State-of-the-art report on innovations for deep renovation

Deliverable Report 6.5

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P2ENDURE

Plug-and-Play product and process innovation for Energy-efficient building deep renovation

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 7723391.

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Colophon

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Publishable executive summary

P2ENDURE promotes evidence-based innovative solutions for deep renovation based on prefabricated plug and play systems in combination with on-site scanning, robotic 3D printing and BIM, demonstrated and monitored at 10 real projects in 4 geo-clusters with EU-wide replication potential.

This deliverable 6.5 focuses on activities executed in relevant EU-funded projects where the aim was to identify state-of-the-art renovation technologies that lack market uptake but show a high replicability potential and could be further developed (increasing their TRL level) and applied inside the P2ENDURE project. Furthermore, the use and integration of 3D scanning, ICT and real-time monitoring techniques for energy efficient building retrofitting applied in different EU-funded projects was investigated. It was analysed whether these technologies enable renovation tasks to be executed in a smarter way, thus successfully reaching the expected energy targets.

The report is based on the assessment of the existing state-of-the-art technologies and draws mainly from concluded and on-going EU-funded project's sources: websites, public available deliverables articles, discussion with project members etc. Around 30 projects and their developed solutions were reviewed. Not all final results and analysis of the technologies implemented on the demonstrated buildings are (yet) publically presented therefore it was not possible to verify product's actual performance (mostly described product's objectives). Although only a limited number of EU-funded projects was analysed, this allows for an overview on new upcoming renovation possibilities and trends that can be applied in for building deep retrofitting.

List of acronyms and abbreviations

AR: Augmented Reality

BIM: Building Information Model

DHW: Domestic Hot Water

EBC: Energy in Buildings and Communities

ECM: Energy Conservation Measures

EU: European Union

GIS: Geospatial Information System

GCP: Ground Control Points

GPS: Global Positioning System

HVAC: Heating Ventilation Air Conditioning

ICT: Information and Communication Technology

IEA: International Energy Agency

IEQ: Indoor Environment Quality

IPS: Indoor Positioning System

LCA: Life Cycle Analysis

PnP: Plug and Play

R&D: Research and Development

RES: Renewable Energy Source

RoI: Return on Investment

SBS: Sick Building Syndrome

SME: Small and Medium-size Enterprise

TRL: Technology Readiness Level

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1. Introduction

1.1 Why are deep renovations needed?

Due to the stricter European Union (EU) regulations aiming to reduce energy consumption (2020 goals), the design of energy efficient buildings and reducing the energy performance of existing buildings are becoming of vital importance [1].

With an increasing age of the building stock and their energy wastage, this creates a need for deep renovation of the existing old building stock. Such deep renovations should become of primary concern in order to obtain high energy savings and reach EU targets. In response, EU is trying to enhance energy efficiency improvements by funding different research and innovation projects through instruments such as H2020, FP7, IEE [2]. Research, development and innovation are key policy components of the EU strategy for economic growth and energy targets achievement. In the end, overall retrofitting will play a crucial role in in Europe to achieve their goals in terms of energy efficiency targets.

1.2 Aim of the report

The aim of this report is to analyse the latest developed plug and play solutions (building components, heating, ventilation and air conditioning (HVAC) systems) that can be used for deep renovation. A large number of innovative technologies have been developed from recent EU-funded projects that support deep renovations. While these technological solutions are mostly available at a demonstration level, there is a lack of market uptake and supply-chain collaboration models. Better communication and awareness of each other's activities is one of the central ideas in promoting better collaboration between different ambitious EU projects and developed services.

This deliverable 6.5 therefore focuses on activities done in relevant concluded or on-going EU-funded projects where the aim is to identify state-of-the-art renovation technologies and concepts developed in these EU-supported projects. The report will help identifying the technological solutions that lack market uptake but show a high replicability potential and could be further developed (increasing their technology readiness level (TRL)) and applied in P2ENDURE project. It has also been investigated the use of 3D scanning, Building Information Modelling (BIM), Information and Communication Technology (ICT) and real-time monitoring techniques for energy efficient building retrofitting. This enables renovation projects to be implemented in a smarter way, thus successfully reaching the expected energy targets.

Most of the reviewed projects focus on developing optimal breakthrough renovation solutions that could present innovative cost-effective solutions but it seems not enough effort is done after the projects durability to achieve clear integration of these state-of-the-art technologies into the market (still fragmented renovation processes). This report focuses on a presentation of the innovative solutions that have a high level of flexibility and scalability, seem to prove to deliver expected performance and to allow market uptake.

The table 1 shows a list of projects that do not only launched advanced technologies allowing a step forward in deep renovation approach but also the projects that define systematic renovation strategies for their retrofitting initiatives including design, execution and maintenance of the retrofitted building. Table 2 presents projects that do not only deal with a supply (manufacturing) side but address renovation process as a whole strategical approach including assessment of the demand side.

Funding scheme	Name of the project (official website)	Main objectives
H2020	MORE-CONNECT (2014-2018) www.more-connect.eu/	The challenge of the MORE-CONNECT project is to make a major step forward in deep renovation field by the introduction and application of prefabricated modular building elements. The project comprises: product and process innovation, innovative market approach and cost and quality optimization.
H2020	INSITER (2014-2018) www.insiter-project.eu/	INSITER aims to eliminate the gaps in quality and energy-performance between design and realization of energy-efficient buildings based on prefabricated components.
H2020	BERTIM (2015-2019) www.bertim.eu/	BERTIM develops timber prefabricated modules which will provide the opportunity to renovate old buildings while improving energy performance, air quality, aesthetics, comfort, and property value at the same time, while ensuring low intrusiveness during renovation works.
H2020	IMPRESS (2015-2018) www.project-impress.eu/	IMPRESS will develop a new range of easy to install panels, which reduce energy demand while preserving or improving the building aesthetics. The project will also focus on the development of an Iterative Design Methodology (IDM) through an examination of international approaches, such as the BuildingSMART alliance and will develop a process map for successful application of the methodology.
H2020	E2VENT (2015-2018) www.e2vent.eu/	E2VENT will develop, demonstrate and validate cost effective, high energy efficient, low CO2 emissions, replicable, low intrusive, systemic approach for retrofitting of residential and commercial buildings. Use of ventilated façade system, heat recovery units, number of photovoltaic cells, natural lighting strategies, and insulation thickness; are variable depending on the characteristics of the building to be retrofitted.
H2020	Eensulate (2016-	EENSULATE project aims to develop innovative lightweight (35%

