Strength, Weakness, Opportunity, and Threat (SWOT) Analysis about the state of the industrialization sector in each country of the participating partners is shown. Linking this analysis to the parameters obtained in previous sections, several conclusions are drafted to propose the INFINITE kits that are more feasible to be installed in each of the countries.

Austrian chapter

Context

Austria is estimated to have one the highest prefabricated shares among the central and northern part of Europe as per the overview of market study by Roland Berger [59]. The main features are:

- Energy efficiency regulations are likely to positively impact the prefabrication market.
- The market volume of 1+2 family housing is expected to continue its growth during 2022 but a slower pace.
- The Austrian prefabricated housing market displays a good balance of finishing types. Timber-frame is the prevailing material type.
- Austria reveals a high share of prefabricated housing (c.355 In 2017). The western part of Austria has a lower share than the eastern part of the country.
- The mid-price segment is estimated to account for the largest share of prefabricated housing. The mid- and high-price segments are forecast to grow strongest in the upcoming years.
- In Austria, prefabricated houses are typically sold directly to end customers.
- Large developers almost exclusively focus on traditional technologies to retain control of the construction process and to optimize costs.
- Small, prefabricated housing manufacturers are reported to cooperate with regional developers on projects of up 10 houses. However, this is rarely for large manufactures.

Putting the focus on timber construction, qualitative interviews with representatives from companies (IBE Solutions, CREE buildings, holzbau austria) involved in research and implementation of prefabricated elements were conducted. The history of prefabrication in Austria is closely linked to the **strong economic sector of the timber industry** and the resulting know-how of the field. Austria has a large forest stock (47%) and the timber industry is one of the largest employers of all industrial sectors in Austria, especially in economically underdeveloped regions [60].

Over the last years, prefabrication has revolutionised timber construction. The timber construction sector takes on a pioneering role in construction when it comes to digitalisation and automation. Due to modern computer-controlled machines and innovations in transport and lifting tools, the **share of prefabricated housing in Austria has increased**. It is difficult to quantify the current share of prefabrication in relation to conventional construction methods, but the trend moves towards maximum prefabrication (planked, technical installations, windows...). **Depending on the manufacturer,** the processes are already more or less industrialised, partly being manufactured horizontally (on tables), either turned over by crane, or automatic turners. Robots are used to blow in thermal insulation, or for joining parts (nail and clamp robots). The same applies to machines for panel cutting.

Currently the focus here is mainly on new buildings, but more established solutions for the digital mapping of existing buildings are contributing to the increased use in retrofitting as well. Various R&D companies (e.g., AEE Intec, GROPYUS, Rhomberg, CREE buildings…) also located in Austria have developed different solutions for industrialized building and renovation. Especially **multifunctional energy facades** have a high synergetic potential for use (cost reduction) and play an important role for decarbonising the energy system. Trend-setting concepts and products are available, but due to their variety there is still a need for research.

The Austrian timber construction sector has recovered well from the corona pandemic. Incoming orders have increased by +6.8 % in the 1st to 3rd quarters of 2021 (compared to -5.3 % in 2020). More than half of the companies reported a good demand situation in the 4th quarter of 2021. **Prefabricated house construction and the roof extension/refurbishment are the segments with the highest growth**, as a recent survey shows [61].

For customers in Austria, prefabricated buildings have gained in popularity and the **demand has risen visibly**. Especially the short construction time and therefore cost reduction potential have led to a higher acceptance. Through best-practice projects, timber construction and thus prefabrication in Austria became more visible to the public. Various information campaigns and publications by the individual associations (see below) led to this knowledge being shared and, in view of the EU requirements, also playing an **increasingly important role in renovations**. In Austria, there is a high potential for additional housing development or **urban densification** (attic extensions made of wood).

Austrian timber construction companies have a high expertise in the prefabrication of timber elements. Most of those **companies are small or medium-sized enterprises**, most of which do not have the personnel or infrastructural capacities for large production lines, a requirement for the serial prefabrication of building components. Currently, the demand for ecological, timber-based materials for buildings is so high that there is a **lack of skilled workers** to handle the large number of orders. However, this is expected to be offset by the **advancing digitalisation and gradual automation of manufacturing processes** over the next five years. There are only few big companies (e.g., Kulmer, Strobl, Dankl, as well as Rubner) which are practising prefabrication on an industrial scale. However, for large projects, **several smaller companies are often contracted** to prefabricate the building elements according to plan (usually divided floor by floor) and assemble them on site.

Common systems are timber frame and timber panel construction as well as solid timber construction. The construction with room cells/modules has the highest degree of prefabrication - a trend currently visible is the prefabrication of bathrooms, kitchens or loggias/balconies in standardised sizes. The cells are completely prefabricated and can be offered in various configurations depending on the field of application (e.g., for hotels, schools or residential buildings). However, when it comes to of transport and size, panels are more efficient ("transporting air" inside the room modules). Current research projects deal with modules that can be unfolded on site to for a more efficient transport. In the near future, a challenge will be to **optimise the transport of prefabricated elements,** also regarding **rising fuel prices**.

Prefabrication and timber market in Austria

The development of the share of timber construction in relation to usable floor space has risen steadily in Austria within the last years: from 14% in 1998 to 20% in 2008 and 24% in 2018. Especially in large-volume construction, further increases of timber construction (and therefore prefabrication) are expected [62].

In order to better understand the timber industry and market in Austria, an explanation of the associations dealing with this topic is needed. The organisations listed below are working on the **quality assurance, development and research of timber construction and prefabrication** in Austria. Those associations focus on their respective competences but are in constant exchange, especially when it comes to standardisation work.

The Association of the Austrian wood industries (Fachverband Holzindustrie Österreich) includes those companies that are responsible for the processing of natural timber resources. Examples for big Austrian companies are Mayr Melnhof Holz, Binderholz, Hasslacher Norica Timber, Stora Enso or Binderholz. They are also known EU- and worldwide for exporting their products (e.g., CLT) to further processing companies. Recent developments have shown that some of these companies are now also **expanding their knowledge regarding prefabricated elements** and employ their own specialised architects for this matter.

The Austrian prefabricated house association (Österreichischer Fertighausverband) unites various manufacturers for prefabricated houses (such as ELK, Hartl Haus, HAAS, etc..) and industry business partners. The Austrian Norm ÖNORM B2310 (Prefabricated buildings) provides information about terms, definitions, and minimum performance. **Mandatory quality checks** are carried out regularly by the independent Austrian Forest Products Research Society (Holzforschung Austria), which is the largest **research and testing institute** for this matter in Austria.

Holzbau austria is a network consisting of about 2400 Austrian timber construction companies. The main concern of this association is to improve the market conditions for those companies. A magazine of the same name as the official organ of the Federal Guild of Timber Construction fulfils the function of an information platform on current technical developments.

proHolz Austria is the marketing organisation of the Austrian forestry and timber industry. Its main purpose is promoting the ecological, economic, and constructional advantages of wood by best-practice examples and relevant information (both for the general public in Austria and for professionals involved in planning and building). They are also active in international sales markets around Austria.

SWOT analysis

The **main barriers** that this country presents are:

- Up to now, only a few selected timber construction companies have the know-how, infrastructure, and experience to realize large-scale projects [63].
- Due to the high potential, robotics is needed to compensate for the shortage of skilled workers. This means that every company who has already moved their development towards automation is increasing their chances of realising larger building projects.)
- Besides single-family house construction, the industrial prefabrication still is not widely implemented. Although there are various industrialised processes for walls, ceilings, and roofs (which are then delivered as individual components) there is no significant serial production

of complete building systems for multi-storey residential, commercial, and industrial buildings. An exception here, as mentioned before, is the production of room cells [63].

Standardisation and quality assurance:

- No generally applicable standards on products/elements (Each company develops its own standard and instructions (the basic requirements for the building envelope with regard to airtightness, moisture protection, fire protection, etc. must of course be fulfilled and common grid dimensions are respected - according to panel dimensions).
- However, regular quality checks by independent testing facilities are required to ensure long term quality of prefabricated modules. The manufacturers and processes are quality-controlled (a third-party inspection institute reissues quality seal after multiple assessments in the quarter). This means that the current focus is not on standardizing components, but production processes, up to and including CE markings.
- Regional differences when it comes to funding and regulations (9 federal states in Austria, of which each provides different incentives, e.g., for renovation) [64].
- No direct funding for industrial prefabrication, lack of incentives.
- Price increase on individual products.
- Availability of building materials (also insulation, up to screws - if they are not commercial sizes, products are not in stock in larger quantities.
- Even though the topic of industrialised building is very present in universities and education of young architects, in older generations of planners there are still considerable knowledge gaps. The will to deal with systematic construction methods is seen critically amongst most planners (lack of individuality).
- For a successful implementation, a change in the structure of timber manufacturing companies is required. However, these seem to be developing slowly [63].
- Standardization is necessary to achieve better planning and approval security. This includes the development of building systems, tailored to the individual building types (residential buildings, office buildings, commercial buildings, etc.) [63].
- Further research and development are essential, this can only be successfully handled in close cooperation between architects, engineers, and entrepreneurs [63].

The **main opportunities** (besides the general driving factors for prefabrication already mentioned) are:

- Market increasingly demands resource-optimized buildings.
- In the next years, shifts in the value chain are expected and a great amount (also in renovation) will be shifted to prefabrication. Industrial manufacturing will also play a serious role in residential construction in the foreseeable future.
- Ideally, serial production can influence the issuing of building permits. A faster procedure would be possible if serially produced components no longer have to be approved individually, but a general approval is sufficient [65].
- Prefabrication makes sense, particularly in refurbishment; it is no longer adequate to completely cover the building for a long time in order to provide full thermal insulation.
- Processes have to be standardised better and with higher quality than in the 80s.

