H2020-NMBP-ST-IND-2018-2020-GA 958218

PLUG-AND-USE RENOVATION WITH ADAPTABLE LIGHTWEIGHT SYSTEMS

PLURAL

D1.6

PLURAL kits Standardization

in EU building stock typologies

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958218

	Name	Date
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Reviewed by WP leader	**NTUA**	09/06/2023
Reviewed and edited by	**Project Coordinator**	09/06/2023

Distribution list

External		Internal	
European Commission	1x	Consortium partners	1x

Change log

Issue	Date	Pages	Remark / changes	Pages
0.1	06/07/23	30	First draft PA	All
1.0	09/10/23	37	Final version reviewed by NTUA	All

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Terms, definitions and abbreviated terms

PnU	Plug and Use
MODEST	Multi-objective Decision Support Tool
HVAC	Heating, Ventilation and Air Conditioning
RES	Renewable Energy Sources
PV	Photovoltaic
NTUA	National Technical University of Athens
PA	Pich Architects
VVV	Voula – Vari - Vouliagmeni
CVUT	Ceske Vysoke Uceni Technicke V Praze
SPF	Institute Fur Solartechnik
ZRS	ZRS Architekten GvA
ITEC	Instituto de Tecnología de la Construcción

1. Summary

Based on the outcomes of PLURAL work previously reported in the frame of D1.1 (Requirements: Context of application, building classification, used consideration – Definition of requirements and constraints), D2.6 (Final Design of PnU kits), WP5 (BIM Parser) and WP7 (Real and virtual building demonstration. Pre-and post-renovation monitoring and assessment. Validation of PLURAL solutions), Deliverable 1.6 identifies, and analyzes the types of the European building stock that the PLURAL kits could be installed, taking into consideration the different climatic conditions, building typologies and their local standards. The impact on the required time and economic aspects for the completion of each renovation stage are also considered in this report. Ongoing or completed H2020 projects that deal with similar topics, their approaches and published results are analyzed and compared with the PLURAL solutions.

D1.6 is a public deliverable aiming to provide condensed information about the feasibility of the PnU kits for implementation in different EU building stock typologies.

2. Introduction

D1.6 is the outcome of the work performed in the frame of Task 1.7 of the PLURAL project. The main target of T1.7 is to evaluate the outcome of D1.1, D2.6, WP5 and WP7, the overall behaviour of each PnU kit and determine whether they can be used for deep renovation in the various types of residential builings of the EU's building stock. For this purpose, the main properties of the three PLURAL PnU kits, namely the ConExWall, Denvelops Comfort, SmartWall are examined in terms of:

- **Climatic conditions:** The EU climatic conditions are considered, and a categorization of building types (multifamily house, apartment blocks) is made.
- **Thermal performance**: The U-values of walls of the candidate renovation sites are summarized.
- **Economic aspects**: Renovation cost of Plural PnU kits and the cost of façade renovation projects in EU building after 1945 are reported.
- **Architectural/structural and technical properties:** The structure and components, functional performance and the aesthetics of the PLURAL solutions are considered.
- **BIM modelling:** Data, properties, also environmental information related to BIM modelling are examined.

The above-mentioned properties of PLURAL kits are compared with data from other H2020 projects dealing with prefabricated façades.

As a result, general recommendations are given which European countries and in which building type(s) the PLURAL PnU kits could be applied.

3. Evaluation of PnU requirements and constraints

In this section, the three PnU kits are evaluated in terms of climatic zones and countries in EU, building classification, thermal behaviour and cost.

3.1 Climate constraints

ConExWall (to be installed at the Czech demo site: KASAVA)

This PLURAL kit can be applied in all climate zones, but especially in cold climates. It is most suitable for central and northern European countries. Table 3-1 represents climate zones and countries. ConexWall is appropriate for **ZONE 01- ZONE 04.**

Denvelops Comfort (to be installed at the Spanish demo site: TERRASSA)

It can be applied to Mediterranean and Oceanic climate zones. It requires extreme heating. Appropriate for **ZONE 08- ZONE 12** (Table 3-1).

SmartWall (to be installed at the Greek demo site: VOULA)

It is suitable for almost every European climate covering the heating and cooling requirements, except from the extreme cold conditions, such as the Northern European countries. Appropriate for **ZONE 04- ZONE 8- ZONE 12** (Table 3-1).

TABLE 3-1. REPRESENTED CLIMATE ZONES AND COUNTRIES

WCSI SCSI COMBINATION	NUMBER	COUNTRIES and REGIONS
W4S0	ZONE 01	**Sweden,** Estonia, Iceland, Norway and Finland
W3S1	ZONE 04	**Germany, Czech Republic, Switzerland,** Belgium, France, Croatia, Luxemburg, Hungary, Austria, Romania, Slovenia, Poland.
W2S2	ZONE 08	**Spain,** Italy, Albany and Montenegro.
W1S3	ZONE 12	Malta, **Greece**

3.2 Installation constraints

ConExWall (Czech demo: KASAVA): This PLURAL kit can be installed only on the external side of the wall.

Denvelops Comfort (Spanish demo: TERRASSA): It can be installed only on the external side of the wall.

SmartWall (Greek demo: VOULA): It can be installed either on the external or the internal side of a facade.

3.3 Thermal improvements of the demo sites and how the PLURAL kits meet renovated buildings' needs

TABLE 3- 2. PNU THERMAL PROPERTIES AND ENERGY PERFORMANCE OF THE DEMO SITES

ConExWall (Czech demo: KASAVA)

Parameter	Unit	Original building	Renovated building
Thermal properties			
U-value wall (incl. ConExWall)	W/m^{2}K	1.35	0.18
U-value window	W/m^{2}K	approx. 1.3	0.60
U-value roof	W/m^{2}K	0.99	0.10
Solar shading type	-	Internal blinds	Windows-internal blinds

The new calculated U-value of the renovated wall including the ConExWall is **0.18** W/m^{2}K. The height of the modules is limited to **2.7** m.

Parameter	Unit	Original building	Renovated building
Cooling energy demand		No active cooling	No active cooling
Heating energy demand	kWh/a	32,000	4,542
DHW production demand	kWh/a	4,266	4,266
Overall primary energy	kWh/a	69,402	302
Renewable energy production	kWh/a	-	11,187
nZEB standard reached?	Y/N	N	Y
Which document defines the nZEB standard?	N/A	"Act. No 406/2000 Coll." and "Decree No. 264/2020 Coll." define nZEB standard in Czech Republic	

Denvelops Comfort (Spanish demo: TERRASSA)

Parameter	Unit	Original building	Renovated building
Thermal properties			
U-value wall	W/m²K	0.48 / 0.52	0.19
U-value window	W/m²K	2.96	1.16
U-value roof	W/m²K	0.46	0.46

Parameter	Unit	Original building	Renovated building
Cooling energy demand	kWh/m²	15.78	19.19
Heating energy demand	kWh/m²	26.52	12.96
DHW production demand	kWh/m²	26.84	24.96
Overall primary energy	kWh/m²	102.49	79.97
Renewable energy production	kWh/m²	10.83	89.73

SmartWall (Greek demo: VOULA)

Topic	Unit	Original building/apartments	Renovated building/apartments
Thermal properties			
U-value wall	W/m²K	2.44	0.22 – 0.43 depending on the Type of SmartWall panel installed on each facade
U-value window	W/m²K	4.2	1.4

Topic	Unit	Original building		Renovated building	
		A1 Apartment	A2 Apartment	A1 Apartment	A2 Apartment
Cooling energy demand	kWh/m^2	42.6	50.3	29.6	34.7
Heating energy demand	kWh/m^2	75.2	70.2	14.4	9.5
DHW production demand	kWh/m^2	15.1	20.0	15.1	20.0
Overall primary energy	kWh/m^2	300.0	321.0	12.4	8.8
Renewable energy production (yearly)	kWh/kWp	–	–	1566.84	1566.84

The U-value of the walls after renovation with the PLURAL kits ranges between 0.18 to 0.43 W/(m^{2}K). All the PLURAL solutions can be applied to all types of buildings, such as Single Family, Terrace, Multifamily, Apartment blocks with up to 7 storeys.

The SmartWall kit cannot be applied to buildings higher than 4 storeys due to structural stability and specific seismic design.

The SmartWall is the only PLURAL PnU kit that can be applied on a historical façade, since it can either replicate the external façade or can be installed on the internal side of the existing envelope.

The presence of balconies affects the application of the ConExWall kit. For the installation of ConExWall kit the balconies must be dismantled and new balconies should be re-built after the installation.

Also, structural requirements and envelope performance limitations set that the Window-to-Wall Ratio (WWR) of the building façade should be lower than 35%.

3.4 Renovation costs with PLURAL kits and EU renovated buildings' cost

Generally, the cost of façade renovation solutions varies from country to country within the EU and remains uncertain because it relies on individual agreements shaped by supply and demand dynamics. However, in certain countries, pricing is subject to regulation. It is a common phenomenon that these pricing agreements are not accessible to other potential participants in the market, which hinders

transparency and leads to price discrepancies. Consequently, it becomes challenging to compile comparable renovation costs across Europe.