	2020) http://www.eensulate.eu/	weight reduction compared to the current best performing modules), highly insulating energy efficient components as well as associated enabling materials for cost-effective retrofitting and new construction of curtain wall facades. Eensulate represents an ambitious project, which aims to introduce a novel unitized curtain wall system capable of meeting the market demand.
H2020	REnnovates (2015-2018) www.rennovates.eu	REnnovates project aims to develop a holistic systemic deep renovation concept using smart services, technical solutions and developing smart energy-based communities resulting in energy-neutral housing by reducing energy consumption and maximizing the use of renewable energy.
H2020	NewTREND (2015-2018) http://newtrend-project.eu/	The NewTREND (New integrated methodology and Tools for Retrofit design towards a next generation of Energy efficient and sustainable buildings and Districts) project seeks to improve the energy efficiency and performances of the existing European building stock by developing a new participatory integrated design methodology specifically targeted to the retrofit of buildings and neighbourhoods, fostering collaboration of all the stakeholders in the value chain, engaging occupants and building users and supporting all the refurbishment phases towards whole life-cycle optimisation.
H2020	MOBISTYLE (2016-2020) www.mobistyle-project.eu/	MOBISTYLE methodology will elaborate an approach leading to an efficient and long-lasting change of user behaviour and consequently towards more energy efficient building usage. Tailor made tools and information services will be developed for the different energy end-users types.
FP7	EASEE (2011-2014) www.easee-project.eu/	Inside EASEE project a tool-kit for envelope retrofitting of existing multi-storey and multi-owner buildings was developed. It combines novel design and assessment strategies, with scaffolding-free installation approaches, to reduce energy demand, minimizing the impact on occupants while preserving the façade original appearance.
FP7	ADAPTIWALL (2013-2017) www.adaptiwall.eu/	ADAPTIWALL uses nanotechnology to develop a multifunctional and climate-adaptive panel for energy-efficient buildings. This novel panel consists of 3 elements: lightweight concrete with nano-additives for efficient thermal storage and load bearing capacity; adaptable polymer materials for switchable thermal resistance; and total heat exchanger with nanostructured membrane for temperature, moisture and anti-bacterial control.
FP7	A2PBEER (2013-2017)	A2PBEER aims to develop a cost effective, “energy efficient retrofitting” methodology for public buildings. The A2PBEER methodology included

	www.a2pbeer.eu/	existing available building solutions and also advanced innovative ones developed by the project.
FP7	iNSPiRe (2012-2016) www.inspirefp7.eu/	The aim of iNSPiRe project was to tackle the problem of high-energy consumption by producing systemic (6) renovation packages that can be applied to residential and tertiary buildings (suitable to a variety of climates while ensuring optimum comfort for the building users).
FP7	RetroKit (2012-2016) www.retrokitproject.eu	The vision of the RetroKit project was to develop and demonstrate multifunctional, modular, low cost and easy to install prefabricated modules. Retrofitting is often associated with social, technological, industrial and economic barriers. The RetroKit project addresses these problems in order to increase the EU retrofitting rate and contribute to EU energy reduction commitments.

Table 1: List of EU-funded projects that deal with new state-of-the-art technologies for deep renovations.

Funding scheme	Name of the project (official website)	Main objectives
IEE	ZEBRA 2020 (2014-2016)	The key objective of ZEBRA2020 was to monitor the market uptake of nZEBs across Europe and provide data and as well as recommendations on how to reach a high level nZEB standard.
H2020	REFURB (2015-2018) http://go-refurb.eu/	REFURB gives an overview in a one-stop-shop model and establishes local partnerships and energy solutions close to consumers in the participating countries. The project seeks to approach energy renovations from the buyer's point of view and provide house owners with a compelling offer.
IEE	NeZeR (2014-2017) http://www.nezer-project.eu/	NeZeR is focused on promotion of smart and integrated NZEB renovation measures in the European renovation market.

Table 2: EU-funded projects analysing the current building market and finding new systematic renovation strategies that would make deep renovations more efficient.

1.3 Main objectives of deep renovation

According to the EU Energy Efficiency Directive, the 'deep renovation' term represents a cost-effective refurbishment that reduces both the delivered and final energy consumption of a building by a significant percentage compared with the pre-renovation levels; typically more than 60% energy saving [1]. Not only improving the energy efficiency, by applying deep renovation also improved indoor quality and improved social environment (inhabited site) should be achieved.
'Cost-effective' means that higher energy performance is resulting in the lowest cost during the estimated economic lifecycle of the building, and a quick Return on Investment (RoI) for implemented solutions through energy savings.
The definition of deep renovation applies within the framework of major renovation, which means: more than 25 % of the surface of the building envelope undergoes renovation; or, the total cost of the renovation of the building envelope or the technical building systems is higher than 25 % of the value of the building, excluding the value of the land upon which the building is situated.

1.4 EU-funded projects focusing on a development of innovative technologies for deep renovation

The report is based on the assessment of the existing state-of-the-art technologies and draws mainly from EU-funded project's sources: websites, articles, researches etc. This report should give an insight on innovative solutions recently developed and lessons learned in the field of innovative deep renovation concepts.
It should be noted that the goal of the report is not identifying and analysing the challenges and barriers that prevent boosting wide spread of developed technologies for deep renovations. Hence, these challenges are directly related to actual deep renovation executions in practice and therefore need to be addressed on a national and EU level. The report in the end presents an overview of the issues that are largely discussed in the reviewed projects. These barriers need to be essentially tackled and overcome if the aim is to reach an efficient deep renovation market transition.