Table 37 Austrian SWOT analysis on industrialization

	STRENGHTS	WEAKNESSES
INTERNAL ORIGIN	·High-quality thermal refurbishment and renewal of building services are possible with less inconvenience for residents & fast construction time. ·Ecological construction. ·Process quality (more controlled, employee-friendly, better working conditions). ·Less space required for intermediate material storage on site (cost and time savings for permits). ·Construction site less vulnerable to theft/burglary during refurbishment. ·Companies have long experience and high expertise with timber construction and prefabrication (Good quality of workmanship). ·Good calculability (more realistically plannable construction time and costs, fewer surprises).	·Higher manufacturing costs of prefab elements compared to conventional composite thermal insulation system (especially timber construction)- Covid intensified this issue. ·Connecting building technology - Junctions are most susceptible to manufacturing errors. ·Prejudices: Impairing architectural planning (less Individual). ·Long (pre-)planning phase. ·Not enough trained workforce for high demand. ·Only few companies have capacity for industrialised manufacturing.
	OPPORTUNITIES	THREATS
EXTERNAL ORIGIN	·Industry: Consistent improvements in processing quality, production technology and site management. ·Very high demand for timber-based construction/renovation. ·Use of BIM could promote standardising different building elements/modules. ·Easier implementation of renewable energy systems such as PV or solar thermal collectors. ·Through assembly and disassembly, the deconstruction remains recyclable. ·Exemplary effect of projects.	·Integral planning/communication between different planners and contractors is essential (Only then it is possible to optimise costs throughout the entire process). ·High logistical requirements over a short period of time must be taken into account during planning. ·Increased requirements for dimensional accuracy.

Conclusions:

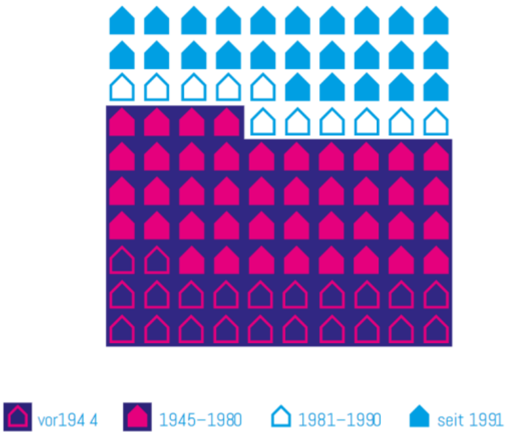


Figure 28 Residential buildings in Austria by construction period. Source: [66].

– Around two thirds of buildings in Austria have been built before 1990. In terms of energy efficiency, **60% of the total housing stock is considered to be in need of renovation** [66].

– Greatest opportunities in existing buildings - biggest potential in terms of cost & mass: residential + office buildings first or focus on large market niche where framework conditions work.

– Around 73% of Austrian residential buildings are single-family homes (B06A individual Residence), even in cities (>20.000 inhabitants) the share of single and two-family houses is with 67% quite high. Many single-family homes were built in the 1970s, are over dimensioned (therefore expensive to renovate) and were erected on large properties [67]. So, having less height and being a single owner, it is easier to apply industrialization in general and INFINITE products in particular.

– At the beginning of 2020, there were around 2.11 million residential buildings and 4.88 million flats in Austria. Of the residential buildings, **87.1 % are single- and two-family houses and 12.9 % are multi-family houses** [68].

– Urban sprawl and high sealing rates are a big problem in Austria, which is why the redensification (e.g., of post-war buildings), especially in urban areas, has gained in importance.

– According to section 7.2.3.8, the percentage of social housing – dwelling/units (O03E) in the country, is about 16% of the total built stock. In general, this type of building has a single owner, which will facilitate the energy renovation of the building and the dwellings.

– The timber industry in Austria has a complete value chain that leads to high production density and domestic value creation [69].

– In July 2020 the Austrian National Council passed the Forest Fund to support the domestic forestry and timber industry with 350 million euros. It includes the **timber construction offensive** for an **increased use of timber as a building material** as well as investments in timber construction research. In the government programme 2020-2024 timber construction in Austria is mentioned as a climate protection measure - construction projects in the public sector should function as showcase examples [70].

– Photovoltaic makes a lot of sense (especially in the city of Vienna - gas boilers have to be exchanged) - gas and oil prices are rising, building laws have to change. According to section 7.2.3.3 Share of fuels in the final energy consumption in the residential sector for space heating, more than 1 out of 4 dwellings still use Gas (B11C), which could be replaced by systems using renewable energies. There is a lot of room for improvement.

– According to section 7.2.3.1 the share of dwellings with central heating systems (collective and individual heating) (B04D) is around 95%, so it will be much easier to incorporate BIST kits.

- The Austrian Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (BMK) will **continue to support thermal building renovations** in 2022 as a step towards Austria's targeted climate neutrality in 2040. A total of 650 million euros is available for private households, businesses, and municipalities to facilitate the transition from fossil-fuelled domestic heating to a sustainable heating system and **push the renovation offensive** 2021/2022 [64].
- Solar systems are also promoted by the Climate and Energy Fund in order to advance an environmentally and climate-friendly electricity supply. In addition, the individual federal provinces in Austria offer subsidies for renovations or solar installations.
- At the city or municipal level, more financial support is offered for roof or façade greening. The city of Vienna in particular is taking on a pioneering role here.

With all the above, it can be concluded that **all INFINITE kits** have a high potential to be used in Austria.

French chapter

Context

In France, the use of prefabrication, or even standard building models, is regularly presented as the solution to improving the efficiency of the construction sector. The Elan law was an attempt to introduce specific provisions to promote the use of these processes, and the mission entrusted in February 2019 by Julien Denormandie, Minister of Urban Affairs and Housing, to Bernard Michel and Robin Rivaton to accelerate the development of innovation in construction sector clearly goes in this direction. However, some restrictions and limits associated to these processes are often highlighted by the construction stakeholders and architects for instance recommend being careful with the prefabrication approach [71].

"Prefabricated architecture is most often the object of a profound aversion, linked to the trauma associated with large complexes which is not the case in our European neighbours' countries" (Yvan Delemontey, architect, and architectural historian) [72].

At the end of the 1950s and the beginning of the 1960s already, the policy of large housing estates encouraged the use of prefabrication to build faster, much, and less expensively. At that time, new processes are emerging. Mechanization, rational organization of the construction site and prefabrication in concrete become the new generative principles of the architectural project. Simple shapes such as bars and towers are favoured along the crane path. This facilitates the installation of concrete plants close to the construction site in a search for time savings and the use of unskilled labour. Models related to industrial prefabrication systems have also been widely used for the construction of colleges and high schools, hospitals, swimming pools and administrative buildings. But the first cities were built in a hurry and quickly deteriorated. Insulation is non-existent. Because of lack of maintenance, the buildings deteriorate even before all the equipment is finished. The reduction in competition between companies and the cost of construction, the architectural and urban poverty generated, the lack of sociological reflection will show that the miracle solution of the industrialization of the sector, as well as the policy of models, prove to be errors with serious social, environmental, and urban consequences.

This observation led to the end of the policy of large housing estates, with the circular of Olivier Guichard, Minister of Equipment, of March 21, 1973. This was followed by the publication of two structuring laws for the quality of constructions: that of the January 3, 1977, on architecture and that of July 12, 1985, known as MOP. However, this has not marked a total halt to this trend: the prefabrication and industrialization of construction elements have logically developed, with an offer of industrialized structural elements (pre-slabs, stairs, façade panels), multiple technical elements, such as pre-assembled or pre-wired electrical panels, or assembled, concerning several trades, such as prefabricated bathrooms.

On November 23, 2018, the Elan law provided prefabrication with a definition, inserted in the Construction and Housing Code (CCH). The code article L. 111-1-1 thus specifies that "**prefabrication consists of designing and building a structure from prefabricated elements assembled, installed and implemented on site**. These prefabricated elements are inseparably one with the works of viability, foundation, framework, enclosure, and cover of the construction and can integrate the insulation and the reserves for the various networks. They are produced on site which can be either a factory or a workshop, or a temporary installation adjoining the construction site" [71].

The **off-site concept** takes over from prefabrication, which was promoted by the ELAN law, but goes further. Offsite is defined as prefabrication plus an industrialized dimension of on-site assembly and transport from production to site. The off-site approach is an opportunity for the construction sector. Despite the multiple environmental and regulatory constraints that are now imposed on structures in France and that are reviving interest in off-site construction, the share of prefabricated products remains minor in France, unlike certain countries in Northern Europe, North America or Asia, geographical areas in which off-site construction is experiencing double-digit growth. However, the impulsion given by major construction sites in urban metropoles, combined with the difficulty of recruiting skilled labour on site, is accelerating the off-site construction approach.

Finally, another opportunity for the prefabrication and off-site construction expansion is identified in France through the Recovery Plan launched recently to support the renovation of the building stock (objective: 500,000 housing units renovated per year). However, the construction companies encounter large difficulties to recruit, and the Recovery Plan recommends avoiding the use of posted workers. Therefore, how to build and renovate massively without qualified professionals, knowing that it takes "years to train a construction worker? " The potential solution is "to reindustrialize France thanks to off-site construction". Prefabrication will make it possible "to free up skilled labour for construction sites", but also to "transfer hours from the construction site to the factory" [73].

The Batimat/Campus-Hors-Site/TBC Innovations barometer, published in November 2021, compiles the results of a study carried out among two hundred construction industry players in June 2021 [74]. Its purpose is to decipher "the expectations, behaviours and uses of project management and project management actors faced with the opportunity of Off-Site Construction in France". This study revealed important items in terms of current use of off-site construction and the barriers and weaknesses associated to this process. Off-site construction is unanimously a solution for the future for professionals, but for which an effort to structure, train and support professionals is necessary. The opportunity is there, especially for the residential segment, the market must now pass a first stage of maturity with numerous and successful feedback [75].

SWOT analysis

The main barriers items the France encounters as regards to the prefabrication expansion are the following:

- Certification process of the innovative construction technologies.
- Application of industry methods that will require an important use of digitalisation tools. Practices must integrate these tools at different levels, despite the significant delay of the construction sector in this area.
- Lack of collaboration between the actors, the training as well as the corporate culture.
- Funding is needed to create the industrial production network throughout the territory and support the emergence of a Market.

The main Items that may encourage and push the prefabrication process in France are the following:

- RE2020 implementation. The share of prefabrication (workshop construction) will increase, due to the significant use of wood and bio sourced materials that is emerging with the new regulation RE 2020. For a decade now, wood construction has moved away from the construction site. CLT (cross-laminated), an industrial panel for structural use measuring 3.5 x 15 to 20 m, is establishing itself on the wood derivatives market, allowing to replace the concrete in the floors and walls of small buildings thanks to its resistance and its controlled cost. For other bio sourced or geosourced materials (hemp, straw, earth, etc.), governed by technical advice and professional rules, prefabrication in different forms, in wooden boxes for example, is encouraged.
- Increase in the environmental requirements and labels that could encourage the off-site construction mode.
- Frugality is now a strong theme In France that encourages the optimization of the quantities of materials used.