Despite the efforts and initiatives of the European Commission to encourage innovative renovation schemes and facilitate the industrialization of retrofitting technologies, high costs persist in being the barrier for the development of a mass market for serial renovation. According to Buildings Performance Institute Europe (BPIE)[1], prefabricated renovation projects achieve costs of approximately 1000 €/m^2. This level is expected to fall to 500-550 €/m^2 in a mature market. Particularly, the expenses associated with the production of facades have not seen the anticipated reduction. This is primarily attributed to the fact that production capacities remain relatively small and lack robust industrial-scale capabilities. The current decline in costs is primarily due to process enhancements and the decreasing expenses related to energy system components, such as photovoltaic systems and heat pumps.

When it comes to prefabricated solutions for deep renovation, the typical building types considered are terraced houses and small multi-family dwellings constructed between 1950 and 1970, characterized by simple building structures. Within the EU-27, approximately 1.3 billion square meters of residential building space fall within this category. A deep and industrialised renovation of 75% of the floor space in these buildings would result in a substantial market worth €1,150 billion (equivalent to €1.15 trillion), based on an average cost estimation of 900 €/m^2 for achieving net-zero renovation standards[2]. The average annual investments from the earlier period of 2012-2016 for the energy-related deep renovations was estimated 219 €/m^2 [3].

THE OVERALL IMPLEMENTATION COST OF THE PLURAL KITS IN THE THREE REAL DEMONSTRATION BUILDINGS (VVV, TERRASSA AND KASAVA) IS PRESENTED IN

Table 3-3. The values include 10% waste and consumables.

TABLE 3-3. ANTICIPATED COST FOR RENOVATION WITH PLURAL SOLUTIONS

PLURAL PnU kit	Cost
Denvelops Comfort	477 €/m^2 facade area
SmartWall (blank Type)	400 - 700 €/m^2 facade area

[1] https://www.bpie.eu/wp-content/uploads/2021/11/BPIE_Deep-Renovation-Briefing_Final.pdf

[2] Building Performance Institute Europe: COVID-19 RECOVERY: INVESTMENT OPPORTUNITIES IN DEEP RENOVATION IN EUROPE, 2020. Available at: https://www.bpie.eu/wp-content/uploads/2020/05/Recovery-investments-in-deep-renovation_BPIE_2020.pdf

[3] Ipsos Belgium and Navigant (2019) Comprehensive study of building energy renovation activities and the uptake of nearly zero-energy buildings in the EU Final report. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/1.final_report.pdf

ConExWall	N.A.

The implementation of the prefabricated solutions of the PLURAL project is expected to further reduce the renovation cost (compared to the conventional techniques)[4]:

- at least 6%, due to material and labour savings as a result of prefabrication in industrial environment,
- at least 20% due to savings from "all-in-one" PnUs' greater productivity, and
- at least 5% due to savings from large scale projects.

Certain cost-sensitive issues that the stakeholders often have to deal with including the current project are listed below:

- *Architectural design*: the design of the facade whether it is destined to preserve old aesthetic elements or introduce new modern features, can significantly impact costs.
- *Unforeseen Structural Issues*: Once the renovation work begins, hidden structural issues might be uncovered that need to be addressed. This could include issues like water damage, rot, or unstable foundations. Dealing with these unexpected problems can increase costs.

3.5 Summary of outcomes

The ConExWall kit can be applied in all climate zones, but especially for cold climates. It is more suitable to central and northern European countries. (**ZONE 01** Mainly in 5 countries Sweden, Estonia, Iceland, Finland and Norway; **ZONE 04** Mainly in Germany, Czech Republic, Switzerland, Belgium, France, Croatia, Luxemburg, Hungary, Austria, Romania, Slovenia, Poland). The new calculated U-value of a renovated wall including the ConExWall is 0.18 W/m^{2}K.

The Denvelops Comfort is installed only on the external side of the wall and is suitable for the most European countries except from Nordic conditions with extreme heating demands, while the system can be modified in order to cover the heating and cooling demands of the Southern countries (Mediterranean condition with high cooling needs). (**ZONE 08** in Spain, Italy, Albany and Montenegro (also present in some regions of Slovenia, North Macedonia, Portugal, France, Greece; **ZONE 12** Mainly in Malta (also present in some regions of Greece, Spain and Portugal). It can be installed only on the external side of the wall. For buildings with more than 7 storeys and high window-to-wall ratio (more than 35%) the kit should be appropriately designed to cover the energy demands and meet the safety requirements. The U-value of the wall of the renovated building with Denvelops Comfort is 0.19 W/m^{2}K.

[4] NTUA (2020): "D1.1 – Requirements: Context of application, building classification, used consideration – Definition of requirements and constraints" of the HORIZON 2020 project PLURAL. EC Grant Agreement No. 958218, Athens, Greece.

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The SmartWall is suitable for almost every European climate covering the heating and cooling requirements, except from the extreme cold conditions, such as the Northern European countries. (**ZONE 04** Mainly in Germany, Czech Republic, Switzerland, Belgium, France, Croatia, Luxemburg, Hungary, Austria, Romania, Slovenia, Poland; **ZONE 8** Mainly in Spain, Italy, Albany and Montenegro (also present in some regions of Slovenia, North Macedonia, Portugal, France and Greece; **ZONE 12** Mainly in Malta (also present in some regions of Greece, Spain and Portugal). It can be installed either on the external or the internal side of the building facade. It can only be installed on flat surfaces and on buildings up to 4 storeys on height. The U-value wall of the renovated building with SmartWall solution is 0.22 – 0.43 W/m^{2}K, depending on the Type of SmartWall panel installed on each façade.

Lastly, when it comes to cost of prefabricated solutions for deep renovation, the average annual investments from the earlier period of 2012-2016 for the energy-related deep renovations was estimated 219 €/m^2. Also, the implementation of the prefabricated solutions of PLURAL project is expected to reduce the renovation cost (compared to the conventional techniques) at least 6%, due to material and labour savings as a result of prefabrication in industrial environment, at least 20% due to savings from "all-in-one" PnUs' greater productivity, and at least 5% due to savings from large scale projects.

4. Evaluation of PnU design

4.1 Architectural and structural characteristics of PLURAL kits

In this section, the three PnU kits are evaluated in terms of structure and components, functional performance and the aesthetics of the solution. The potential adoption of the PnUs to EU renovated buildings is examined by using the Tabula website. The analysis is based on the previously prepared D2.6: Final design of PnU kits.

ConExWall

The ConExWall is mounted to the façade from the outside. The ConExWall is held at the top and bottom by anchors that are attached to the façade before the modules are mounted. The anchors are advantageously screwed into the storey ceilings, as these ceilings are in many cases concreted and thus sufficiently stable. The statics and stability of the old façade at the anchor points must be clarified at an early stage in a renovation project in order to find a suitable procedure.

In order to be able to use the ConExWall with its external wall heating, the opaque façade of the existing building to be renovated must have a heat transfer coefficient (U-value) of approx. 0.9 W/m^{2}K or greater. If the existing façade has an external thermal insulation layer, this insulation layer must be removed.

The size of the ConExWall is determined on one hand by the structure of the façade and on the other hand by the transport possibilities (size of truck used for transportation from prefabrication to the construction site). The façade modules are usually rectangular, have a height of one storey and can be selected in width to match the building structure or the truck. A vertical orientation over several storeys and a reduced width accordingly is also possible.

The max. panel height is 2.7m, which is always less than the needed construction height of the panels, which is why there will always be more than 1 horizontal joint per floor. The typical width of a façade is also more than the limitation of 7-8m, which is why there will also be vertical joints on most of the facades.

The old windows of the building are replaced by integrating new windows in the prefabricated façade module at their position in the façade. If the old windows can be dismantled inwards, the dismantling can be carried out after the installation of the ConExWall. With corresponding additional expenditure, it is also possible to enlarge the wall opening in order to insert larger windows.

Concluding, the ConExWall can be used in EU renovated buildings (multifamily house and apartment block) from different construction periods.

Denvelops Comfort

These PnU kits are based on stainless steel light substructure, which allows for adding multiple components, such as cladding, thermal insulation, weathering membrane, PV panels, aluminium

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windows and ventilation unit and its channels. All these components are attached to the vertical guidelines by special connectors or frames.

The façade is connected to the existing building at its top part with a fixed anchor, adding only wind anchors for horizontal loads along the vertical edges of the system sequences. The modulation of the façade can be adapted to EU block of residential dwellings but for this it needs to be adapted to the existing façade layout, mainly windows, in a way that the window edges become the sequence edges, in most of the cases.