1.5 IEA annexes focusing on building renovations

International Energy Agency (IEA) has established an Implementing Agreement on Energy in Buildings and Communities (EBC). The main function of EBC is to undertake research and provide an international focus for building energy efficiency. The EBCs tasks are undertaken through a series of research projects, so-called 'Annexes'. Several of these annexes are addressing the renovation techniques for different applications (educational, governmental, residential buildings) in a broader scale. Completed projects that addressed this topic are:

- Annex 46 'Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)' (2005-2010) aimed to develop a tool and guidelines for decision makers to improve the working environment of government buildings through energy-efficient retrofitting projects [3].
  Link: http://www.iea-ebc.org/projects/completed-projects/ebc-annex-46/
- Annex 50 'Prefabricated systems for low energy renovation of residential buildings' (2006-2011) focused on a development and demonstration of an innovative whole building renovation concept for residential buildings (apartment) [4].
  Link: http://www.iea-ebc.org/projects/completed-projects/ebc-annex-50/

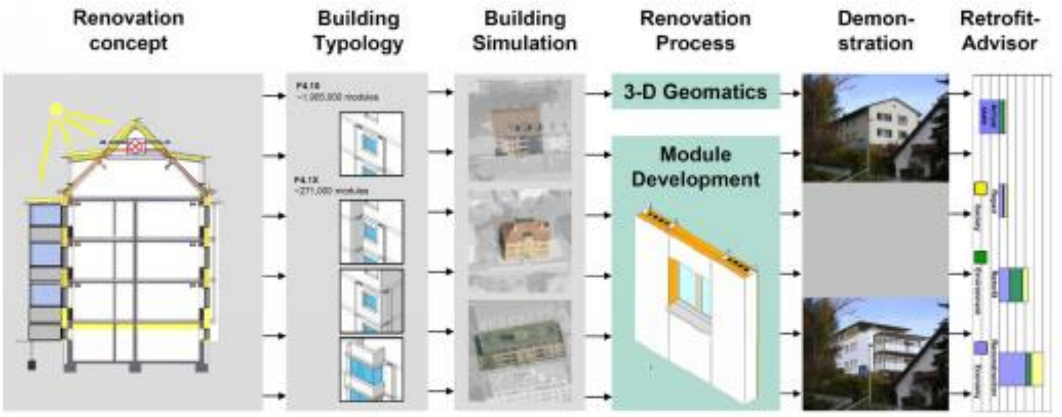

Figure 1: Research steps of ECBS Annex 50 - From renovation concept to planning tool [].

- Annex 55 'Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)' (2009-2013) was focusing on development of a decision support data tools for energy retrofitting measures [5].
  Link: http://www.iea-ebc.org/projects/completed-projects/ebc-annex-55/

Hence, with a fast recent development of the new renovation techniques, some of the concepts presented in these annexes can be considered sequentially outdated. Still, the results of these annexes reflect the current state of the market and indicate the risks and barriers of the demand-supply side when it comes to retrofitting. More than that, it shows that the market is lacking a reliable comprehensive renovation methodology and strategy that would allow for highly efficient and well acceptable deep renovations of the old building stock.
As already discussed, a whole renovation concept is more important than solely implementation of innovative technical solutions. The decision for renovation is not simply a combination of different state-of-the-art technologies but it includes much more complex interaction between the different groups of

people (users, building owners, contractors, municipality, and government), information, financial and business related issues. Current ongoing projects of IEA EBC (annexes) that deal with some of these issues are:

- Annex 56 'Cost-Effective Energy & CO2 Emissions Optimization in Building Renovation' (2010-2016)
  This annex focuses on a development of a methodology for establishing cost optimized targets for energy consumption and CO2 emissions in building renovation. It aims to determine cost effective combinations of energy efficiency and renewable energy supply measures. To support this methodology, case studies will be presented to encourage decision makers to promote efficient and cost effective renovations [6].
  Link: http://www.iea-annex56.org/
- Annex 61 'Business and Technical Concepts for Deep Energy Retrofit of Public Buildings' (2012-2016)
  The work inside Annex 61 is focused on creating a framework along with selected tools and guidelines that will significantly reduce energy use (by more than 50%) in government and public buildings undergoing renovation. One of the main objectives is to present highly innovative and effective bundled packages of energy conservation measures (ECM) for selected building types and climatic conditions. Furthermore, the aim is to develop and demonstrate innovative, highly resource efficient business modes for retrofitting buildings [7].
  Link: http://iea-annex61.org/

2. Deep renovation technologies

Most common deep renovation measures are: adding insulation and improving the airtightness of the building envelope, roof retrofitting, installation of PV panels, heat recovery, efficient HVAC systems, changing and changing the windows. Hence, several reviewed projects aim to develop whole deep renovation packages that have integrated different solutions (components) chosen by the client.

The hypothesis is that due to the different regulations, technologies, materials, different cultural and historical aspects and different climate conditions, it is difficult to offer a single prefabricated renovation package suitable for all the cases. EU-funded projects which strive to develop renovation packages were analysed where the building owner can renovate his building by a one-stop-shop concept [8, 9]. It was investigated whether these renovation concepts (incorporating different available solutions) can be adapted to different architectonic configurations and typologies.

2.1 Prefabricated systems for building envelopes

Most often as a basic renovation measure, renovation of the building envelope is done. Most of the old European buildings (from 1960-1970) have a poor thermal insulation. Improving the facade can lead to energy savings and improved thermal comfort, including reduction of drafts and better airtightness. The most common renovation technique includes adding insulation on the external part of the building envelope on the site (removal of current façade and adding new layers). This presents a traditional renovation technique that requires an extensive labour work to be done on the site and larger risks for damage since exposed to different conditions (outdoor force, weather conditions). On the other hand, using high level of prefabrication can decrease these risks and reduces the renovation process on site (fewer disturbances for the inhabitants). Installing prefabricated elements therefore present an alternative where most of the work is normally made in the factory.

Using prefabrication modules (elements) is an option which has several advantages:

- Prefabricated modules combine different functions: structural stability and insulation.
- Fabrication in a factory is more accurate, secure and easier than on site.
- Shorter assembly time on site (in factory finalized as much as possible).
- Typically cheaper and less waste produced (optimized automated production line).
- The use of standard products and designs (several dimensions and shapes).
- Building-service systems can be integrated as part of the construction elements.

Hence several problems have been recognized when developing and integrating prefabricated modules:

- Detailed planning and coordination (information flow, guarantee).
- New business models are required.
- Complex installation system.
- Mistrust of the traditional building industry in prefabricated solutions (believed that the quality is lower).

2.1.1 MORE-CONNECT modular panels (H2020)

MORE-CONNECT project explored different modular design concepts to develop favourable optimal solution when considering:

- Complete removal of the facade and full replacement by new elements
- Partial removal of the facade and partial replacement and addition of elements
  No removal of facade and addition of prefab elements [8].

The following examples are showing the basic horizontal – oriented module division, vertical division of modules can be applied as well. It may be favourable especially for the low floor buildings. The principles of the connection positioning are similar.