The construction will change profoundly in the coming years under the pressure of the lack of labour and the reduction of carbon emissions. The lack of qualified resources is cited as the main reason for adopting technologies of industrialized construction over the past three years (72%), in the face of cost pressure (67%), pressure on deadlines (64%), better uses (31%) and security issues (28%). Regulation acts as a powerful spur to innovation [76].

Table 38 French SWOT analysis on industrialization

	STRENGHTS	WEAKNESSES
INTERNAL ORIGIN	· Implementation times reduced. · Reduce the hardship of construction sites. · Limit nuisance for residents. · Maintain or even reinforce the quality level of construction. · Reduce construction waste materials. · Limiting pollution on site. · Previous successful experiences.	· Prefabricated elements are supposed to be more expensive if the transport is considered in the global economic equation. · Investments costs are important for a weak rentability. · Lack of offers, and many systems are not certified. · Carbon footprint of transporting the prefabricated elements by road transport. · "Light" construction methods, with wood or metal frames, have construction characteristics that are not suitable for all sites. · An increase in the delocalization of construction in modules pre-assembled in the factory modifies above all the role of the various actors by depriving access to the order of craftsmen and SMEs close to the construction site, and which constitute an essential part of the economic activity of a region.
	OPPORTUNITIES	**THREATS**
EXTERNAL ORIGIN	· National environmental objectives and targets and national regulation context evolution. · BIM development, digital design, and management. · Current difficulties of recruitment on the execution functions. Better attractivity for young people. · Need to reduce nuisance from construction sites.	· Construction culture is far from the industrial culture. · The performance and quality of prefabricated products is not always verified and rarely controlled. Claims assessments too often rule out the quality of prefabricated or ready-to-use products because their analysis is very expensive.

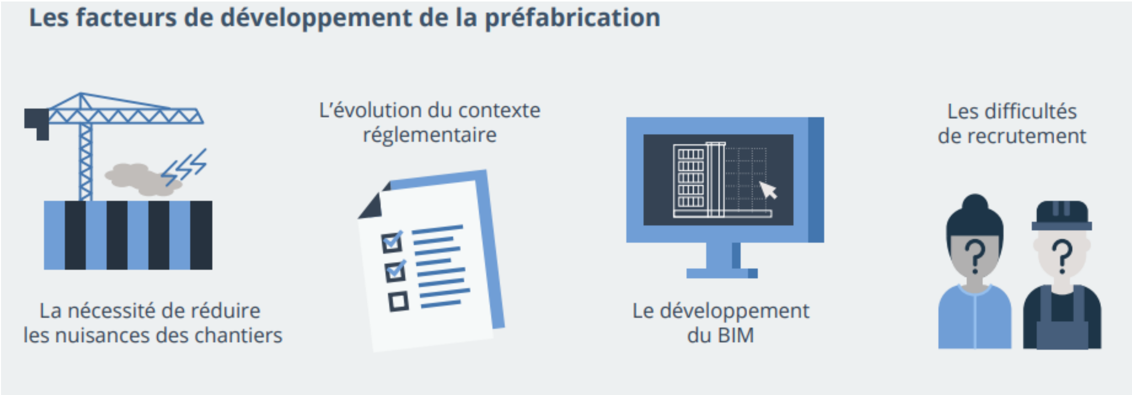


Figure 29: Developement factors of prefrabrication - Infography from "LES IMPACTS DE LA PREFABRICATION, INDUSTRIALISATION, SUR L'ORGANISATION DES ENTREPRISES ET METIERS DU BTP", Observatoire des métiers du BTP

Based on the statistics obtained for the development of the deliverable and considering the uniqueness of this country that due to its extension and depending on the area has similar characteristics to the countries of the north but also of the south, we can conclude that:

- France is the third country in the EU with the highest residential building stock (2017, section 7.2.3.2, total number of individual residences a collective residence). Furthermore, more than 60% of the residential buildings were built before 1980 (section 7.2.3.4, B15A) and generally do not have thermal insulation. And the growth in the number of dwellings has been waning since 1980 1980, with a trend of inadequate growth in housing supply relative to the growth in the number of households [77]. This indicates that their energy efficiency is low and with great room for improvement, so they are likely to require major renovations to meet new regulations and current comfort conditions. This is one of the main opportunities to apply industrialization in retrofit processes using INFINITE kits for deep renovation.
- Considering the building floor area that is occupied by residential dwellings (totalling some 3076.88 million m²), of this, 32% is occupied by multi-family buildings [77] (Collective Residence-B06B), which implies that for the installation of the different KITS at building level and especially for deep renovations, an agreement will have to be reached between all the owners, if the building is not owned by a single owner.

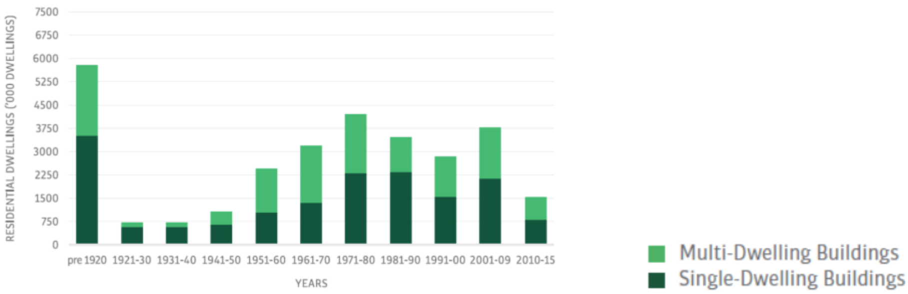


Figure 30 Residential building space trends in France. Source: [77]

On the other hand, since 68% of the floor area is occupied single-dwelling buildings, it will be easier to address the renovation of these type of buildings to install INFINIT kits.

- Related to the above, the share of dwellings with central heating systems (collective and individual heating) (section 7.2.3.1, B04D) is around 98%, so it will be much easier to incorporate BIPV kits.
- Regarding the parameter share of fuels in the final energy consumption in the residential sector for space heating (section 7.2.3.3), about 35% of the dwellings still use Gas (B11C). Considering the national context, nuclear energy occupies the largest share (44.66% in 2015), followed by petroleum products (30.97%). France enacted the Energy Transition Act for Green Growth in 2015, paving the way for the transformation of its energy system with the aim of reducing nuclear energy's share in electricity production to 50% by 2025 [77]. Therefore, heating systems could be replaced by systems using renewable energies, which is already used by 1 out of every 3 dwellings in the country (B19A).
- The high levels of solar radiation in the southern part of the country, like most southern European countries, indicate a high photovoltaic potential and therefore more profitable will be the generation of solar energy (BIPV and BIST kits).
- If we look at the percentage of social housing – dwelling/units (section 7.2.3.8, O03E) in the country, it ranks fourth in the European Union, with 15.70% of the total built stock. In general, this type of building has a single owner, which will facilitate the energy renovation of the building and the dwellings.
- Even though some areas of the country, according to the Water Risk Atlas and indicators [56], are at medium and high risk of water stress, there are no water restrictions, so the green envelope kits are a tool for deep renovations in France.

To conclude, **the INFINITE kits** with greater viability to be installed in France are:

- Passive eco-compatible & green envelope.
- Energy and fresh air distribution envelope.
- Energy generation BIPV kit.
- Energy generation BIST kit.
- Adaptable BMS (aBMS).

German chapter

Context

A pioneer of industrial prefabricated construction in Germany was Walter Gropius, who in 1960 founded a company together with Konrad Wachsmann that developed a construction modular system to produce single-family houses [78].

Today, very high levels of prefabrication are already achieved for load-bearing structures and building envelopes in certain building systems. Individual component groups, such as façades for commercial buildings, are predominantly prefabricated [78]. At the end of 2019, the prefabrication rate across Germany reached 20%, while at the turn of the millennium was still 13.5%. Since 2015, the percentage of residential units delivered using prefabrication technology in Germany has increased slightly from above 9.1 % to 10.5 %, which means that just slightly over one-tenth of residential units delivered over 4 years was built using prefabrication technology [79]. Examples of companies that offer comprehensive services in housing prefabrication include Firmengruppe Max Bögl and GOLDBECK GmbH which operate on the German market [79].

Table 39: New residential units delivered using prefabricated construction technology in Germany in the years 2015–2020. Source: [79]

Germany	2015	2016	2017	2018	2019	2020
Residential units in total	216,727	235,658	245,304	251,338	255,925	268,774
Large panel Large block	19,720	27,985	27,970	28,140	27,812	28,101
Percentage share	9.1%	11.9%	11.4%	11.2%	10.9%	10.5%

The high demand for prefabricated houses and energy-efficient buildings is contributing to the growth of the building market. The increasing importance of moving from cities to rural areas is beneficial to the development of the prefabricated housing market. In addition, the significantly higher market security, fixed prices at the start of the project, fixed deadlines, and minimized risk of delays are catalysts for substantial growth in the prefabricated construction industry. The eastern part of Germany shows the strongest growth momentum [80]. Timber-frame is a common material type of prefabricated housing and is expected to further gain in relevance. This development is supported by the increasing relevance of sustainability and ecological structures. And timber as renewable raw material supports this trend. Besides this, requirements of construction components with higher energy efficiency increasingly support the prefabricated market segment. Germany has a stable GDP Development and GDP Development is one of the closest proxies for construction development [81]. At present, prefabrication can be supported by Building Information Modelling technology, which enables the creation of a common data model for all stakeholders and includes information about the life cycle of the building and its maintenance needs. The use of prefabricated products and building components is seen as a good option if the building objects of a project are at least 100 flats, but preferably 150 to 200 flats at one or more locations. In this way, the potential of serial construction can be exploited, especially by housing companies with large new construction volumes. [82]

Despite these advantages and opportunities, prefabricated components are rarely used in residential construction in Germany. The reason for this lack is mainly on the one hand linked to the designers, who often lack the relevant knowledge and experience of this construction method. On the other hand, it is also due to the housing companies, which, although seem to have a basic acceptance of this construction method, are not aware of its technical and economic advantages. Beyond that, limited design options are often not fully context- or user-specific and can lack the ability for customization. Attracting customers with customized features can be a big challenge for designers and planners. As the increasing demand for construction occurs, productivity in construction should also be increased. Parts of production have been outsourced, mostly to countries where conditions are more favourable. The skilled worker's shortage indicates that the construction industry is becoming less attractive compared to other industries [78]. Some studies show that the growth rate of labour productivity in the German construction industry from 1998 to 2015 was rather below average relative to the economy. Accurately estimating productivity carries risks, because productivity assumptions are highly sensitive and can impact the entire project [83]. At the level of components, the products are manufactured industrially in large quantities regardless of demand. The low productivity of the construction industry leads to high prices and error rates. Additionally, a certain conservatism prevails in the construction sector, starting with the persistent reluctance to embrace new ideas, through the lengthy processes during planning permission and construction implementation, to the maintenance of structures and ultimately the dismantling of these structures [78]. Saving money and thus renting out flats more cheaply with prefabricated multi-family houses from the factory is not yet possible. So, demand from the few suppliers is still too low for that [84]. At present, the network of production companies for system elements is relatively thin, so this type of construction can be hardly applied in many regions. The reason for this is that the supplier for new construction with prefabricated elements is characterized by several larger companies that work with a regional focus. This construction method is currently limited to a few regions with a very strong demand for new buildings [82].