Accordingly, the Denvelops Comfort can be used in EU renovated buildings (multifamily house and apartment block) in Mediterranean–mild zones from different construction periods. The first step will be to define the solution based on the technical drawings and characteristics of the original building and the climatic conditions of its location and decide the length of the sequences and frames that are needed to divide the total length of the new façade. The system can be limited regarding its size, as depending on the climate conditions the unit's outer dimensions, particularly thickness, can be a restrictive parameter.

Also, the aesthetics result of the solution proposed allows every design that fits the building by means of the cladding.

SmartWall

The structural analysis took into consideration the following types of SmartWall modules:

- SmartWall type 1 (blank panel);
- SmartWall type 2 (panel with window & fan coil unit);
- SmartWall type 3 (panel with balcony door);

and for each one of the aforementioned types, the panel is anchored on the existing walls. The prototype dimension is 2.500mm (h) x 1.200mm (l) x 170mm (w), consisting by a double-glazed window with roller blinds and PV panel.

The SmartWall production cannot be fully automated, since the parts and components depend on the particular project design.

SmartWall is a solution that in terms of aesthetics has almost no limitations or restrictions as different setups and designs can be developed / applied according the specific demands of the owner / architect / engineer. A very wide range of materials / technologies can be integrated into and onto it and it can replicate existing building's aesthetics by using the same materials / finishes as the existing or original building.

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4.2 Matching of technical characteristics of PnU kits to EU building stock characteristics for deep façade renovation

ConExWall

The Czech building stock (Figure 4-1) is examined as an example using the web tool Tabula (https://webtool.building-typology.eu/#bm). The building classes listed in the tool are examined according to their suitability for use of the ConExWall. Basically, buildings with large and uniformly structured façade surfaces and opaque façade surfaces with a high heat transfer coefficient of approx. 0.9 W/m^{2}K (possibly after removal of existing, old façade insulation) are suitable for the ConExWall.

Buildings that appear to be well to very well suited for use of the ConExWall, according to the listed criteria, are marked with a green frame in **Error! Reference source not found.**. These buildings have a large volume, a simple structured façade and have U-values of around 0.9 W/(m^{2}K) according to Tabula. Also, only heating system must be implemented as there is no need for cooling of this building typology. The heat could be supplied by an air-to-water heat pump (HP) in the case of the ConExWall, which is suitable to renovate complete thermal envelope of the buildings for continental warm-humid zone.

TABLE 4 presents the U-value of the buildings, based on the Tabula webtool, for the construction years that the ConExWall could be used, and the U-value after the renovation with ConExWall. The U-value at the existing state ranges between 0.87 W/(m^{2}K) – 1.36 W/(m^{2}K), while the renovation with ConExWall reduces the U-value to 0.16 W/(m^{2}K) – 0.18 W/(m^{2}K).

TABLE 4. THERMAL TRANSMITTANCE VALUES (U-VALUE) BEFORE AND AFTER CONEXWALL APPLICATION FOR CZECH BUILDINGS

Construction year	Pre-renovated wall	Renovated Wall with ConExWall
… 1920	1.36 W/(m^{2}K)	0.18 W/(m^{2}K)
1921 - 1945	1.36 W/(m^{2}K)	0.18 W/(m^{2}K)
1946 - 1960	1.36 W/(m^{2}K)	0.18 W/(m^{2}K)
1961 - 1980	1.08 W/(m^{2}K)	0.17 W/(m^{2}K)
1981 - 1994	0.87 W/(m^{2}K)	0.16 W/(m^{2}K)

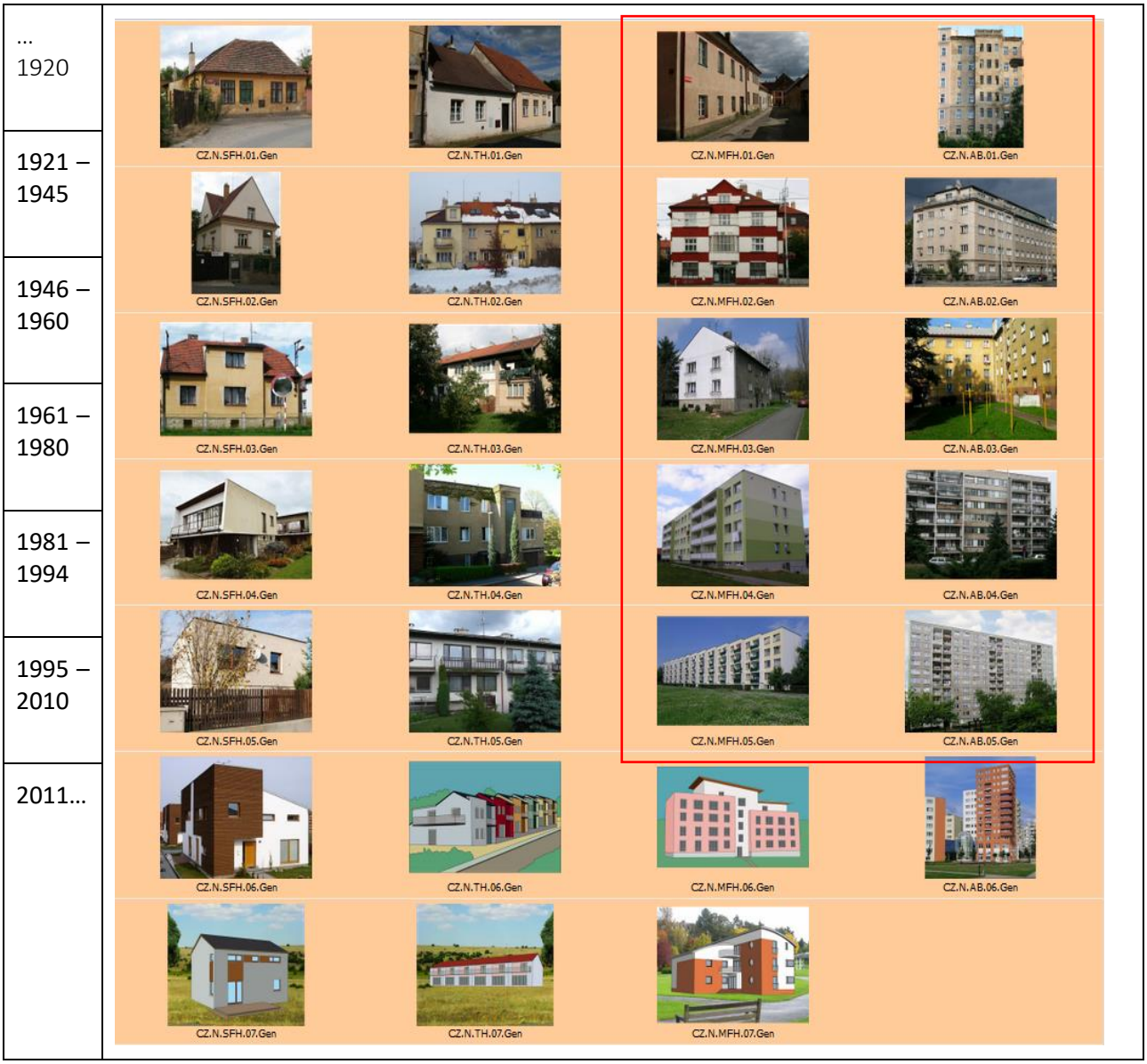

FIGURE 4-1 CLASSES OF THE CZECH BUILDINGS IN THE TABULA-TOOL (HTTPS://WEBTOOL.BUILDING-TYPOLOGY.EU/#BM) SUITED FOR THE CONEXWALL

Denvelops Comfort

The thermal resistance of the façade, considering only the mineral wool insulation with thickness of 100 mm is 2.90 m^2K/W. The Denvelops Comfort is equipped with a ventilation unit that supports room heating and cooling system by control of supply air (max. air flow is 90 m^3/h). Moreover, produced energy by PVs can be used for cooling - mainly during the summer season and especially during daytime. Photovoltaic energy sources can be used for direct heat generation in winter or cold generation in the summer.

TABLE 5 presents the U-value of the buildings depending on the construction year, at the existing state and the U-value after the renovation with Denvelops Comfort, based on the Tabula webtool. The U-value at the existing state ranges between 0.48 $W/(m^2K)$ – 2.56 $W/(m^2K)$, while the renovation with Denvelops Comfort reduces the U-value from 0.20 $W/(m^2K)$ to 0.30 $W/(m^2K)$. The Denvelops Comfort could be used for the facade restoration of buildings located in a Mediterranean climate region and constructed between 1930 and 2006 (Figure 4-2). The buildings before 1930 can be characterized as historical buildings (forbidding the use of Denvelops façade), while the buildings after 2007 have a relatively good insulation performance, without significant need for thermal performance upgrade of the envelope.