- Geometrical variant A: No removal of existing wall, parapet windows (Figure 2, left)
- Geometrical variant B: Possible parapet removal (Figure 2, right)

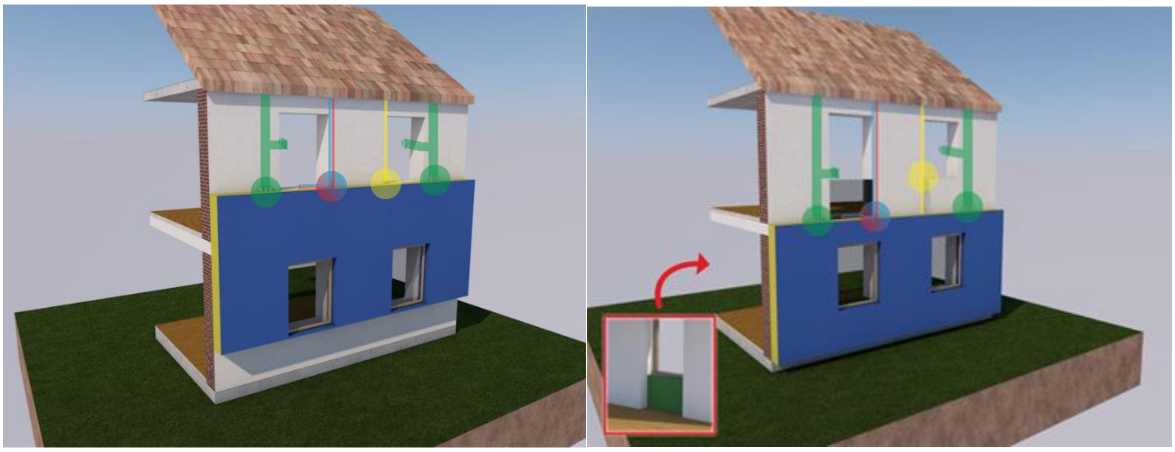

Figure 2 (left): Optimal position of modules in situation when in the external wall are windows with parapets that cannot be removed and the opening cannot be enlarged. Pipes of the heating system are connected beneath the window sill.

Figure 2 (right): Optimal position of modules in situation when there is an option to remove the at least one of two parapets and use the new gap for connections of heat distribution system at the floor level. New parapet cover must be done (left box, in green).

- Geometrical variant C: possible parapet removal, new French window (Figure 3, left)
- Geometrical variant D: all parapets removed, different window heights (Figure 3, right)

Figure 3 (left): Optimal position of modules in situation when a French window is required by the design.

Figure 3 (right): Optimal position of modules in situation when a French window is required by the design. New parapet and floor cover (left bottom box, in green)

- Geometrical variant E: all parapets removed, only French windows present (Figure 4, left)
- Geometrical variant F: original façade removal (Figure 4, right)

Figure 4 (left): Optimal position of modules in situation when two French windows are required by the design.

Figure 4 (right): Variant F for total replacement of the original façade wall. The newly built interior plasterboard wall (included in the refurbishment modules) will be provided (left box, in green).

Figure 5: First prototypes of MORE-CONNECT prefabricated panels [8].

Project's website: http://www.more-connect.eu/ (product in a research and development phase)

2.1.2 BERTIM prefabricated modules (H2020)

BERTIM aims to develop a standardized product for the wood industry for building energy efficient renovation. Beside integration of the building components (windows and balconies) also community HVAC systems will be integrated as part of the module. A 3D installation module for community systems (ventilation with heat recovery, DHW with solar panels) will be developed and the envelope will include a distribution system for ventilation air and domestic hot water for every dwelling in the building. Thus BERTIM system will allow a deep building renovation by the exterior, reducing the intrusiveness of renovation works nearly completely. Only the removal of the existing window once the external timber layer is installed will be carried out from the inside of the dwellings.

The product will be customized only in terms of the insulation needs for the different climatic areas. However, the general design of the modules and the prefabrication process will be unique. The product will be developed in timber and will use recyclable materials, for a low carbon footprint.

The product characteristics and fabrication process based on mass manufacturing processes will be defined and carried out in real industrial settings to assure the efficiency of the process and cost-effectiveness. Figure 6 shows prefabrication steps of BERTIM building envelope module.

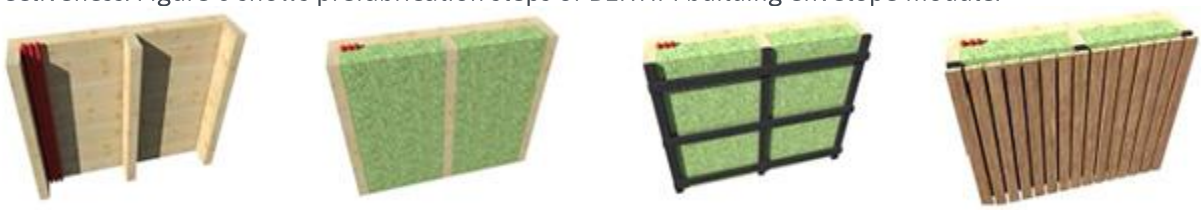

Figure 6: Development of the BERTIM prefabricated building envelope module [10].

On the contrary to the state of art developments, the BERTIM concept is based on self-supporting structures. As a consequence, the load of the modules is not supported by the existing structure avoiding structural reinforcement needs and reducing installation time. In order to assure the self-supporting of the structures, the assembly systems of the modules with the façade will be designed in order to allow vertical movements between the two elements [10].

Project's website: http://www.bertim.eu/ (product in a research and development phase)

2.1.3 IMPRESS prefabricated panels (H2020)

Partners working together on the IMPRESS project will develop three prefabricated panel options for building renovation:

- A polyurethane based insulated panel with improved thermal performance and light radiation.
- A thin, lightweight pre-cast concrete sandwich panel with optimum thermal and weathering resistance.
- A lightweight pre-cast concrete sandwich panel incorporating Phase Change Materials (PCM) to adapt the thermo-physical properties of the building envelope and enable optimum passive heating and cooling benefits.

The first two options are suitable for over-cladding while the third option is suitable for re-cladding. All panels will have embedded sensors, which are available off-the-shelf, and will be used for the assessment of the final product performance, integrated with the building in-use [11].