Table 40 German SWOT analysis on industrialization

	STRENGHTS	WEAKNESSES
INTERNAL ORIGIN	·Digital technical support: BIM Technology. ·Higher market security: reliability of cost estimations. ·Timber-frame for prefabricated housing: supported by the increasing relevance of sustainability and ecological structures.	·Deficiencies in skilled workforce resources. ·Limited design options: lack the ability for customization and increase design complexity. ·Accurately estimating productivity. ·Variable spatial distribution of providers.
	OPPORTUNITIES	THREATS
EXTERNAL ORIGIN	·The high demand for turnkey or prefabricated houses and energy-efficient buildings. ·The increasing importance of moving from cities to rural areas. ·The increase in the prefabricated housing construction investments. ·Higher energy efficiency requirements.	·Conservatism in the construction sector. ·For housing companies: not aware of the technical and economic advantages of this construction method. ·High-quality demand and price expectations from costumers. ·No cost saving.

Conclusions

Being aware of these limitations and potentials, and based on the statistics obtained for the development of the deliverable, it can be concluded that:

- Germany is the first country in the EU with the highest residential building stock (2017, section 7.2.3.2, total number of individual residences a collective residence).
- Almost 75% of the residential buildings were built before 1980 (B15A) and generally do not have thermal insulation. This indicates that their energy efficiency is low and with great room for improvement, so they are likely to require major renovations to meet new regulations and current comfort conditions.
- According to the Federal Statistical Office, more than half of the 19 million residential buildings in Germany are more than 40 years old. Around five million houses have even been standing for more than 60 years. Around 65% of façades of buildings in Germany are uninsulated, and another 20% do not represent the construction state of the art [85].
- Buildings that are 40 years old or more due to their old properties need to be renovated. About 70% of buildings in Germany are in urgent need of renovation. The renovation rate has been stagnating at around 1% per year for a long time, depending on building technology and application. It will not be possible to achieve the German government's goal of a climate-neutral building stock by 2050. So, since 2021 the German government bundled its existing programs to promote energy efficiency and renewable energies in the building sector. And the German government has therefore offered substantial billions of available financial supports in recent years to promote building renovation [86].
- Germany is a country rich in water as only approximately 24% of available resources are used in Germany. However, due to unfavourable water balance, especially the central and eastern areas of Germany face a decreased supply of water in the summer months. Water supply and distribution are not yet prepared for the water shortage in Germany. Due to this, the risk of drought increases and can have a negative impact on agriculture, forestry as well as energy- and water supply [87].
- There is a greater number of single-family buildings, around 58% (B06A individualResidence), so having less height and being a single owner, it is easier to apply industrialization in general and INFINITE products in particular.
- Related to the above, the share of dwellings with central heating systems (collective and individual heating) (B04D) is around 91%, so it will be much easier to incorporate some of the products.
- Regarding the parameter share of fuels in the final energy consumption in the residential sector for space heating, about 48% of the dwellings still use Gas (B11C) and the 23,6% is using oil & petroleum products (B11E), which could be replaced by systems using renewable energies. There is a lot of room for improvement.
- Solar panels have been installed on German rooftops since long to enable roof-based systems to generate power. However, to achieve the German government’s goal of climate neutrality in the building stock by 2050, it would not be enough to install solar panels on all suitable roofs in Germany. Building façades can offer about twice the capacity for photovoltaic modules as roofs, although this is still not in real application. [88].
- Even though some areas of the country, according to the Water Risk Atlas and indicators [56], are at extremely high risk of water stress, only very punctually due to the heat wave in 2019 did the authorities of the German cities of Loehne and Bad Oeynhausen (center-west) impose restrictions on the consumption of drinking water. Its use was limited to "vital needs".

Therefore, all INFINITE kits have a great feasibility to be installed in the German building stock.

Italian chapter

Context

Considering a general analysis on the main structural materials, prefabricated construction can be divided into concrete, steel, wood, or hybrid solutions. Dealing with the corresponding trade associations (AssoBeton, Fondazione Promozione Acciaio and FederLegnoArredo) evidence shows that there is not a clear definition of what should be included in off-site production. Indeed, each sector is already manufacturing a portion of prefabricated components because even traditional construction processes include a percentage of industrialization. However, the main problem is that the pre-manufactured value (PMV), which measures the value created by executing off-site works on the overall project costs, is often too low because on-site works are still prevailing [89].

Starting from the wood industry given the growing attention to sustainability, the relevance of wood and green buildings within the portfolio of private and public entities has been increasing. Indeed, the request for projects with high ESG performances (Environmental, Social and Corporate Governance) is encouraging those tax benefits and financing choices that are guided by a positive environmental and social impact. Also, for this reason, the wood sector has been more resilient against the pandemic crisis compared to traditional construction (- 7% of turnover instead of -12.5%). Nowadays, Italy is the 4th European producer of prefabricated wood elements and it exported 39 million euro of prefabricated houses mainly to Croatia, Switzerland, France, Australia, and Belgium. A total of 3,340 new wood houses and non-residential buildings were built. The 75% of producers were micro and small enterprises (turnover < 5 million euro). Trentino Alto Adige is the homeland of the biggest and most specialized wood businesses, covering the 49% of the national production (followed by Lombardy and Veneto regions) [90].

Switching to the steel industry, the whole production is currently built offsite since the 80 – 90% of works are managed in the factory and they are divided into heavy metal carpentry and light steel frames. Both categories have a medium-high positioning in the market, because they are quality products with a high profitability in terms of Return on Investments but only if the whole building life-cycle is considered. Most of the factories are in the North-east area of the Country (Lombardia, Veneto, Friuli Venezia Giulia, and Emilia Romagna). The sector trend is positive reaching the 35% of all construction industry, compared to the 10% of 2010. This shows a slowly cultural change towards steel production which suffered from the lack of a valid legal framework (officially regulated in 2008 only). The market is growing also because steel, thanks to its lightness, is a suitable material for anti-seismic interventions, one of the main construction priorities and challenges in Italy.

Moving to the concrete industry, nowadays it's the least oriented towards industrialization because it's still affected by the legacy of homologated prefabrication of the '70s and its production process has some inherent limits in terms of precision and numerical control. Within the residential sector, the production is oriented towards prefabricated slabs and concrete blocks which still need to be cast-in-place in a limited manner, representing the typical example of traditional prefabrication which is just a first small step towards an off-site industrialization process. In fact, finished and self-supporting panels are mainly used for big and more standardized buildings, in the commercial and industrial sectors. However, according to 2020 data, the amount of concrete intended for prefabrication and for the residential sector are both slowly growing [91].

In Italy, the culture of prefabrication reached the maximum of its popularity around the '50s with the post-war international reconstruction movement. Criticized for its homologation, around the '70s it soon lost its attractiveness for the residential sector, and it survived mainly for industrial and standardized buildings or infrastructures.

Only with the new millennium, the technological improvements (robotization, GPS, drones) and the speed up of the digitalization process (BIM modelling, Design for Manufacturing, Internet of Things) led the way to customized prefabrication. Despite the existence of few companies (mainly based in Lombardy, near Brescia and Bergamo, in Trentino Alto Adige, in Veneto and Tuscany) working with an off-site approach in Italy and abroad, the concept of off-site production (meant as every construction process which is done in a controlled indoor factory setting to increase efficiency, quality and sustainability in an evolute way respect to the first prefabrication wave) is still not clear and it has been introduced in Italy only in 2015 by Rebuild, an Italian platform to foster building innovation [92].

Even though it's still hard to undoubtedly quantify the volume of modern industrialized production among old-school prefabricated solutions, off-site construction is slowly increasing and it's gaining attention of the most advanced players, the first movers of the sector. In 2017, 3400 prefabricated houses were built which increased to 1 house out of 14 in the 2019, for a total 700 million euros [93]. The current focus is mainly on new buildings and only a very small group of companies are focused on retrofit interventions. The main components producers are specialized in structural elements, infill panels, optimized technical components and, in a few cases, 3D modules (typically bathroom or kitchen cells). It is increasingly common, in the most cutting-edge companies (usually providing engineering services to redesign traditional projects into off-site processes), the integration of electric, heating and ventilation systems within the prefabricated solutions. However, the most diffused off-site production is related to the wood industry and based on the general contractor model providing turn-key prefabricated houses (mainly to private clients who favour comfort, speed, and sustainability to construction costs) [94].

SWOT analysis

From an external point of view, the **manufacturing Italian sector represents a fertile ground** for the industrialization of the construction process, both in terms of size and recognized know-how. Indeed, Italy is the 8th biggest manufacture worldwide and the 2nd in Europe, so there are the right conditions for a hybridization of the two industries since the manufacturing increased productivity, due to the new digital technologies, gives way to lean and controlled production even in the construction sector ensuring a higher quality of products and processes [92].