TABLE 5. THERMAL TRANSMITTANCE VALUES (U-VALUE) BEFORE AND AFTER DENVELOPS COMFORT APPLICATION FOR SPANISH BUILDINGS

Construction year	Pre-renovated wall	Renovated Wall with Denvelops Comfort
1901 - 1936	2.56 $W/(m^2K)$	0.30 $W/(m^2K)$
1937 - 1959	2.27 $W/(m^2K)$	0.30 $W/(m^2K)$
1960 - 1979	1.33 $W/(m^2K)$	0.27 $W/(m^2K)$
1980 - 2006	0.60 $W/(m^2K)$	0.22 $W/(m^2K)$
2007 - …	0.48 $W/(m^2K)$	0.20 $W/(m^2K)$

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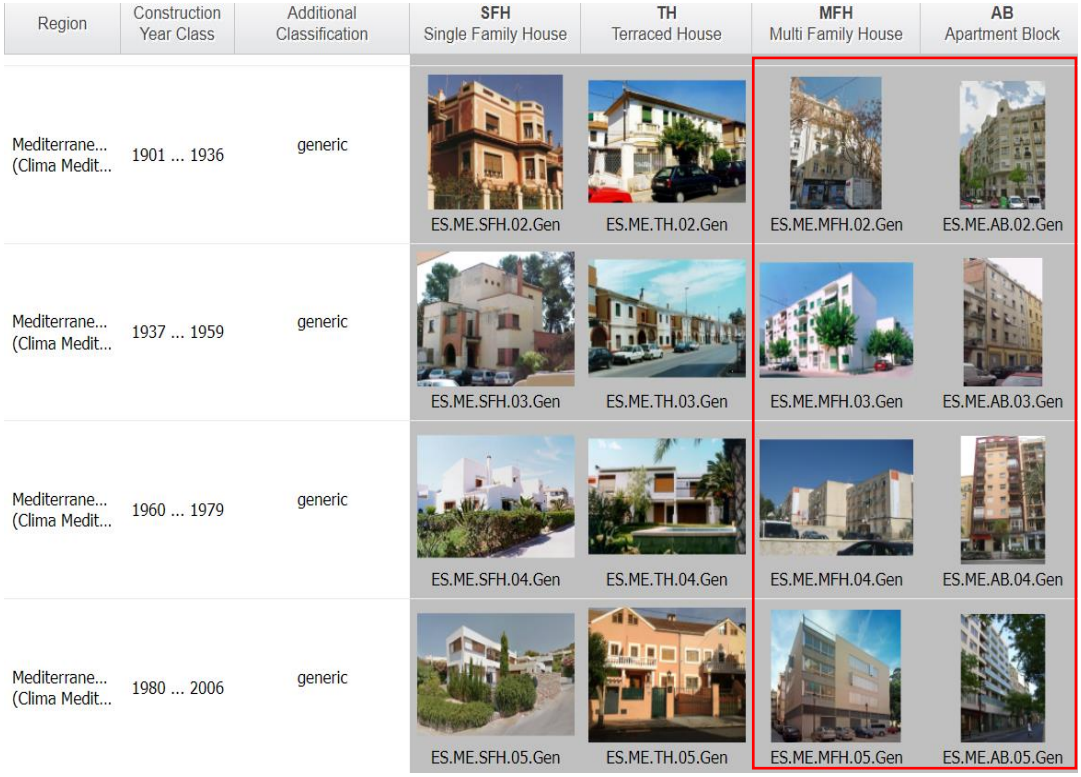


FIGURE 4-2 CLASSES OF SPANISH BUILDINGS IN THE TABULA-TOOL (HTTPS://WEBTOOL.BUILDING-TYPOLOGY.EU/#BM) SUITED FOR THE DENVELOPS COMFORT

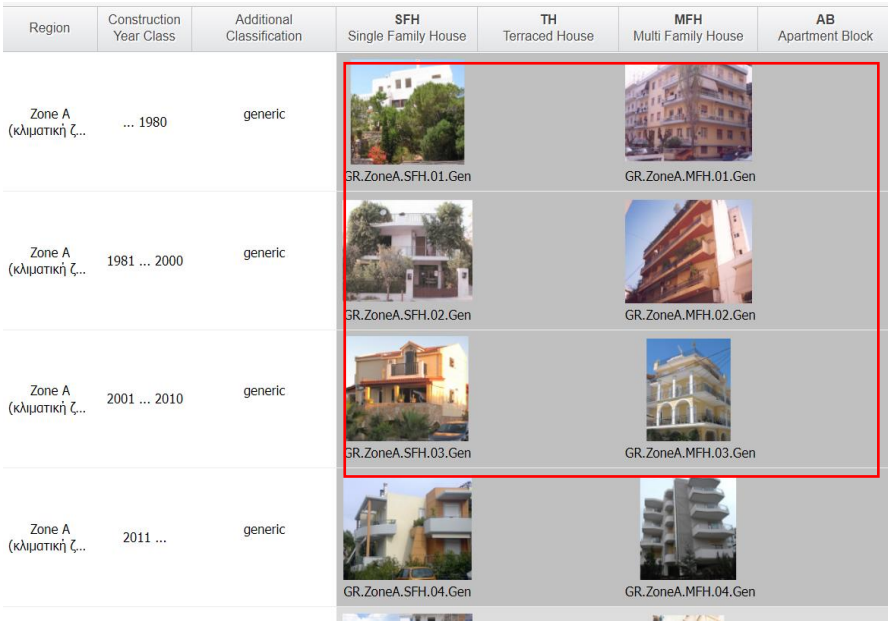
SmartWall

Any type of insulation materials (e.g. rockwool and/or VIP -Vacuum Insulation Panels) could be used with the SmartWall as insulation, depending on wall thickness and thermal requirements. For interior renovation, the SmartWall is used with single sheet of gypsum plasterboard. The system can provide both heating and cooling via a mono-block type heat pump and wall mounted fan coils. The specific core system presents significant advantages for climates with high demand for cooling. It can be applied in every European climate covering the heating and cooling requirements, except from the extreme cold conditions, such as the Northern European countries for the external or the internal side.

The SmartWall can be used in the facade restoration of family houses located in a every Greek climatic region. As it can be seen in **Table 6**, the U-value of buildings constructed after 2011 is 0.45 W/(m^{2}K), according to the Tabula webtool, meaning that there is no need for further renovation with SmartWall, based on Greek regulation[5]. For buildings constructed before 2010, the U-value ranges between 0.70 W/(m^{2}K) and 2.20 W/(m^{2}K) and the renovation with SmartWall reduces the thermal transmittance to 0.19 – 0.24 W/(m^{2}K).

TABLE 6. THERMAL TRANSMITTANCE VALUES (U-VALUE) BEFORE AND AFTER SMARTWALL APPLICATION FOR GREEK BUILDINGS.

Construction year	Pre-renovated wall	Renovated Wall with SmartWall
Before 1980	2.20 W/(m^{2}K)	0.24 W/(m^{2}K)
1981 - 2000	0.85 W/(m^{2}K)	0.20 W/(m^{2}K)
2001 - 2010	0.70 W/(m^{2}K)	0.19 W/(m^{2}K)
2011 - …	0.45 W/(m^{2}K)	No need to renovate



[5] Hellenic building regulation (KENAK)

FIGURE 4-3 CLASSES OF GREEK BUILDINGS IN THE TABULA-TOOL (HTTPS://WEBTOOL.BUILDING-TYPOLOGY.EU/#BM) SUITED FOR THE SMARTWALL

4.3 Maintenance and repair

ConExWall

The ConExWall consists almost exclusively of passive components that do not require any particular maintenance. The integrated sun shading system of ConExWall does not require any cleaning or maintenance and it is long lasting. The heat pump and decentralised fancoil units, of which one unit should be installed per room with high usage, are subject to the usual maintenance intervals.

Denvelops Comfort

The maintenance of the Denvelops Comfort façade will depend on the material selected during the design process for cladding. In case of using painted aluminium tiles, applying a mild cleaning procedure is encouraged every 2 years, and a profound cleaning procedure every 10 years. A similar approach can be considered for the maintenance of the PV panels. The filters of the ventilation unit need to be replaced once every 3 to 6 months.

SmartWall

The SmartWall panels are designed and fabricated in such a way to minimise the future need for maintenance and repairs. Major maintenance is to be planned once every 10 years. Even when maintenance and / or repairs might be needed, the design of the SmartWall panels allows easy and uninterrupted access to components installed into it, minimising the need of extensive and messy works inside or outside the habitant areas of the building, resulting to very limited disturbance of the occupants.

4.4 Summarizing Remarks

The ConExWall can be fitted to existing residential buildings in Czechia, constructed between 1920 and 1994, that have a large volume and a simple façade and existing wall U-values of 1.36 -0.9 W/(m^{2}K). These building typologies require only a heating system and there is no need for cooling. The heat can be supplied by an air-to-water heat pump (HP). The ConExWall is suitable for renovation of the complete envelope of the buildings for continental warm-humid zone. It does not require maintenance.

Denvelops Comfort can be used in the facade restoration of buildings located in a Mediterranean climatic zone constructed between 1901-2006. These buildings have wall U-values ranging from 2.56 to 0.48 W/(m^{2}K). The Denvelops Comfort maintenance depends on the material selected during the design process. In case of using painted aluminium tiles, a mild cleaning procedure is encouraged every 2 years.