Project website: http://www.project-impress.eu/

2.1.4 E2vent ventilated façade system (H2020)

E2VENT main goal is the development of an energy efficient ventilated facades for optimal adaptability and heat exchange able to achieve remarkable energy savings, through the integration of an innovative adaptive ventilated façade system, including:

- A Smart Modular Heat Recovery Unit (SMHRU) for the air renewal allows the heat recovery from the extracted air using a double fux exchanger. Indoor Air Quality is ensured while limiting the energy losses.
- A Latent Heat Thermal Energy Storage (LHTES) based on phase change materials will provide a heat storage system for heating and cooling peak saving.
- A smart management that controls the system on a real time basis targeting optimal performances. It will embed new sensors, communicate with existing systems and recover predicted weather.
- An efficient anchoring system that limits thermal bridges [12].

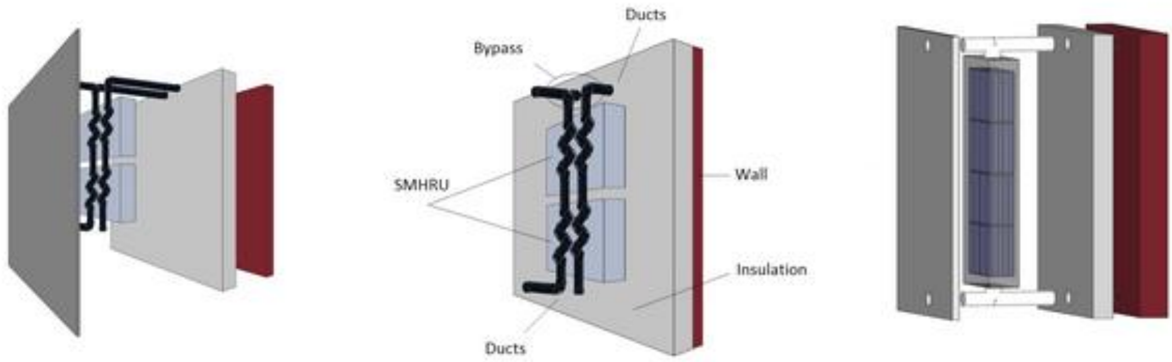

Figure 7: E2vent system (left), Smart Modular Heat Recovery Unit (SMHRU, middle) and Latent Heat Thermal Energy Storage (LHTES, right) [12].

Project's website: http://www.e2vent.eu/ (2015-2018)

2.1.5 EEnsulate curtain walls (H2020)

EENSULATE project aims to develop innovative lightweight (35% weight reduction compared to the current best performing modules), highly insulating energy efficient components as well as associated enabling materials for cost-effective retrofitting and new construction of curtain wall facades. Eensulate represents an ambitious project, which aims to introduce a novel unitized curtain wall system capable of meeting the market demand. It is expected to be an affordable (28% reduction of total refurbishment costs), high performance prefabricated façade, retrofitting solution with reduced weight and thickness. It aims to bring existing curtain wall buildings to "nearly zero energy" standards, reducing energy bills by at least 20% while complying with the structural limits of the original building structure and national building codes.

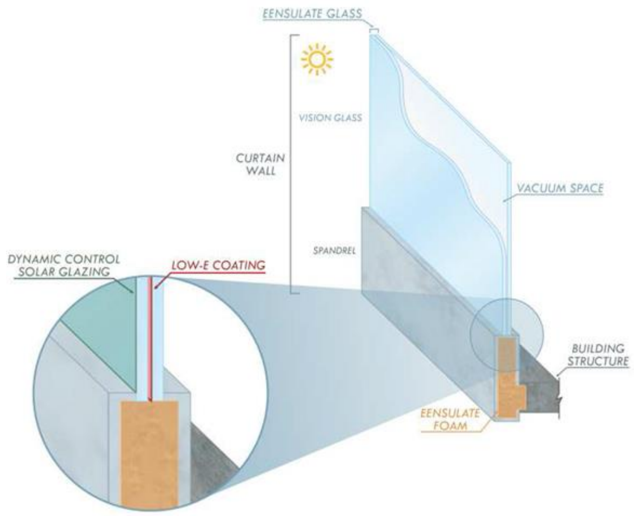

Figure 8: Scheme of the EENSULATE technology for high performance curtain walls [13].

Eensulate draws a strategy for sustainability of curtain walls by leveraging on:

- High durability (maximum service life) of the enabling materials and overall component
- Good thermal breaks between the curtain wall and the sub-structure through the innovative spray foam
- High R-value due to the Vacuum Glass as those achievable with triple glazing systems but with lower weight and less material use. Also, the low temperature manufacturing process for the vacuum glass allows the use of low-E and spectrally selective glass coatings, which can significantly reduce energy loads and improve comfort close to the wall

Due to the variable ratio between the spandrel and vision glass, Eensulate will match any existing façade design (where there are no constraints on original architecture) as well as new buildings. Furthermore, Eensulate is expected to allow for fast retrofitting due to its characteristics, which would minimize the disruption of business and impact on occupants. The innovation potential and market competitive advantage lies in the combination of three different material innovations in a single product platform, scalable from Basic to Premium. Eensulate components will make use as much as possible of existing components such as frames, structural silicon, gaskets, etc.), although some kind of adaptation will certainly be required.

The project output is a product family that will be promoted in two different levels of performance. First, Eensulate Basic expects to tackle both the vision glass and spandrel, and drastically reduces thermal bridges associated with interfaces between the spandrel and the sub-structure. Second, Eensulate Premium expects to add, through thermo tuneable coating, the dynamic solar control behaviour in a cost-effective way and integrate multi-functionalities as self-cleaning and anti-fogging properties. During the installation of these products, special spray foam – Eensulate spray foam – is used to increase insulation of the building [13].