Furthermore, Italian products already have a good quality reputation abroad so industrialized construction **solutions could be exported** to all those markets which require high levels of performances and quality guarantees, even if costs are still quite high compared to the average supply. It's an emblematic example the ongoing program to build 50 MOXY hotels across Europe using a semi-modular structure of CLT engineered by Wood Beton spa (a point of reference in the production of structure and mixed industrialized wood-concrete construction systems) for Vastint (Real estate company of IKEA group) [95]. In general, Italy is also famous for exporting modular bathroom pods with already-installed tiles to exploit the local and unique qualified labour. However, the main barrier is given by the distance between the production site and the main construction sites since prefabricated elements have significant logistic costs for their dimensions and weight. National demand for offsite and modular solutions, despite the growing interest of the real estate sector, has not reached a tipping point so far.

Beside the supply side, another significant opportunity comes from the demand market. In Italy, there are more than **16 million residential units to be renovated** [96]. Since it's not feasible to move all the tenants in temporary solutions, the construction industry, spurred on by customer needs, must reduce on-site works and discomfort. As regards the new buildings segment, the main challenges and opportunities come from the **strong expansion of the social housing market** under the pressure of the decreasing purchasing power of Italian citizens, particularly after the pandemic crisis. In both cases, off-site production is the only answer able to increase productivity while reducing time and costs of construction over time.

On the contrary, there is still a high (but decreasing) number of families, final users and even designers who inherited the old concept of prefabrication associated to low value, durability, and performances. Most engineering and design studios are still rooted in a **project-specific approach** which do not consider the optimization of the whole supply chain, leaving to customers the freedom to change their mind at an advanced stage of the project. The **high level of distrust** currently prevents the industrialized solutions to be quickly scaled up and to effectively penetrate the market. It's, then, necessary that the whole off-site sector focuses on innovating and alongside obtaining quality assurance certifications, as it has already happened for the prefabrication of wood houses, but it's not yet broadly diffused elsewhere (steel, concrete, hybrid, technical systems). This cultural barrier must be overcome by publicly investing in **training the construction workforce** and promoting off-site production, to have more educated and conscious industry professionals [94].

In parallel, the regulatory stimulus for the industrialization has been indirectly provided by the **Superbonus and Sismabonus 110% incentives** introduced in 2020 with the so-called "Decreto Rilancio". The primary goal is the energetic and seismic renovation of residential buildings which fostered (together with a massive wave of traditional interventions) innovation in the direction of more performing, cheaper and faster prefabricated solutions. However, there is still the need of a regulatory framework evolution and creation of specific type of contracts which enable a correct risk distribution, interests' management and return on investments. In this sense, in Italy, the anti-seismic adaptation challenge, if properly regulated, is a unique opportunity to show the benefits of off-site industrialized renovations.

Focusing on the internal perspective, even if innovation is growing, the Italian construction sector remains one of the **most unproductive industries in Europe** with an average unproductivity index of 45% [92]. Furthermore, the **sector employees are aging**, having 25,8 % of workers between 55 and 64 years old by 2030 (forecast based on mixed sources by ANCE, OCSE, European Commission and FMI), and the **average educational level is very low**: only the 13,5% of employees have highly qualified jobs, which doesn't help to increase the sectorial productivity [97]. Finally, the **cost of labour**, which is one of the lowest compared to the other sectors, does not encourage investments in off-site production because decreasing the on-site workforce is not yet convenient [98]. Therefore, as for the demand side, construction suppliers are still grounded in a **project-based approach** which favours the single order optimization instead of looking at the overall benefits of an industrialized process able to increase the efficiency of multiple orders.

However, current technological opportunities are enabling processes industrialization bringing to a fast increase of productivity with a double advantage: they start to attract young resources and competences, renewing the sector, and they foster efficiency allowing **SMEs** (**which represent the 98% of the whole construction companies**) to become competitive on the market [99]. Finally, higher profitability enables more and more small enterprises to exploit their reactivity to invest in off-site innovation, generating a virtuous circle. However, looking at the downside, **small construction companies** (in 2017 there were 2,6 employees/firm in Italy) **are usually undercapitalized** so they are not structured for implementing and scaling innovation unless bigger businesses join the disruptive wave.

Together with the bottom-up SMEs independent initiatives, high-quality industrialized production is facilitated by the **Energiesprong movement**, a deep retrofit model born in the Netherlands and imported in Italy in 2021 by EDERA (new centre for the innovation and decarbonization of the built environment) [100]. Its objective is to create the proper market conditions to make the supply and demand meet and, so, to speed up a deep renovation on large scale through industrialisation process. Currently, different supply chains have been created to work on different prefabricated solutions, which will be tested in 2022 on **real pilot buildings** in need for deep renovation and located in the North area of the Country. All these demonstrative interventions will exploit the mentioned national incentives wave to have a proper return on investment despite the high production costs associated to innovation but in future these solutions will leverage their performances and industrial cost reduction potential.

Indeed, **costs** are one of the main weaknesses since, in Italy, too many **calls for tender** are still focused on sub-contracting and lowering the offering construction price (even up to the 70%), instead of aiming for quality assurance [94]. In this sense, innovative off-site solutions, whose economics are based on a total cost of ownership approach, are not yet considered till a broader cost analysis perspective is recognized by the market.

Table 41 Italian SWOT analysis on industrialization

	STRENGHTS	WEAKNESSES
INTERNAL ORIGIN	·Positive rate of growth. ·Shorter on-site works needed. ·High number of innovative and reactive SMEs. ·Energiesprong innovation movement. ·First industrialized retrofit pilot buildings.	·High rate of aging workers. ·Difficulties to find skilled employees. ·Undercapitalized small construction companies. ·Project-based approach from the suppliers' side. ·High costs of off-site solutions. ·Downward calls for tender. ·Lack of quality assurance certifications.
	OPPORTUNITIES	THREATS
EXTERNAL ORIGIN	·Current sector unproductivity. ·Technological development and process digitalisation. ·Size and know-how of the manufacturing sector. ·Good reputation and quality for export. ·Huge number of buildings to be renovated. ·Increasing need for social housing. ·Energetic and seismic incentives.	·High level of distrust among users. ·Project-specific approach from the designers' side. ·Lack of skills, proper training, and promotion programs. ·Low cost of labour.

Conclusions

In view of the existing statistics, we can conclude that:

- Italy is the second country in the EU with the highest residential building stock (2017, section 7.2.3.2, total number of individual residences and collective residence). There is a great number of multi-family buildings, more than the 80%, (B06B collective residence), which implies that for the installation of certain products and especially for deep renovations, an agreement will have to be reached between all the owners, if the building is not owned by a single owner. A total of 93% of the residential dwelling stock in Italy is owned by private owners, and 72% of it is occupied by owners followed by private tenants (18%). Consequently, 90% of single family buildings and 65% of multi-family buildings are owner-occupied [101].
- Related to the above, the share of dwellings with central heating systems (collective and individual heating) is around 97%, (section 7.2.3.1, B04D), so it will be much easier to incorporate some of the systems.
- Regarding the parameter share of fuels in the final energy consumption in the residential sector for space heating, about 58% of the dwellings still use Gas (section 7.2.3.3, B11C), which could be replaced by systems using renewable energies.

- Almost 70% of the houses were built before 1980 (section 7.2.3.4, B15A). During this period, the absence of building codes and the need for rapid reconstruction and expansion after the Second World War translated into a large share of very poorly insulated buildings [101]. This indicates that their energy efficiency is low and with great room for improvement, so they are likely to require major renovations to meet new regulations and current comfort conditions.
- The high levels of solar radiation, like most southern European countries, indicate a high photovoltaic potential and therefore more profitable will be the generation of solar energy.
- Due to cultural reasons, it is common not to try to prevent the entry of daily light through the openings in the façade, and therefore to prefer other options different from the automatic darkening of the windowpanes, to which they are not as used as in countries located more to the north.
- Despite the fact that basically the whole country, according to the Water Risk Atlas and indicators [56], is at extremely high risk of water stress, only occasionally in Rome have restrictions on the use of water in public fountains been established.

INFINITE kits with greater viability:

- Passive eco-compatible & green envelope
- Energy and fresh air distribution envelope
- Energy generation BIPV kit
- Energy generation BIST kit
- Adaptable BMS (aBMS)

Dutch chapter

Historical context

Prefabrication and industrialized building have a long history in the Netherlands. In the period between 1950-1979, approximately 400 to 450 thousand so called ‘system houses’ were built in the Netherlands (about 15 percent of the total housing production at the time). In the first phase experiments were done with all kind of industrialized prefab constructions from more traditional prefab (like ERA, MUWI, WILMA) to extreme prefab (like Airey, Polynorm). These brands often indicate the specific quality of the homes. Also, well-known ‘modern’ architects contributed and gave their name to it. In the second phase, from the mid-sixties, it has increasingly become a ‘contractor building’. The appearance has faded somewhat into the background. In that period, the emphasis was increasingly on technical quality and the comfort to be achieved in large quantities, instead of on appearance and identity. Mass was the key word and large series dominated, while recently also the ‘series of one’ are explored.

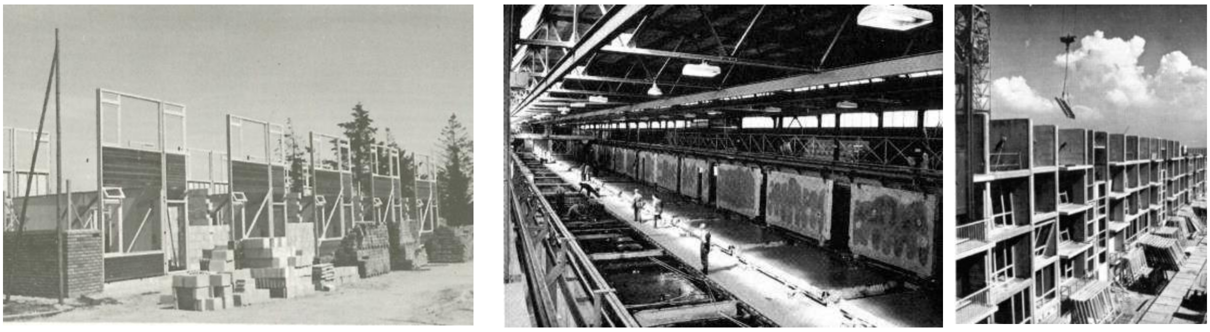


Figure 31 Examples of Dutch industrialized system building in the 60's. Source: [102]

The aim was to solve the enormous demand (i.e., shortage) of houses after the war. Prefab was considered as the way to achieve a better cost-quality ratio and a larger production volume, in the event of a shortage of labour capacity (skilled workers). The key lay in repetition and prefabrication. This view fitted perfectly into the spirit of the post-war period. The architectural language of that time perfectly allows for the abstraction of equality and a certain uniformity. In that sense, it was almost the reflection of the time period. Since 1975 this changed. The total production of housing is declining. At its peak in 1973, more than 150,000 homes were built in the Netherlands. In the period 1975-1979 this was on average only 106 thousand homes. This decline also gradually became the end of the prefab system builders. Typically, the supply side did no longer matched with the demand side, demanding more varieties. Urban renewal, with the first large scale building renovation projects (like the e'novatie program), took up part of the capacity of the construction sector, starting in the 1980s (i.e., from new construction to existing construction). The current stock of modular housing can be considered against this background.