The SmartWall can be used in facade restoration of family houses located in a every Greek climatic region and constructed before 2010. For buildings before 2010, the U-value ranges between 0.70 W/(m^2K) and 2.20 W/(m^2K) . The system needs very limited maintenance and repairs.

5. Evaluation of BIM for prefabricated renovation with the PnU kits

This section summarizes findings and PLURAL developments that relate to the use of BIM (Building Information Modelling) for the renovation process in different EU countries. Additionally, it highlights the potential of a new tool called "BIM Parser", developed in PLURAL, to retrieve data, properties, and environmental information about the PnU kits to be used for the calculation of Key Performance Indicators and other decision-making processes. The BIM Parser can significantly promote the use of BIM in renovation projects.

5.1 Parametric BIM modelling of renovation projects

The extent of implementation of BIM in construction and renovation projects is key in verifying the possible use of PLURAL solutions. To obtain the below reported data different data sources were used. These include the European Construction Sector Observatory[6] **(**ECSO), which analyses and carries out comparative assessment on the construction sector in the 27 EU countries and the UK, aiming to provide policymakers and stakeholders with up-to-date information on market conditions and policy developments. The information on the percentage of architects and contruction companies that use BIM is retrieved from the European Architectural Barometer[7].

Figure 5-1 tabulates the collected statistics. They are ordered on the basis of the Gross Domestic Product (GDP) of each country from the highest to the lowest. The BIM usage/adoption data covers new and renovation projects. The ECSO data were used with a weighting of the BIM adoption ranking scale (0 is 0% and 4 is 100% adoption). For those countries that no ECSO data were available mean values were calculated, interpolating data from countries with relatively close values. The GDP of each country and the average value of BIM use are shown in Figures 5-2 and 5-3, respectively.

[6] https://single-market-economy.ec.europa.eu/sectors/construction/observatory_en

[7] https://www.usp-research.com/market-reports/european-architectural-barometer/

	Germany	France	United Kingdom	Italy	Spain	Netherlands	Switzerland	Poland	Sweden
GDP 2022	3.867	2.643	2.600	1.909	1.329	941	768	655	558
Extent of BIM adoption	1,8	n/a	n/a	2,7	1,5	2,7	n/a	n/a	3
Percentage of architects using BIM	23%	38%	49%	25%	34%	81%		33%	
Percentage of construction companies using BIM	70%	55%	73%					43%	

GDP 2022	Percentage of architects using BIM
Source: Eurostat	Source: European Architectural Barometer Q4 2019 USP Marketing Consultancy
Units: billion euro at current prices	Units: %
Extent of BIM adoption	**Percentage of construction companies that use BIM**
Source: European Construction Sector Observatory (2019?)	Source: PlanRadar GmbH, 2021 https://www.planradar.com/gb/bim-adoption-in-europe/
Units: scale ranking from 4=*Very large extent* to 0=*Not at all*	Units: %

	Belgium	Norway	Ireland	Austria	Denmark	Romania	Czechia	Finland	Portugal
GDP 2022	552	551	503	448	375	286	276	267	239
Extent of BIM adoption	2,5	n/a	2,8	3,5	4	2	2	3	2
Percentage of architects using BIM	40%								
Percentage of construction companies using BIM				20%					

GDP 2022	Percentage of architects using BIM
Source: Eurostat	Source: European Architectural Barometer Q4 2019 USP Marketing Consultancy
Units: billion euro at current prices	Units: %
Extent of BIM adoption	**Percentage of construction companies that use BIM**
Source: European Construction Sector Observatory (2019?)	Source: PlanRadar GmbH, 2021 https://www.planradar.com/gb/bim-adoption-in-europe/
Units: scale ranking from 4=*Very large extent* to 0=*Not at all*	Units: %

	Greece	Hungary	Slovakia	Bulgaria	Luxembourg	Lithuania	Latvia	Estonia	Cyprus
GDP 2022	208	170	108	85	78	67	39	36	27
Extent of BIM adoption	1,3	3	n/a	1	2	3	2,2	2,7	1
Percentage of architects using BIM									
Percentage of construction companies using BIM									

GDP 2022	Percentage of architects using BIM
Source: Eurostat	Source: European Architectural Barometer Q4 2019 USP Marketing Consultancy
Units: billion euro at current prices	Units: %
Extent of BIM adoption	**Percentage of construction companies that use BIM**
Source: European Construction Sector Observatory (2019?)	Source: PlanRadar GmbH, 2021 https://www.planradar.com/gb/bim-adoption-in-europe/
Units: scale ranking from 4=*Very large extent* to 0=*Not at all*	Units: %

FIGURE 5-1 EUROPEAN ENERGY-RELATED HOUSING RENOVATION. MARKET SHARE AND BREAKDOWN (AVERAGE 2012-2016)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958218