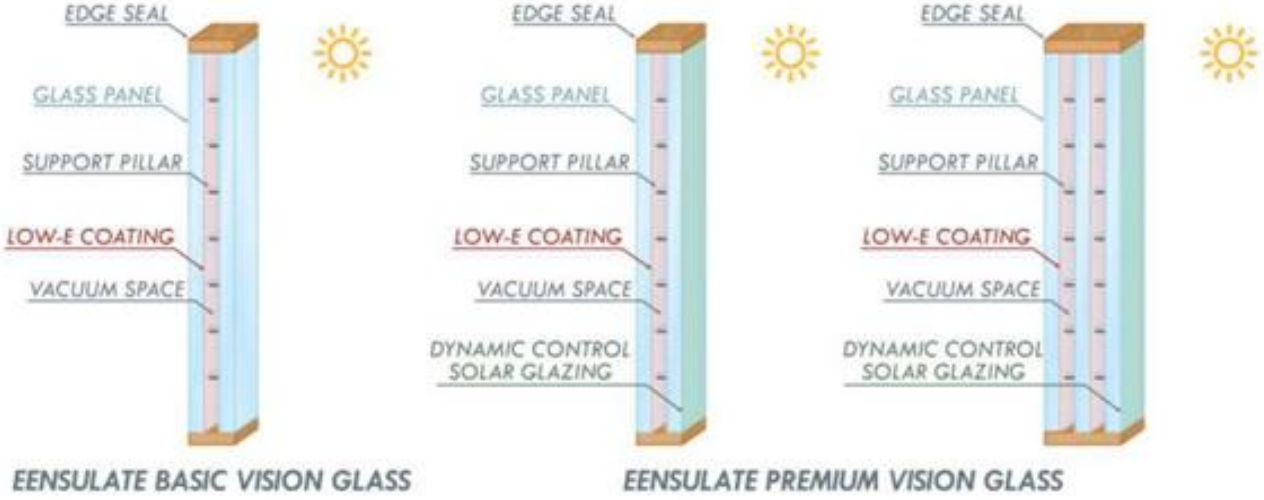

Figure 9: EENSULATE products [13].

Project website: http://www.eensulate.eu/home

2.1.6 REnnovates (H2020)

To improve the insulation value of the building, with minimal inconvenience for the tenant, building components are prefabricated. Prefabricated insulated façade including window frames and finishing is made off-site and transported to the project. The installation of the new façade takes only 15 minutes.

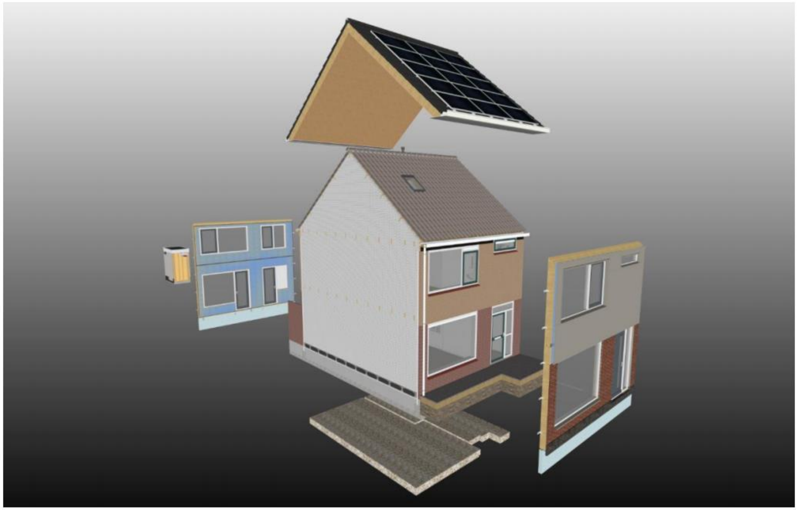

Figure 10: REnnovates Building components.

Project website: http://rennovates.eu/ (2015-2018)

2.1.7 EASEE Multilayer precast façade panel (FP7)

The team involved in EASEE project developed energy retrofitting solution for the application on existing building walls. This presents a multi-layer prefabricated façade sandwich panel characterized by an internal insulation layer and by two external layers of Textile Reinforced Concrete (TRC). The insulating material is used to transfer the shear between the external TRC layers. The maximum size of the panel is 1.50 x 3.30 m2; the panel height is properly chosen in order to fasten it to the frame concrete beams through four connectors placed near to the corners. The panels are fastened to the corners through suitable anchors and loaded by means of a distributed load (considering wind pressure and suction as the main load acting on the panel) [9].

Figure 11: Test façade at Politecnico di Milano: erection of the façade (left) and the completed façade (right) [9].

Project website: http://www.easee-project.eu/ (project finished in 2014).

2.1.8 MeeFS multifunctional façade system (FP7)

The aim of the project MeeFS (Multifunctional energy efficient façade system for building retrofitting) was to develop, evaluate and demonstrate an innovative energy efficient multifunctional façade system developed for the residential building renovations.

MeeFS is focused on a development of different components composing the multifunctional energy efficient façade system that can be applied during building retrofitting. It is composed of the structural panels which are to be fixed onto the façades of buildings and the technological modules which are to be fitted into the panels [14].

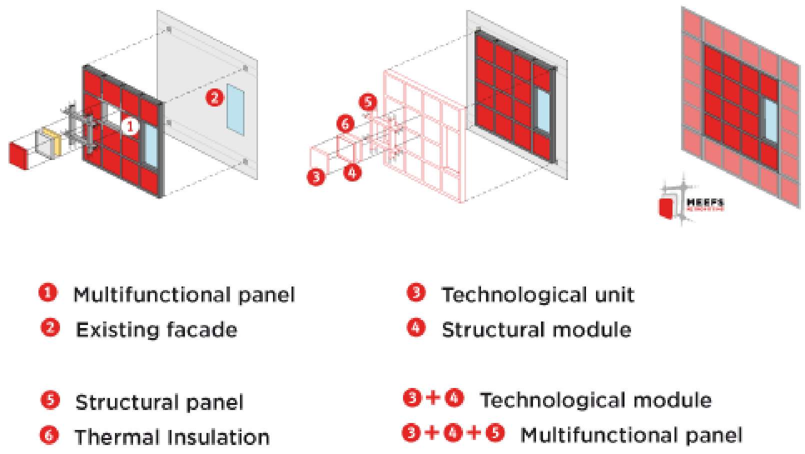

Figure 12: MeeFS concept: A Multifunctional Energy Efficient Façade System for Building Retrofitting [14].

The whole façade system is managed and controlled by an Intelligent Control System. For the energy management aspects, a management software is established called the Building Energy Management System. Finally, a guide of design and an accompanying decision-support system has been developed to ensure the proper implementation, maintenance and use of the façade system.

The developed solution was demonstrated on a demonstration building in Spain in October 2016, in the region with continental climate (in summer above 35°C and in winter below 0°C). The panels have been pre-assembled in a nearby workshop and transported on-site using a dedicated lifting beam. The pre-assembled panels were then hoisted directly into their definitive position and securely attached to the supporting trays. Once the modules were properly installed, they were connected to the Building Energy Management System, which will manage and monitor the functioning of the active modules of the multifunctional façade, monitor the energy consumption, as well as sun orientation for photovoltaic units and water feeding for organic green components. The performance of the refurbishment will be monitored through an extensive array of sensors deployed in the dwellings [14].