Energiesprong and Stroomversnelling introducing prefab and industrialized renovation solutions

Also, behind this background, it can be understood that prefab and industrialized renovation was a very feasible option in the Netherlands for large scale renovation of the post war buildings stock.

Between 2000 and 2005 the first ideas of so called 2D Plug & Play renovation elements were developed and the possible market was mapped. Typical for many of these systems build houses is the presence of a concrete tunnel-shaped bearing core (partition walls and floors), with light-weight façades. These façades can be completely demounted and replaced by a new façade in less than a day. Alternatively, for traditional brick façades prefab renovation elements were developed that can be placed and mounted on the existing façade.

Figure 32 Prefab renovation with total replacement of the façade

Figure 33 Prefab renovation with placing prefab elements on the existing façade (BAM)

Prefab industrialized solutions were not limited to building envelope elements. Also, prefab platforms for building services were developed (like BAM, Volker-Wessels, Factory Zero):

Figure 34 Examples of prefab platforms for building services ('house engines' or 'climate modules'). Source: [122]

Between 2010 and 2016 large scale programs like Energiesprong (initiated by the ministry of BZK and managed by Platform 31), later resulting in Stroomversnelling, were launched. This gave prefab renovation a boost and it was adopted and applied by many Dutch construction companies like BAM, Volker-Wessels, Heymans, van Wijnen etc. It resulted in NZE renovation concepts called Zero-on-the-Meter (in Dutch: NOM, Nul op de Meter). Energiesprong as a brand is launched in France, UK, Germany and Italy.

The approach and the legacy of Energiesprong was also the bases for the H2020 project MORE-CONNECT, (Development and advanced prefabrication of innovative, multifunctional building envelope elements for Modular Retrofitting and Smart Connections, 2015 – 2018), the 1st H2020 project on prefab renovation, followed by several other projects.
Since 2029 a new development is taking place, making prefab elements also circular, initiated by projects like H2020 DRIVE 0 (Driving decarbonization of the EU building stock by enhancing a consumer centred and locally based circular renovation process, 2019 – 2023) and UIA SuperLocal.

Figure 35 Overview of the Dutch post-war prefab system building flows and its potential for prefab renovation.

Some considerations about threats

From the Dutch deep-renovation market, using prefab industrialized solutions it can be seen that since the first deep-renovation projects, being conducted from 2007, this approach resulted in severe cost reductions from €120,000,- (excluding VAT) towards 65 – 85,000,- (excluding VAT) per single-family dwelling. About €25,000,- to €30.000,- is spent on the building envelope. Equally, about the same amount is spent on installation and finishing respectively. In comparison, from this it can be derived that the relative cost advantage of deep-renovation over new-build is limited, while the cost of new-build fall in the same range (excluding demolition and land costs). In both cases the return of investment is about 40 – 50 years within the social housing market. However, to come to this price reduction and moreover, to make further steps in price reduction, larger amounts of deep renovation projects are necessary, leading to a further market uptake, upscaling and mass production. In next the recent steps in price reduction of renovation projects in the Netherlands are shown.

Figure 36 Price reduction of deep renovation in the Netherlands since 2010. Source: [103]

It also needs to be considered that prefab deep-renovation solution have to compete with alternative investment decisions. For example, building owners could:

1. suspend investment in favour of the status quo;
2. invest to preserve the property for a shorter period of time up to 10 years);
3. invest to renovate the property (as built) with minor energy efficiency improvements (for a period up to 25 years);
4. invest to transform the property according to the principles of a near energy zero build environment (for a period up to 50 years);
5. invest to replace the property, or;
6. to sell the property.

It is also expected that deep-renovation solutions have to compete with less radical investment decisions, like upgrading dwellings to label B instead of NOM (Zero on the Meter). This is for example covered by so called ‘no regret’ renovation solutions, like the component renovation approach of Bouwhulp/Alliantie +. Also replacing dwellings (demolition and rebuilding) or selling properties (transferring responsibilities to another owner) can be competitive options. There is also important

to take in consideration, within a social housing context that there is a significant mismatch between the investor and the beneficiary of the improvements which can constraint ROI considerations and consequently, discourage decisions on investment.
Currently, a viable business case for prefab industrialized solutions is absolutely possible, but it still requires high investments which tend the be recovered over a relative long period of time. Nevertheless, Return on Investment (ROI) covers 40-50 years for the full deep renovation (i.e., a total renovation, not only the envelope). However, component renovation with single modules as part of the deep-renovation solution fall within the range of a ROI of 8-10 years which is in the range of, for example, photovoltaics.
Moreover, it is expected that the investment cost of some other modules, like 'house engines' (prefab platforms for building services, will be reduced substantially due to economies of scale and eventually have a ROI of less than 10 years.

Table 42 Deep-renovation investments versus new-build investments (demolition cost; land cost not included). Source: [103].

Concept characteristics	First generation deep-retrofitting projects in The Netherlands (2007)	Second generation deep-retrofitting projects in The Netherlands; cost optimization (2021)	New-build
Energy label (improvement)	G/F → A++	G/F → ZEB	A++
€/dwelling * (case study)	€90,000-120.000,-	€65,000-85.000,-	€115,000,-
€/dwelling * (reference)	€65,000-85,000,-	€45,000-65,000,-	€82,000 (social housing) - €300/m3 (Fakton, 2014)

Some considerations about opportunities
A modular prefab deep-renovation approach is transforming outdated and energy consuming housing into (near) energy zero buildings of new build quality and thus depend on both a retrofit cost part (restoring building quality) and an investment cost part (improving building quality). Improving a dwelling with industrialized solutions is considered to add value to the property in terms of overall building quality including energy performance and indoor climate. In sum, given the relative low (operational) energy costs in contrast to the high investment costs it must be considered that it is not just the decreased energy but is also an investment to:

- Improved indoor climate
- Improved thermal comfort
- Extending the service life of building
- Improving the general living quality (including safety, accessibility etc.)
- Increasing the real estate value
- Less disturbance of occupants

Summarizing SWOT analyses

Table 43 Dutch SWOT analysis on industrialization

	STRENGHTS	WEAKNESSES
INTERNAL ORIGIN	· The Netherlands has a long history of industrialized system building. · Large part of the building stock that needs renovation is suitable for industrialized solutions. · Quite some innovative suppliers on the market (manufacturers, concept developers). · Many qualitative side effects for occupants (improved IEQ, living quality, reduction of disturbance) and home / building owners (enhanced quality, increased value, extended service life, etc.).	· Integrated industrialized renovation solutions often need another way of contracting to be cost effective and competitive towards traditional solutions. · This very difficult for housing companies. · Some innovative solutions cannot be certified (especially with circular solutions). · Total renovation costs in case of full deep ('NOM') renovation.
	OPPORTUNITIES	THREATS
EXTERNAL ORIGIN	· Industrialized 'component renovation' with no regret options makes renovation financially achievable and attractive by a step-by-step approach. · Upcoming One-stop-Shops, offering a total customers' journey make renovation achievable and attractive for individual homeowners (also Energy Communities can play a role in this). · Costs will reduce substantially with a large market uptake. · Specifically in the Netherlands: it is politically decided that houses need to be disconnected from the gas grid. Many of these houses will be all-electric with heat pumps; therefore, renovation is needed to lower the heat demand and supply temperatures. · Façade as a service (however, legal constraints as it is a part of the building).	· Reluctancy for innovations of home / building owners. · No level playing field with traditional construction companies, having an earning model based on extra costs and failure costs. · Rigidity of regulations and certification.

The future of industrialized renovation in the Netherlands

Industrialization of the renovation process is in fact the decomposition of a building in different elements (step1). These elements can be produced and prefabricated off site (step 2).
The next steps in prefabrication are:

- Step 3: further industrializing
- Step 4: automizing
- Step 5: roboting

At this moment, the average renovation and construction process in the Netherlands is not much further the step 2, however some innovators on the supply side are already at step 3.
But once these steps are made it is expected that the majority of building and renovation projects will be industrialized, leading to:

- Better products
- Lower pricing
- Maximum value to customer and companies
- Guaranteed performances

On the short time it is expected that 60% of the renovation market (as well as new construction) will be fully industrialized. However, still 20% of the renovations will be done in a traditional way (i.e., not interested in making the transition). The other remaining 20% are the so called special projects, i.e. project for which no solutions are (yet) available.

Figure 37 The future of the Dutch building industry. Source: [103]

At the same time a question for INFINITE now is to which extend can we establish the steps 3 – 5 together with the kit developers?
Moreover, as one of the main barriers is that there is still no level playing field yet for the market uptake of innovative traditional industrialized solutions versus traditional renovation another way of contracting organization is needed to be cost effective and competitive towards traditional solutions. Within the H2020 DRIVE 0 project new ways of contracting are explored between a client (in this case a housing company, HeemWonen) and two main suppliers, WEBO as supplier of circular prefab façades and Factory Zero as supplier of circular prefab house engines. In following schemes some possible organization models are given; finally model A2 is chosen. Yet the process was very difficult as also several issues like guarantees, responsibilities and liability had to be arranged.