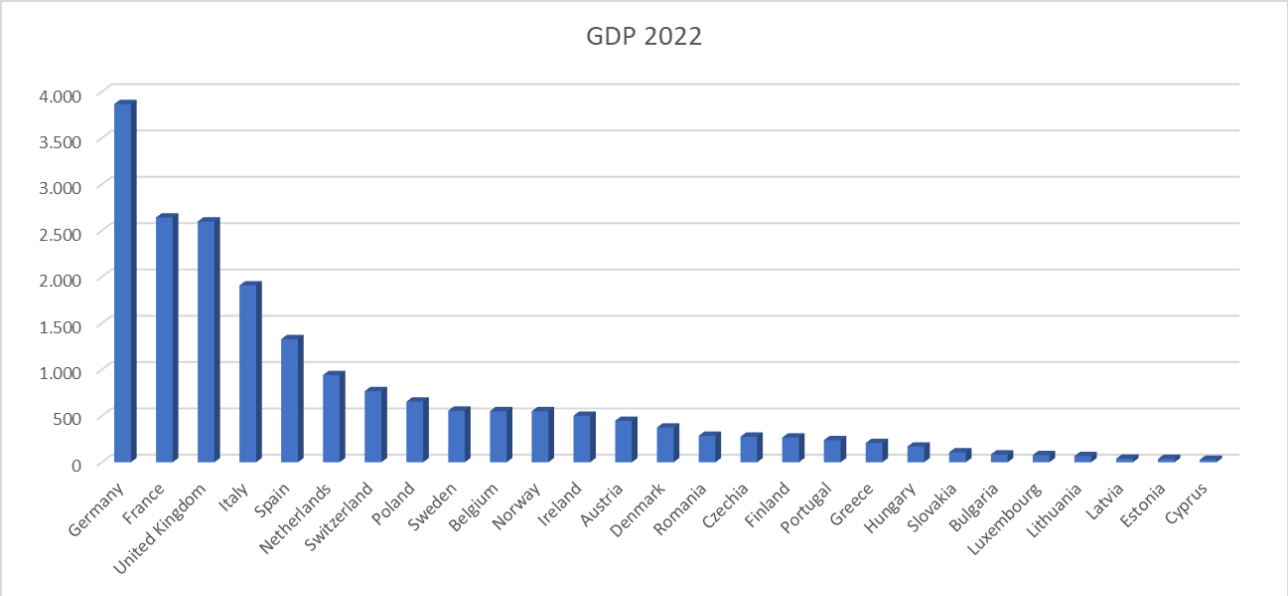


FIGURE 5-2 GDP FOR EU COUNTIES AND UK FOR 2022

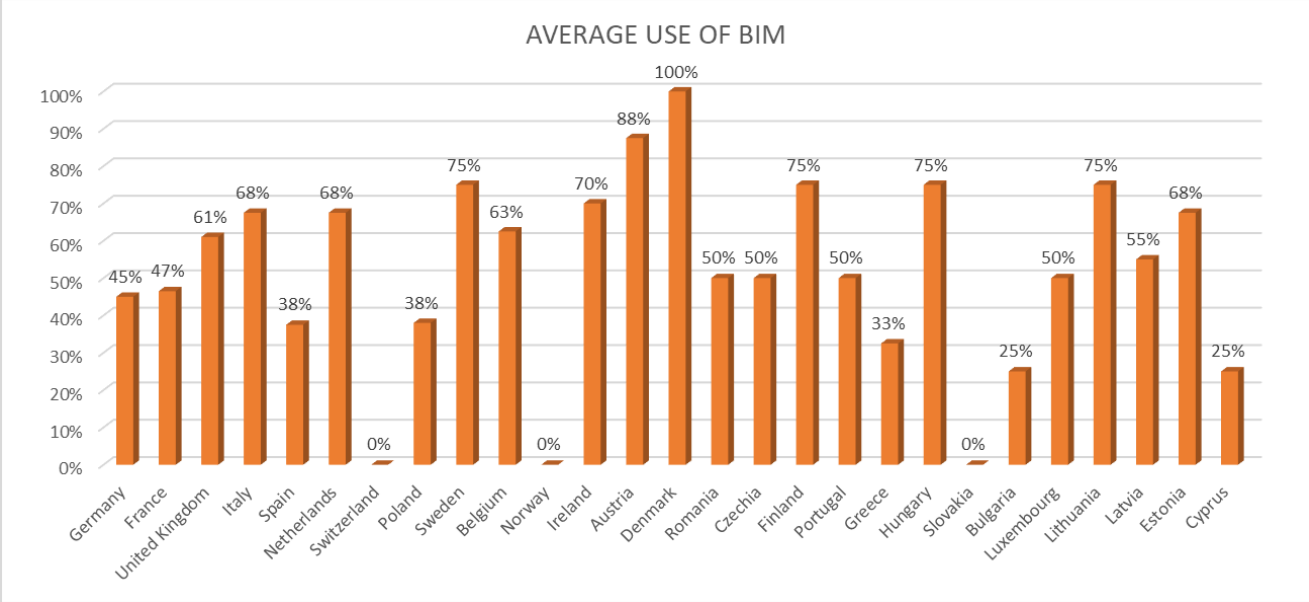


FIGURE 5-3 USE OF BIM BY COUNTRY

Comparing Figure 5-2 and Figure 5-3, in the ten EU countries with the highest GDP (except for Switzerland for which there is no data available) the mean use of BIM is 56%. There is no direct correlation of the GDP with the adoption of BIM. However, it can be stated that BIM is used to create the model of the building in one out of two projects in most of the EU countries. Overall, BIM is well

implanted in building design. This allows us to anticipate that in the future it will be key in the development of construction projects, new ones or in renovation projects.

5.2 PLURAL contribution in BIM of renovation projects

In the PLURAL project a new software (called BIM Parser), that extracts properties from the BIM model of the existing building to send it to the LYSIS platform (the data management platform of the project) to be used in energetic simulations, has been developed. According to the BIM Parser architecture, the BIM parameters that run into the tool are obtained from IFC files and can be stored in LYSIS in an object-oriented database. JSON is the chosen format to represent the information.

The team (partners ITeC and INTRA) working on the BIM Parser and LYSIS platform identified a set of properties, taken from the IFC standard, desirable to be found in the BIM Objects of the PnU kits and the BIM models of the PLURAL demonstration sites. These properties are assigned at the different categories of objects considered by the IFC4 scheme (see Figure 5-4 below).

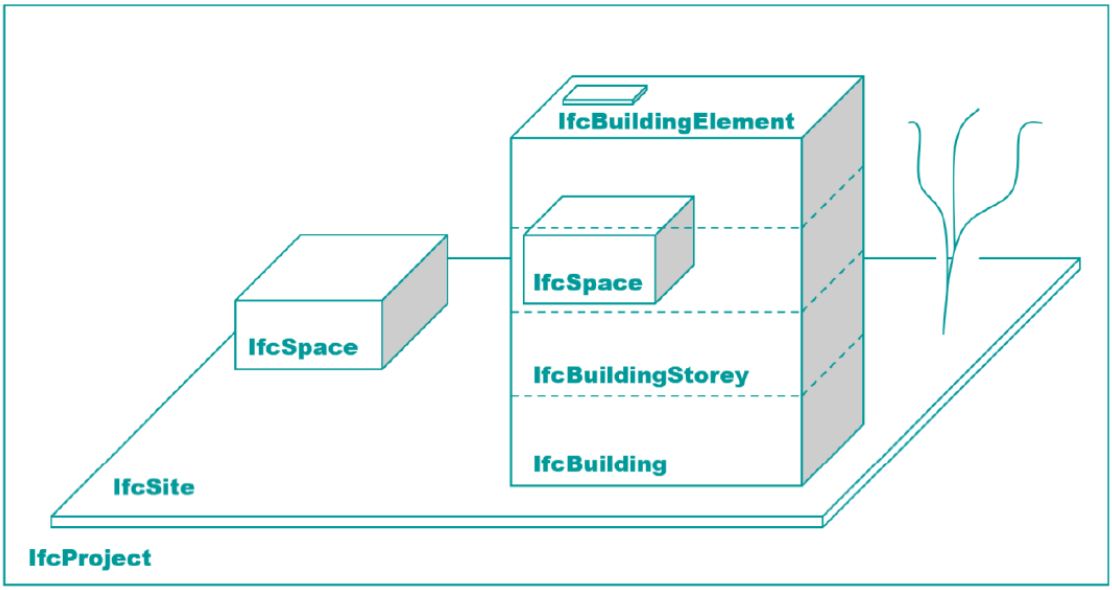


FIGURE 5-4 LEVELS TO ASSIGN BIM PROPERTIES TO BIM OBJECTS ACCORDING TO THE IFC SCHEME

Building Storey Property Sets

The practical experience with models exported from available modelling tools confirms that no information is allocated at the level of building storeys. Thus, no properties at the level of Building Storey are expected in the PLURAL BIM models.

Building Space Property Sets

The BIM Parser and StreamHandler (decision making tool of PLURAL) are designed to manage information about the building spaces and a series of KPIs related to the heated spaces: Non-renewable primary energy balance, Renewable Energy Ratio, Carbon Dioxide (CO2), Illuminance and daylight factor, Primary energy demand / consumption, Thermal Energy demand per area, Electric consumption of mechanical ventilation, Energy consumption for lights and the Total Investments in Greenhouse Gas emissions.

The BIM Parser extracts from the BIM models the area and volume of every heated floor to run calculations for the afore-mentioned KPIs. These data are combined with other data values loaded into the StreamHandler (the project's decision-making tool) from sources different than BIM models.

For the KPI calculations, it is required that the heated spaces of the PLURAL BIM models of the buildings are shaped as IfcSpaces: One single IfcSpace per floor of the Demo building should be modelled and their corresponding area and volume exported into the IFC file according to the IFC4 scheme. If required for other purposes, new properties to come should be defined according to the ifc Property Sets and the eCOB standard.

Building Element Property Sets

BIM Parser and StreamHandler are also being designed to deal with:

• The building elements that envelope the heated spaces, such as walls, windows, doors, slabs and roofs.

• Other building elements that compose the PnU kits and belong to the Electrical, HVAC, Plumbing, Structural or Building controls domains.

BIM Parser Use Case

A BIM Use Case has been modelled containing all the identified classes of BIM objects that may take part in the PLURAL envelopes and PnU kits. The Use Case is made of a simple building made out of building envelopes, spaces and independent components. It was developed as a prototype to run into the BIM Parser and StreamHandler tools in order to confirm the "readability" of items and properties for all the envisaged types of BIM objects in the PLURAL project (the figure below shows a general view of the BIM Parser Use Case). Section 4.1 in D3.2b contains the interaction sequence between the BIM Parser and StreamHandler tested with the Ifc file of the BIM Parser Use Case.

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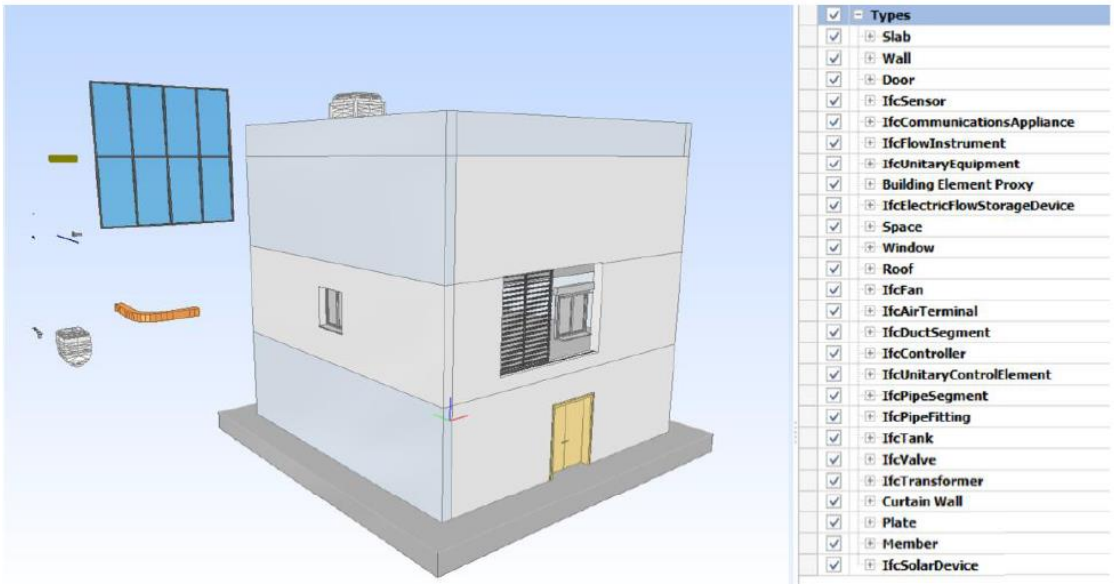

FIGURE 5-5 BIM USE CASE DEVELOPED AS A PROTOTYPE FOR BIM PARSER AND STREAMHANDLER.