Figure 13: Demonstration of the MeeFs solution on a demonstration building in Spain [14].

Project website: http://www.meefs-retrofitting.eu/ (product in a research and development phase).

2.1.9 iNSPiRe (FP7)

The main objective of the developed 'iNSPiRe Renovation kits package' was the integration of different retrofit components (smart windows, smart lighting, HVAC components) as part of the insulated prefabricated building modules. The goal was to produce 5-10 standardized envelope packages for the seven primary target buildings. The developed innovative four facades (two metal/glass and 2 wooden) included integration of HVAC components and the integration of thermal and energy storage systems.

Different configurations of the developed solutions have been applied, monitored and assessed for three demonstration cases in Germany (social housing), Spain (social housing) and Italy (office). Inside the project, also a monitoring system capable of assessing the energy savings and performance of buildings under renovation was designed and a surveillance software that will handle the information produced by the building's monitoring system was built [15].

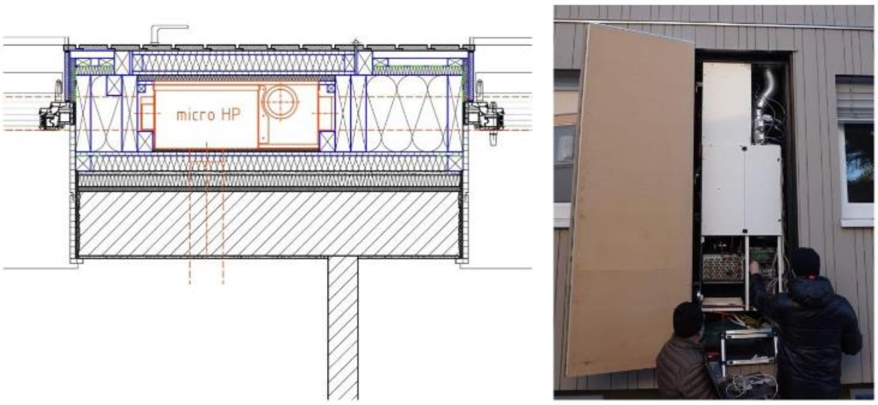

Figure 14: Detail section of the integration of the micro heat pump with MVHR (mechanical ventilation with heat recovery) unit (left) and picture of the installed unit (right) for the demonstration case in Ludwigsburg, Germany [15].

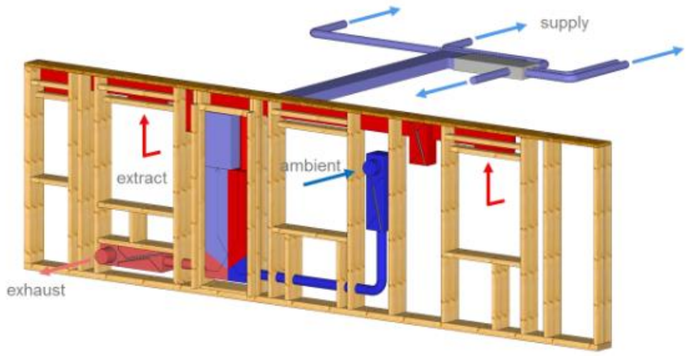

Figure 15: Diagram explaining the concept of the MVHR system with the integrated micro heat pump [15].

Pipes, ducts and wires for domestic water, heating, ventilation, electricity and solar energy generation were integrated to the timber frame façade elements during prefabrication in the workshop, ensuring high quality and reduced building time on site.

Figure 16: Parts of the ventilation system installed in the wall during prefabrication (left) and installation of the prefabricated wall element on the demo site (right) [15].

Project website: http://inspirefp7.eu/

2.1.10 ADAPTIWALL (FP7)

ADAPTIWALL- Multi-functional light-weight WALL panel was developed based on adaptive insulation and nanomaterials for energy efficient buildings. Multi-functional ADAPTIWALL panel consists of three main layers and components that offer different functionalities:

1	THERMAL COMFORT	**Thermal comfort**: The ADAPTIWALL technology and control system aims at keeping a whole year round, comfortable thermal indoor climate.
2	LOAD BEARING	**Load bearing**: The prefab panel fulfils the wind-load and dead-weight bearing functionality.

3	BALANCE	**Balance**: The energy storage (concrete buffer) enables ADAPTIWALL to anticipate to a lack of synchronicity in supply and demand of energy; i.e. the buffer enables to balance day and even week cycles by using its storage functionality. The THEX balances supply and extraction of fresh air in order to assure a healthy indoor climate.
4	STORAGE	**Storage**: Lightweight concrete with additives based on Phase Change Materials (PCMs) for maximizing heat exchange and heat storage capacity.
5	BREATHE	**Breathing:** Compact ventilation and energy recovery system (THEX).
6	CONTROL	**Control:** Inside thermal comfort is assured and controlled through the heating and cooling mode performed by the ADAPTIWALL prefab panel.
7	HARVEST	**Harvesting:** System of glass cladding ,outside thermosiphon plate with insulation and inside radiator, which is by-passed to collect energy in the buffer and release it when needed for heating.
8	PROTECT	**Protect:** External façade protects the building from external weather factors.

ADAPTIWALL provides a new façade panel for energy-efficient retrofitting of buildings reducing the energy consumption by more than 50% in comparison with conventional retrofitting. The basic idea of the ADAPTIWALL concept is to meet the demand for indoor cooling or heating by allowing adaptive energy exchange with the outdoor climate. ADAPTIWALL offers three functionalities that can be adopted according to real time outdoor and indoor climate conditions:

- Heating mode: During the day outdoor heat is harvested, stored in the concrete buffer and released to the inside of the building during the night.
- Cooling mode: During the warm day indoor heat is harvested from the inside of the building, and then the heat is stored in the concrete buffer and released during the night to the outdoor environment.
- Breathing mode: Indoor air is refreshed with outdoor air, without energy-loss with the use of Total Heat Exchanger (THEX) device. Breathing mode runs simultaneously with heating and cooling mode.

Figure 17: Above - Lab scale prototypes of ADAPTIWALL (left) and prototype of membrane separator (right). Below - ADAPTIWALL concept: The different components of the ADAPTIWALL system [16].