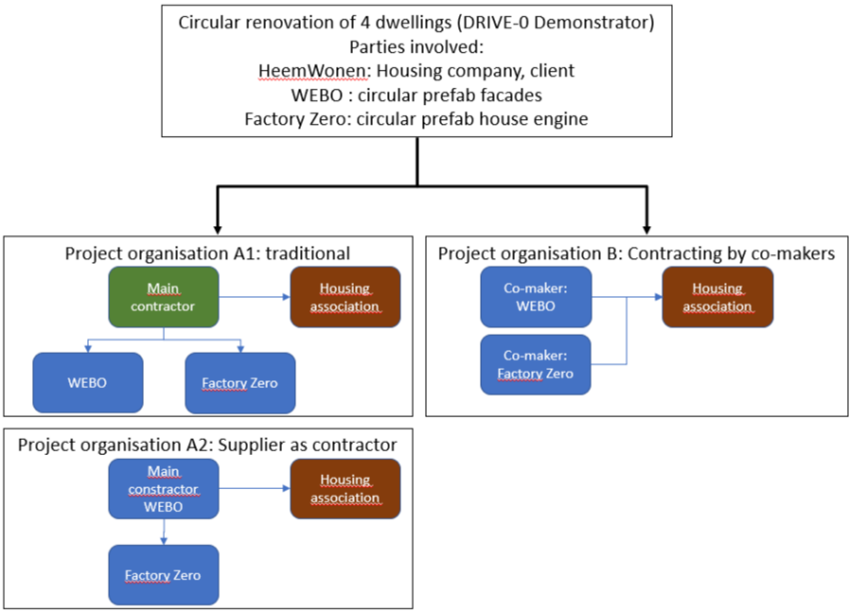


Figure 38 Different project organization models for industrialized renovation (DRIVE 0 – Dutch demonstrator)

Conclusions, lessons learned and recommendations

Lessons learned:

An important lesson, learned from Energiesprong (but also from MORE-CONNECT), is that technological developments are not so much a problem. However, the market uptake is still difficult as the traditional market is still dominated by traditional (large) construction companies.

This results in following observations:

1. There are still too many layers in the renovation process.
2. Clients are in general still reluctant for innovations.
3. Major traditional construction companies have a total other 'earning model' than new innovative companies, i.e., traditional companies often bring out low very and competitive bids and do the actual earning on extra work and failure costs. An 'all in offer', as proposed by many innovators, cannot compete with that.
4. One of the major constraints of further market implementation is the (much) higher quality of the innovative industrialized solutions, compared to traditional solutions, so in fact, prices cannot be compared one-on-one.

Some further recommendations:

- There still is a generalized lack of knowledge on innovative deep renovation design methodologies including the adoption of prefabricated and industrialized systems. This is hindering the wider market adoption of such highly promising technological solutions.
- To avoid too many layers in the renovation process other ways of contracting should be used, for example, directly between a supplier and a client, leaving out a contractor (as explained, this way of contracting is explored in the Dutch pilot in DRIVE 0).
- It is crucial to enhance user's experience of the renovation process, by means of ICT/BMS-supported improved comfort, while ensuring low intrusiveness and allowing aesthetic flexibility in design and accommodating future performance uncertainty.
- It is important to make complexity manageable, ensuring and enhancing product and process quality during the whole life cycle.

- Integration of RES is included and necessary as a solution for achieving energy efficiency and as a necessary step towards nearly zero energy renovation, but has as a single measure just a limited relevance.
- Learning from previous experiences and best practices of technological solutions and optimization objectives for deep renovation and prefab systems could be further developed in follow up (EU) projects. (For example, the Sustainable Places conference series appeared to be a successful platform for knowledge exchange.)
- More holistic approaches and specially user-centric design for deep renovation are needed.
- The most important step to come to further automation, industrialization and hence price reduction is the connection between advanced geomatics (point clouds) and BIM for production as transferring point clouds in BIM is still hand work. If this step can be made, it should be possible to come to a disruptive price reduction, without limiting the quality.

Conclusions:

- Considering that the country belongs to the northern part of Europe and in view of the existing statistics, we can conclude that:
- There is a greater number of single-family buildings, around the 84%, the second highest figure in the European Union, with only Ireland ahead (B06A individualResidence), so having less height and being a single owner, it is easier to apply industrialization in general and INFINITE products in particular.
- Related to the above, the Share of dwellings with centralHeating systems (collective and individual heating) (B04D) is around 91%, so it will be much easier to incorporate some of the systems.
- Regarding the parameter Share of fuels in the final energy consumption in the residential sector for space heating, about 86% of the dwellings still use Gas (B11C), which could be replaced by systems using renewable energies. There is a lot of room for improvement.
- Almost 60% of the houses were built before 1980 (B15A) and generally do not have thermal insulation. This indicates that their energy efficiency is low and with great room for improvement, so they are likely to require major renovations to meet new regulations and current comfort conditions.

INFINITE kits with greater viability:

Considering the context and situation, it can be concluded that some of the INFINITE kits could have a certain potential for a further market uptake in the Netherlands. More precisely:

- Passive eco-compatible & green envelope: considering the latest trends and interests in circular renovation and especially biophilic design principles we foresee a high potential.
- Energy and fresh air distribution envelope: as there are several advanced house engines (also integrated in the building envelope) are on the Dutch market, so no potential expected.
- Energy generation BIPV kit: several similar developments are going on in the Netherlands (even including INFINITE partners), so market potential expected; extra costs might be an issue.
- Energy generation BIST kit: similar solutions were tested a couple of years ago (Interreg MODLAR, H2020 MORE-CONNECT) but the principle was not successful, so not sure about the potential.

- Adaptable BMS (aBMS): this was partly explored in MORE-CONNECT but the further development within INFINITE seems to have a high potential in industrialized plug & play façades.

Slovenian chapter

Context

With the requirements of more sustainable construction and the rapid development of prefabricated building elements and processes, there is quite a strong market in Slovenia for the prefabricated construction of new individual prefabricated houses and industrial buildings, jet to be reflected in the renovation market.

In Slovenia there are some well-known companies [104] (e.g., Lumar IG d.o.o., Rihter, Kager hiša d.o.o., Marles hiše d.o.o., Jelovica, Riko hiše...) which offers not only In Slovenia but also on EU new prefabricated houses. Some of them are involved in R&D of new prefabricated elements. Company Lumar IG d.o.o. R&D is Involved In project AIPAN (Artificial 125ntelligence Pannel) [105], where main result will be a prefabricated AIPAN composite panel, which can be installed in two days according to developers. The panel Is planned to include revolutionary, capacitance-based technology for "sensing" people's micro-locations.

For the industrial buildings, Trimo d.o.o. company provides a permanent construction solution with state-of-the-art automated production of prefabricated elements. They are specialist in prefabricated metal sandwich panels with the possibility to integrate other façade elements, such as PV, ventilation etc.

One example of prefabricates for construction sector is VARIS LENDAVA [106] as one of the leading European manufacturers of ready-made prefabricated bathrooms for all types of users – from hotel chains, residential buildings, nursing homes, hospitals, student dormitories and prisons.

This brief overview of the Slovenian prefabricated construction market and the potential of prefabricated elements for the renovation of buildings shows that potential Is quite strong and provides a good basis for further development. There are some companies that Investigated e.g., wood façade panels as developed In INFINITE project but estimated they cannot be sold at the moment.

Moreover, the long-term strategy for energy renovation of buildings until 2050 in Slovenia, adopted in March 2021, promotes policies and measures to encourage cost-effective deep renovation of buildings, among which the multifunctional thermal envelope of the building, prefabricated components with built-in components for e.g. generation of electricity from solar energy, ventilation, etc. are explicitly mentioned [107].

In the brief overview of Slovenian prefabricated elements and the conducted SWOT analysis (summary in the following Table), the main strengths of prefabricated elements and the possibilities of using them for building renovation are the following: a strong, already existing prefabricated housing industry, which already accounts for about 20-30%, of all new houses in Slovenia, shorter renovation time, lower costs and smaller interventions in the living space and thus less disturbance for the residents during the renovation itself. One of the main benefits is the strengthening of trust in the renovation process and in contractors. There is an issue of mistrust and non-transparent procedures and costs for renovation (and construction) of buildings. The issue are uneducated and unskilled workers, and this can escalate with prefabricated renovation where more specific skills will be needed.

From the externalities point of view, some opportunities have been identified as Slovenia has a rather loose legislation for the renovation of buildings and therefore there are many opportunities to achieve higher efficiency, transparency, and quality of the renovated buildings. In order to achieve this in the coming years, it is crucial to introduce financial support and incentives specific for prefabricated elements and renovation of buildings with prefabricated elements through e.g. the Eco Fund of the Republic of Slovenia in the transition period, as it is the case e.g., in Estonia [108].

For more people to choose prefabricated building renovation in Slovenia, it is important to provide stakeholders with credible information about the feasibility, economic opportunities, and benefits of industrialized prefabricated construction. There is need for changing the mentality and awareness of current professionals in the construction sector, end users and current decision makers to increase the use of prefabricated elements for the renovation of the building stock, especially for multi-storey buildings. In addition, economic incentives are needed in the transition phase of industrially prefabricated elements for renovation in Slovenia, so that they can be cost-effectively retrofitted and become more accepted by the main stakeholders.

SWOT analysis

Table 44 Slovenian SWOT analysis on industrialization

	STRENGHTS	WEAKNESSES
INTERNAL ORIGIN	· Strong Industry for prefabricated elements. · Industrialized prefabricated production of new homes in Slovenia already represents 20-30%. · Faster renovation on-site. · Less disturbance for occupants. · Minimal interference with the interior of buildings during renovation. · More environmentally friendly construction process and less impact on the environment (less wastes). · Transparency and less space for illegal practices connected with the construction process. · Less dependence of building renovation due to weather conditions. · Greater recyclability of installed materials (e.g., wood). · Easier integration of installations and solution of details (before the start of the renovation).	· More expensive than traditional. · Absence of trained workforce. · Systems not known and accepted. · Mistakes are not forgiven when renovating buildings on site, less room for error to be corrected (if mistakes occur). · Fear of fire resistance for those based on wood frame.