All BIM parameters required from a BIM model are explained below:

Location

Location information is composed by building site and orientation.

- Site: Provides information about latitude, longitude and elevation.
- Orientation: Building orientation related to cardinal points.
- Location is used by
  - Air quality – Index CO2
  - Thermal Comfort
  - Thermal Comfort
  - Energy consumption for lights
  - H - Solar irradiation (total or on facades)
  - Illuminance and daylight factor
  - Air temperature
  - H - Solar irradiation (total or on facades)
  - Energy Consumption for DHW
  - Visual Comfort- Daylight Factor
  - Visual Comfort – Daylight Glare Index
  - Comfort Time Availability metrics (TCA, VCA and GCA)

All building spaces

BIMParser provides a list with all building spaces, for each space information provided is:

- Space:
  - Space identifier: identify the space, is used outside BIMParser to check if this space is a thermal zone.
  - Area: space surface.
  - Volume: space volume.
  - List of space enclosures.
  - List of windows: contains all windows present in every space enclosure.
  - List of doors: contains all doors present in every space enclosure.
- List of space enclosures: Set of sides, given a space, enclosures are walls, ceiling and floor. For each side information given is:
  - Type: wall, ceiling, floor.
  - Area: side surface.
  - Volume: side volume.
  - Thermal resistance: total thermal resistance or thermal transmittance are provided. R_{is}, R_N, R_{es}, d_n, λ_n are never provided because BIM tools replace these parameters with thermal transmitance or resistance when exporting to IFC format.
  - List of windows: Each window placed in a side (wall, ceiling)
  - List of doors: Each door placed in a side (wall, ceiling)
- Windows: Information provided for each window is:
  - Type: single window, double window, ...
  - Area: window surface.
  - T: glass transmittance.
  - θ: solid angle. Is not possible to calculate this angle with information given in the BIM file. A constant default value will be provided.
- Doors: Information provided for each door is:
  - Area: door surface.
- Building spaces used by
  - Non-renewable primary energy balance
  - Renewable Energy Ratio
  - Carbon Dioxide (CO2)
  - Illuminance and daylight factor
  - Primary energy demand / consumption
  - Thermal Energy demand per area
  - Electric consumption of mechanical ventilation
  - Energy consumption for lights
  - Total Investments
  - Greenhouse Gas emissions

Building envelope

List of envelop sides, envelop sides are composed by facade wall and roof.

- Envelop side: Information provided for each Envelop side is:
  - Type: facade wall or roof.
  - Area: facade or roof surface.
  - Thermal resistance: total thermal resistance or thermal transmittance are provided. R_{is}, R_N, R_{es}, d_n, λ_n are never provided because BIM tools replace these parameters with thermal transmitance or resistance when exporting to IFC format.
- Building envelops used by
  - H - Solar irradiation (total or on facades)
  - Thermal Transmittance of walls / Thermal Resistance of a wall system

All building devices

- Fans present in the building

List of fans in the whole building.

- Fans used by
  - Electric consumption of mechanical ventilation

All building windows

List of Windows present in the whole building.

- Building windows used by:
  - Thermal Transmittance of windows

The properties that an ifc file must have, are defined by the building Smart International who is leading the digital transformation by enabling better collaboration and digital workflows through the solutions and standards it delivers. So, the software that we have created in PLURAL will be able to extract the properties defined before for each BIM model of any building.

5.3 Concluding Remarks

The following Tables summarize findings in relation to the potential of using the BIM models of the PLURAL solutions for renovation projects. The aim is to identify the countries where it will be more probable to adopt the PLURAL solutions, based on the level of implementation of BIM in projects.

Bim level										
Low	0-20%									
Low-medium	20-40%	Spain	Poland	Greece	Bulgaria	Cyprus				
Medium	40-60%	Germany	France	United Kingdom	Romania	Czechia	Portugal	Luxembourg	Latvia	
Medium-high	60-80%	Italy	Netherlands	Sweden	Belgium	Ireland	Finland	Hungary	Lithuania	Estonia
High	80-100%	Austria	Denmark							

FIGURE 5-6 LEVEL OF BIM ADOPTION IN DIFFERENT EU COUNTRIES

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Country	PROBABILITY OF IMPLEMENTING PLURAL SOLUTIONS BASED ON BIM ADOPTION		
	SmartWall	**Denvelops Comfort**	**ConExWall**
Spain, Poland Greece, Bulgaria Cyprus	Low probability due to BIM adoption – Very high due to climatic zone and technology	Low probability due to BIM adoption – Very high due to climatic zone and technology	Low probability due to BIM adoption – High due to climatic zone and technology
Germany, France United Kingdom Romania, Czechia Portugal, Latvia Luxembourg	Low-medium probability due to BIM adoption in all these countries;	Low-medium probability in Romania, Portugal due to BIM adoption and technology specifications	Low-medium usage probability in all countries; High probability if BIM penetration is not considered.
Italy, Netherlands Sweden, Belgium Ireland, Finland Hungary, Lithuania Estonia	Medium usage probability in all countries	Medium usage probability in Italy	Medium usage probability (Preferred for Sweden, Estonia and Finland)
Austria, Denmark	High probability Preferred solution due to technical characteristics	High probability due to BIM, but technical characteristics not appropriate for climatic conditions	High probability Preferred solution due to technical characteristics

FIGURE 5-7 PROBABILITY OF IMPLEMENTING PLURAL SOLUTIONS BASED ON BIM ADOPTION

The implementation of the PLURAL solutions can be linked to the extent that BIM is implemented in the construction-renovation project process. In countries such as Austria and Denmark, the use of PLURAL kits (Smartwall, and ConExWall) in renovation projects using BIM is more likely, while in countries such as Spain, Poland, Greece, Bulgaria and Cyprus it is seen as less likely due to the lower BIM adoption, although the technical characteristics of SmartWall and Denvelops Comfort are suited for these countries. In these countries, from a market perspective the technology penetration is not affected by the BIM usage.

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6. Evaluation of similar H2020 projects

6.1 Technical solutions of similar H2020 projects

In this section, 5 different Horizon projects (4RinEU, Powerskin+, P2Endure, RenoZEB, StepUPare) are selected and examined with their characteristics and technical solutions and compared to the PLURAL kits. All these projects developed prefabricated modular façades for renovation of multifamily buildings and apartment blocks, as well as of residential buildings. The flexibility of the PLURAL renovation kits in integrating energy production (heat pumps/ fan coils) and air handling systems (heat recovery ventilation units) can be recognised.

You can click on the project name to reach the project website of projects.

EU Project	4RinEU	Powerskin+		P2Endure			RenoZEB	StepUP	PLURAL		
Project Duration	48 months (2016-2021)	48 months (Oct 2019 – Sep 2023)		54 months (Sep 2016 – Feb 2021)			52 months (Oct 2017 – Jan 2022)	54 months (Aug 2019 – Apr 2024)	48 months (Oct 2020 – Sep 2024)		
Renovation Kit		Standard Module	Upgrade	EASEE panel	Fermacell panel	Aluminum Panel	All	All	SmartWall	Denvelops Comfort	ConExWall
Weblinks	http://www.4rineu.eu/reports/index.html	https://www.powerskinplus.eu		https://www.p2endure-project.eu/en/demonstration/plug-play-solutions			https://renozeb.eu/results/plug-play-facade.html	https://www.stepup-project.eu	https://www.plural-renovation.eu https://cordis.europa.eu/project/id/958218		
Climate Zones	All	All	All	All			All	All	Zones 4, 8, 12 (all but extreme cold)	Zones 8, 12 (warmer climates)	Zone 01-04 (cold and mild climates)
Building Stock Characteristics	Multi-storey residential buildings	Non-residential, curtain wall façades	Medium and large residential	Medium and large residential			Medium and large residential	Medium and large residential	Multi-storey residential buildings	Multi-storey residential buildings	Multi-storey residential buildings
Technical Solutions	- Integrated solar shading, - ventilation, - PV,	- Prefabricated façade module (frame construction)	Standard Module + nanocoatings, - PV,	PnP Systems combined with 3D-printed components. - low-e windows, - Folding balcony			Modular Plug & Play Façade with - Integrated PV	Glazing and opaque elements, BiPV, active and	- Prefab module - heat pumps/fan	-prefab ventilated façade and roof	- Prefab timber frame - external