	OPPORTUNITIES	THREATS
EXTERNAL ORIGIN	· Improvement of industrialized prefabricated technologies makes the processes cheaper, faster and reduce prices (scale benefits) [103]. · The industrialized process of prefabricated elements for renovation promises lower energy rehabilitations costs and increase the delivered quality and performances. · Industrialisation reduces the complexity of energetic renovations and eliminates uncertainties regarding investments costs, time and delivered energy performances. · Industrialized renovation allows for a more holistic and coordinated approach along the supply chain. · Lose legislative framework for renovation of buildings (except in the case of cultural heritage and major construction interventions). · Experts from different fields are involved in the implementation, which enables good synergy and interdisciplinary knowledge. · Emergence of new disciplines and branches of knowledge and involvement in the process of building renovation.	· Perspective, awareness, and behaviour of the end user and investor. · There is still a certain distrust of quality among Slovenes in the field of prefabricated elements. · There Is no financial support mechanism in Slovenia for prefabricated renovation · Lack of a commercial action plan from the technology providers for renovation. · Industrialisation of retrofit processes usually lacks in adaptability, making it difficult to implement on all types of buildings. · Most of buildings socks In Slovenia are single family housed with several typologies limiting the use of economy of scale. · Most multifamily buildings are already renovated with ETICS façades. · The development phase and scaling up process generate start-up costs, so industrializing prefabricated elements for renovation does not always lower prices as expected.

Prefabrication has been identified on EU market to reduce the impacts of buildings. Conclusions by V. Tavares et. Al [109] show that prefabrication alone cannot meet SI and EU environmental targets but can (in addition to energy efficiency measures and the refurbishment of buildings) contribute to achieving the envisaged EU targets. Prefabrication still presents a good opportunity to reduce construction costs and increase sector productivity and sustainability.

Considering that the country belongs to the eastern part of Europe, and therefore with similar characteristics to the northern areas, in view of the existing statistics, we can conclude that:

- There is a greater number of single-family buildings, around 77% (B06A individual Residence), so having less height and being a single owner, it is easier to apply industrialization in general and INFINITE products in particular.
- Related to the above, the Share of dwellings with central Heating systems (collective and individual heating) (B04D) is around 86%, so it will be much easier to incorporate some of the systems.
- Regarding the parameter Share of fuels in the final energy consumption in the residential sector for space heating, despite being the fourth in the European Union with the highest consumption of renewable energies with around 60%, it is still far from the almost 81% that Portugal has, the best figure in the Union, there are still almost 30% of homes that continue

to use gas or petroleum products (B11C, B11E), which could be replaced by systems using renewable energies.
- If we look at the percentage of social housing – dwelling/units (O03E) in the country, it ranks first in the European Union, with 17.65% of the total built stock. In general, this type of building has a single owner, which will facilitate the energy renovation of the building and the dwellings.

Therefore, all INFINITE kits have great viability to be installed.

Spanish chapter

Context

In Spain, people began to speak strongly about prefabrication in the construction sector back in 2008, coinciding with the financial crisis and the bursting of the real estate bubble. Despite having spent more than 12 years, its development has been slow.

Nowadays, two uses or applications with different developments can be identified. On the one hand there is constant evolution from an industrial point of view of panels, modules or prefabricated pieces for buildings and construction systems of all kinds, and on the other, the slow penetration of the prefabricated housing market [110].

SWOT analysis

The main barriers that this country presents are:

- Lack of a business fabric or **limited industrial capacity**. Although industrialised construction is growing in Spain, albeit slowly, countries such as Japan, the United States, Sweden, and the United Kingdom are leaders in this new construction model thanks to their more highly developed industrialisation in general. Just a dozen companies in Spain offer industrialized modules and panels ready to be assembled on site.
- **Absence of a trained workforce**.
- Difficulties of **interpretation and rigidity of certain national, regional, and local regulations**, some of them were not thought at the time for this type of construction. Administrative and regulatory brakes have slowed the uptake of this new reality in construction. To this must be added the large number of buildings with patrimonial protection, due to their own historical factors.
- **Many systems are not certified**, which makes work difficult when trying to justify the project under current building codes. It is possible, but it is a tough process if you are not familiar with it, so most of the architects prefer to continue using traditional systems to avoid spending extra hours.
- The **perspective and culture of the potential buyer or user**; since many people still see this type of system or construction as something ephemeral or weak, which does not provide the necessary “robustness” or “permanence” that a home requires.
- **Lack of a key commercial action plan or investment from the public spheres** that helps to make these products or types of construction known to the public opinion. Despite the existence of construction aid or promotion programs, such as the current NextGenerationEU

funds, there is no push for this type of industrialized construction specifically. There is no widespread government and financial support.

- Despite the evolution of systems and digitization of companies, for the moment, in Spain prefabrication is slightly **more expensive than traditional construction**, although this also depends on the materials and quality of construction. There are still few companies that are dedicated to it, so there is more demand than supply, which pushes prices up. It is estimated that the same standard home built with prefabricated systems is currently 10% more expensive than one built with traditional systems [111].

The Spanish prefabrication industry is in full growth and as the market consolidates, prices will become cheaper, as is already the case in Finland, Germany, or Denmark. This type of construction will end up being cheaper than conventional ones. In addition, while the costs of traditional construction are always increasing and there is less and less workforce for that type of market, the trend of industrialized processes is to improve technology to make the process cheaper [110].

A change of mentality is required, both in the training of tomorrow's professionals and in current decision-makers.

Despite the above, it is true that in some areas of the country such as Catalonia, the application of prefabrication as a construction system has been seen as a good opportunity to build mainly social housing and schools in short periods of time [112].

Currently, according to the Platform for Housing Industrialization (PIV in Spanish), which is a non-profit initiative, represented by associations, organizations, companies and professionals, in the field of construction in its different facets, affirms that in Spain industrialized production does not exceed 1000 homes per year, so it only represents 1%, unlike Germany, where 9% of housing construction is prefabricated; Sweden, where this type of construction already accounts for almost all production; The Netherlands, with 50%, or the United Kingdom, with about 7%.

They also affirm that industrialized housing would be susceptible to export thanks to the fact that the construction costs in Spain of this type of housing are lower than the costs in northern European countries, including transport costs to the destination country [113].

Table 45 Spanish SWOT analysis on industrialization

	STRENGHTS	WEAKNESSES
INTERNAL ORIGIN	·Industry in full growth ·Examples of success in the country, mainly social housing, and schools. ·Shorter periods of time vs traditional construction to change mentality of people.	·Absence of trained workforce. ·Many systems are not certified. ·More expensive than traditional. ·Industrialized production does not exceed 1000 homes per year, so it only represents 1% vs Netherlands with a 50%.

	OPPORTUNITIES	THREATS
EXTERNAL ORIGIN	·Industrialized housing will be susceptible to export thanks to the lower costs in Spain, including transport costs. ·Improvement of industrialized technologies makes the processes cheaper and reduce prices. ·Prices will be cheaper as the market consolidates.	·Limited industrial capacity. ·Rigidity of regulations. ·Perspective and culture of the buyer. ·Lack of a commercial action plan from the public spheres.

Conclusions

Being aware of these limitations, and based on the statistics obtained for the development of the deliverable, it can be concluded that:

– There is a considerable number of multi-family buildings, around 41%, (B06B collective Residence), so it fits the archetype or ideal building to perform a deep renovation using the different INFINITE kits.
– Regarding the parameter *Share of fuels in the final energy consumption in the residential sector for space heating*, about 70% of the dwellings still use Oil & petroleum products (B11E) or Gas (B20C), which could be replaced by systems using renewable energies.
– Almost 50% of the buildings were built before 1980 (B15A) and do not have thermal insulation. This indicates that their energy efficiency is very low and with great room for improvement, so they are likely to require major renovations to meet new regulations and current comfort conditions. This is one of the main opportunities to apply industrialization in retrofit processes using INFINITE kits.
– The high levels of solar radiation, as they can extracted from the Photovoltaic geographical information system (PVGIS) tool [114], like most southern European countries, indicate a high photovoltaic potential and therefore higher profitability and faster return on investment after the installation of energy generation systems such as the BIST kit or the BIPV kit.
– Even though the southern areas of the country, according to the Water Risk Atlas and indicators [56], are at medium or high risk of water stress *(Baseline water stress measures the ratio of total water withdrawals to available renewable surface and groundwater supplies. Water withdrawals include domestic, industrial, irrigation, and livestock consumptive and no consumptive use. Available renewable water supplies include the impact of upstream consumptive water users and large dams on downstream water availability. Higher values indicate more competition among users)*, only occasionally in the Canary Islands have restrictions on the use of water been established. This implies that, in general, the use of green envelope systems is possible without restrictions, but in certain cases the use of native or local plant species with low water consumption may increase the viability and make the installation and use more profitable.

With all the above, it can be concluded that the INFINITE kits with a greater potential to be used in Spain would be:

- Passive eco-compatible & green envelope.
- Energy and fresh air distribution envelope.
- Energy generation BIPV kit.
- Energy generation BIST kit.
- Adaptable BMS (aBMS).

7.6 Conclusions

After analysing all the chapters, it can be appreciated that all INFINITE kits might have a big potential to be installed, but the green envelope kit and the BIPV kit, are the ones with the best feasibility.

Table 46 Summary of INFINITE envelope Kits feasibility.

Country / Kit	Green envelope	Air distribution	Smart window	BIPV	BIST
Austria	✓	✓	✓	✓	✓
France	✓	✓	-	✓	✓
Germany	✓	✓	✓	✓	✓
Italy	✓	✓	-	✓	✓
The Netherlands	✓	-	-	✓	-
Slovenia	✓	✓	✓	✓	✓
Spain	✓	✓	-	✓	✓

8. Conclusions

The work presented in this report had the goal to assess the European building stock under the novel spotlight of the industrialised renovation compatibility. Thanks to an extensive work on many different aspects (literature review, industrialised renovation main features, building classifications…), a set of outcomes have been reached as basis for applications.

In particular, the following conclusions can be drawn.

- The most relevant building features of the industrialised renovation have been identified.

- Different building archetypes have been defined per each industrialised retrofit kit as "ideal" building features matching the technologies requirements.

- A collection of the industrialised market country-related characteristics has been done in order to map the available information in terms of data, building owners profiles, regulation framework, and so on.

The amount of information collected and assessed thanks to the presented work will be able (i) to better lead the industrialised technology design, better addressing the building stock key features and needs; (ii) prepare the field for a market-potential mapping activities, that will proceed within the INFINITE projects in the upcoming years.

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