	- energy hub, - ceiling fan	featuring -IGUs and - VIP insulation	- batteries, - heat storage (PCM)	- rooftop retrofitting - prefab HVAC systems / integrated HVAC systems			panels -	passive thermal energy storage	coils - solar collectors for DHW - PV panels - ventilation devices - fire protection - sensors and control systems - energy harvesting windows - multi-functional coatings	- integrated heating and cooling (Air handling Unit) - energy harvesting windows - PV panels on façade and roof	heating and cooling system - Windows with integrated shading system - Independent heat recovery ventilation unit -Heat pump/fan coils
Thermal Performance: Wall Panel	0.13 W(m²K)	≤ 0.098 W(m²K) (opaque module)		U<0.18-0.23 W(m²K)			0.12 W/(m²K)	n.a.	0.22 – 0.43 W(m²K) (dep. on type of SmartWall panel)	0.19 W(m²K)	0.18 W(m²K)
Thermal Performance: Window	window: 0.8 W/(m²K)	IGU: U ≤ 0.80 W/(m²K)		n.a.			0.66 W/(m²K)	n.a.	1.4 W/(m²K)	1.16 W/(m²K)	0.6 W/(m²K)
Main Materials and Thermal Insulation	Timber frame; Rockwool (Norway), Mineral wool (Netherlands and Spain), Cellulose (Netherlands), XPS (Spain)	Glass, Metal frame, Foam, Butyl; Insulation Glazing (transparent modules) and vacuum insulation (opaque modules)		Steel Frame, reinforced concrete, polystyrene insulation	Timber Frame	Alumi-num	Steel Frame	n.a.	Steel or timber frame	Steel	Timber frame

n.a. = not available, no information could be found

6.2 Renovation Cost

Cost information and economic aspects of Horizon 2020 projects are retrieved from the ***4rinEU*** project [8](Link). The project estimated the total costs for prefabricated elements of the Norwegian demo site of the project excluded VAT to be approximately 516,000 €. Costs include production, transportation and mounding of the elements, as well as technical equipment, on site work and materials, rig, waste handling and exterior work. With a total floor area of approximately 400 m^2, the total cost was approximately 1,290 €/m^2. The element costs form approximately half of the total cost per square meter. Elements with integrated technologies are more costly to produce, integration off-site normally saves 12-15 % compared to doing the installations at site.

For the Spanish demonstration building of the 4rinEU project the cost of the Façade Panel Solution is 1,041 €/m^2. The cost of the solution is related to the cost of timber as it is the main component. Overall, timber cost is increasing in the European market due to its increasing demand.

In general, the estimate for traditional renovation seems a bit lower than prefabrication (see Figure 6-1). However, a straightforward comparison cannot be made. The main differences are found for the façade and roof elements, including material cost and man-hours related to the job. The number of invoiced person-hours for the project was 1,250. This includes approximately 175 man-hours for repair after the water leakage and removal of asbestos. For the traditional approach, the estimate is approximately 1,280 man-hours. This corresponds to a 17 % reduction in needed man-hours.

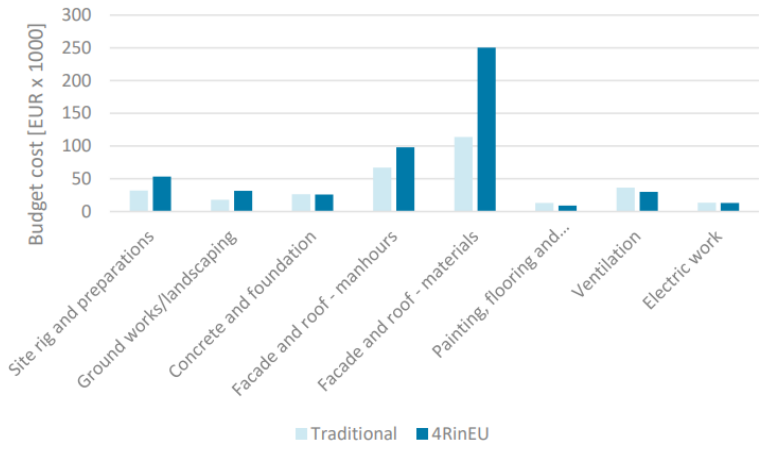

FIGURE 6-1 BUDGET COSTS FOR A TRADITIONAL RENOVATION AND THE 4RINEU RENOVATION

[8] http://www.4rineu.eu/wp-content/uploads/2021/06/4RinEU_D5.3_Deep-renovation-package-in-the-demo.pdf

Furthermore, the project ***P2ENDURE*** which developed a complex Plug & Play (PnP) solution combining multifunctional wall panels with smart windows and prefabricated HVAC systems, has estimated that the total cost of retrofitting is reduced by 40% due to efficient manufacturing and efficient use of labor; quick assembly time of just 0.5 day to place engine, connect pipes/ducts, and then operate with predictable performance; the weight of the modules reduced by 35% compared to traditional components, due to redesign and combination of functions.

An accurate comparison will be made in the future when the final costs of PLURAL kits are determined.

6.3 Summarizing Remarks

Five different Horizon 2020 projects that developed prefabricated modular facade panel solutions were selected to compare in the future the PLURAL solutions. All selected solutions targeted residential multi-family and multi-storey buildings.

The 4RinEU solution is suitable for timber structures, Powerskin+ and RenoZEB are for steel frame systems. P2Endure and PLURAL solutions are compatible with all types of building structures. The P2Endure project includes prefabricated integrated HVAC systems, Renozeb and 4RinEU projects have integrated PV panels. The PLURAL solutions also have HVAC systems and integrated PV panels.

As a potential benefit, all projects identified quick installation, customizable modularization, easy access/replacement of technologies. The integration of HVAC systems into multifunctional façade is a key technology that numerous EU-funded projects have dealt with. They all aim to assess what is feasible or technically suitable by integrating various combinations of heat pumps, convectors, ventilation (mostly mechanical) and heat recovery systems, embedded RES, thermoelectrical parts and smart control systems.

Since all five projects are suitable for all climate zones, PLURAL kits can be applied in these areas with similar approaches without any difficulty. The table suggests that the PLURAL solutions can have similar restoration market volume as these projects.

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7. Conclusions

The three PLURAL PnU kits namely the ConExWall, Denvelops Comfort, SmartWall were the object of this deliverable in terms of their climatic conditions, thermal performance, economic aspects, architectural/structural and technical properties, integration on BIM based platform. The properties of the PLURAL kits were compared to other H2020 prefabricated façade projects. The applicability of these kits in the EU's building stock was evaluated.

ConExWall kit can be applied in all climate zones, but especially for cold climates. It is more suitable for central and northern European countries.

Denvelops Comfort can be installed only on the external side of the façade wall and is suitable for most European countries except from Nordic conditions with extreme heating demands, while the system can be modified in order to cover the heating and cooling demands of the Southern countries (Mediterranean condition with high cooling needs). For buildings with more than 7 storeys and high window-to-wall ratio (more than 35%) the kit should be appropriately designed to cover the energy demands and meet the safety requirements.

SmartWall is suitable for almost every European climate covering the heating and cooling requirements, except from the extreme cold conditions. It can be installed either on the external or the internal side. It can only be installed on flat surfaces and on buildings up to 4 storeys.

ConExWall can be fitted to buildings that have a large volume and a simple façade and wall U-values 0.87 W/(m^{2}K) – 1.36 W/(m^{2}K). Renovation with ConExWall can reduces the U-value to 0.16 W/(m^{2}K) – 0.18 W/(m^{2}K).

Denvelops Comfort can be used for façade restoration of buildings located in the Mediterranean climatic zone and constructed between 1930-2006. The U-value of such buildings at the existing state ranges between 0.48 W/(m^{2}K) and 2.56 W/(m^{2}K), while the renovation with Denvelops Comfort reduces the U-value from 0.20 W/(m^{2}K) to 0.30 W/(m^{2}K).

SmartWall can be used for façade restoration of residential buildings located in every European climatic zone. For Greece, it is ideal for buildings constructed before 2010 with U-values ranging between 0.70 W/(m^{2}K) and 2.20 W/(m^{2}K). Renovation with the SmartWall reduces the thermal transmittance to 0.19 – 0.24 W/(m^{2}K).

The PLURAL solutions can be linked to the level of adoption of BIM in the construction process of renovation projects. In countries such as Austria and Denmark, the use of PLURAL kits (Smartwall, ConExWall) in projects using BIM is more likely, while in countries such as Spain, Poland, Greece, Bulgaria and Cyprus it is seen as less likely, despite the favourable climatic conditions for the technology application. Also, the BIM based LYSIS platform and Multi-objective Decisions Support Tool (MODEST) developed in the project creating libraries of prefabricated units can result in time savings of 15–20 %.

Overall, in the recent years, there has been a significant increase of the building renovation rate in EU. The investment in renovation market has significantly increased between 2017 and 2019 (35.6%),

particularly for residential buildings. On the other hand, residential buildings (single-family houses and apartment buildings) being constructed until 2000 consume approx. 75 kWh/m^2 – 184 kWh/m^2 gross floor area in EU, which is high. Due to the unfavourable A/V ratio (area to volume), single-family houses perform worse than apartment blocks. There is a large part of building stock that does not comply with the targeted energy efficiency standards.

There is a significant need for a large fraction of the building stock to be renovated, to reduce the energy demand and to achieve the net zero standard by 2050. The PLURAL kits with optimized active solutions (modular facades integrating smart energy production systems, control and storage solutions) are capable of fulfilling the specific demands of different climates and building typologies in the EU market.