Project website: http://www.adaptiwall.eu/ (product in a research and development phase)

2.2 Windows replacement

Old buildings have installed windows with high heat transfer coefficients (U > 2.5 W/m2K). Therefore, changing the old windows with energy efficient windows having two or three-layer glazing can have a high impact on reduction of heat transmission leading to a lower energy demand. According to the European Commission, excessive heat loss and gain through windows are deemed to account for about 4 % of Europe's total energy consumption [http://cordis.europa.eu/article/id/400002-smart-windows_en.html]. Therefore, all across Europe, consortiums of EU researchers are working hard on new concepts of smart windows that will help to reduce the energy consumption of buildings.
According to building’s location and climate different shading solutions (external, integrated, internal) can be applied (shutters, blinds, overhangs, louvres etc.). Several innovative products have shading solutions integrated as part of the window system where the window opening and shading is controlled through the building automation system. Such integration of different function in one system reduces the number of components to be installed separately on the site. Passive lighting strategy can be achieved by applying light shelves which allows reflection of the daylight deeper into the space reducing the demand for artificial lighting.

2.2.1 A2PBEER Smart windows (FP7)

For the demonstration cases in A2PBEER project, windows that can be rotated by 180 ° were applied in order to reduce the thermal radiation from the outside during summer season, and reduce the thermal dispersion from the interior in the winter. This is viable due to the double positioning of the low-E glass. The smart window provides natural ventilation, rotating and locking mechanisms which enhance anti-burglary features. It satisfies the needs for high energy-efficiency, better indoor climate, and top class security features. The reversible window technology is enabled by hydraulic gaskets and burglar-proof electro-magnetic locking mechanisms fully integrated in the frame. There are 3 affordable innovative components:

- Active gaskets allowing sealing, ventilation or release with simple hydraulic or pneumatic systems.
- Structure of the frame with rotating sash across either horizontal or vertical axes.
- Window locks and control system, with possible integration with building automation, HVAC control systems and centralized security features [17].

Thermal properties of smart window have been mainly assessed by means of computer simulations. The calculations have been carried out for different European climates taking into account current regulations for U value of building envelope in varied countries or window orientation in order to assess energy benefits for different glazing sets.

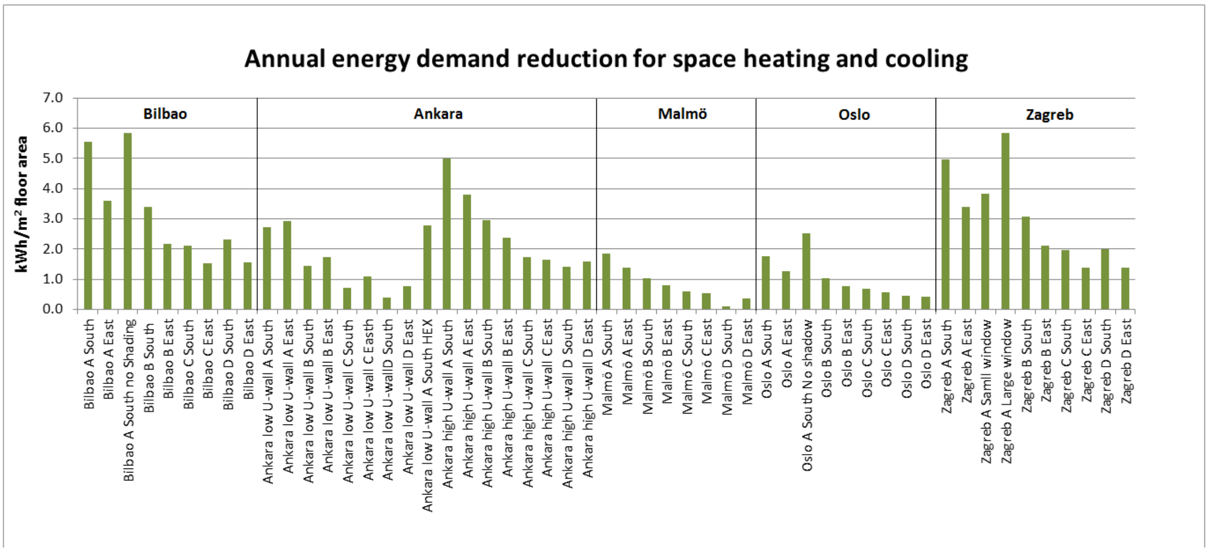

Figure 18: Annual energy demand reduction due to the installation of new A2PBEER smart windows.

Calculations of energy demand required for heating and cooling have been compared with the same window, however fix in one position (with low-e coting facing outside). The results show that in each case and for every type of glazing used we are able to decrease annual energy demand. In certain situations the decrease is equal to 5.8 [kWh/m2 floor area] which corresponds to 17% decrease of needed energy just by changing the position of low-e coating.
Two prototype windows have already been installed in Malmo (Sweden), presented on the figure below, and couple of next will be installed in Bilbao (Spain).

Figure 19: A2PBEER Smart window prototype installed on a demonstration site in Malmo, Sweden.

It is planned to test thermal behaviour of building envelope after retrofitting actions, however due to integration of other systems (internal or external building insulation) apart from smart windows, the results of test will not show the behaviour of a single component, but will assess the behaviour of new envelope in general. Due to this fact thermal benefit strictly related to change of smart windows can only be recognized through computer simulations.

This smart window has been jointly developed by P2ENDURE SME partner: Bergamo Tecnologie SPZOO and is available as a commercial product: http://www.bergamo-tecnologie.eu/index.html.

Project's website: http://www.a2pbeer.eu/

2.2.2 CLIMAWIN (FP7)

The CLIMAWIN project lead to a development of an advanced ventilation window system that consists of a double glazed window, an intelligent (electronically regulated) valve, room and zone sensors, optional integrated blinds and an inbuilt photovoltaic power system (optional from 2017 on). During winter months, the system takes advantage of the heat that is normally lost through the glazing surface and instead uses this heat to preheat fresh air coming in to increase the comfort. In summer, the product is capable of reducing the unwanted solar gains and still enables sufficient transmission of the daylight. The CLIMAWIN uses electronically controlled valves and flaps to regulate the air coming in, maximizing heat recovery and preventing condensation. It does not need rewiring therefore it is suited for retrofit of existing buildings [18].

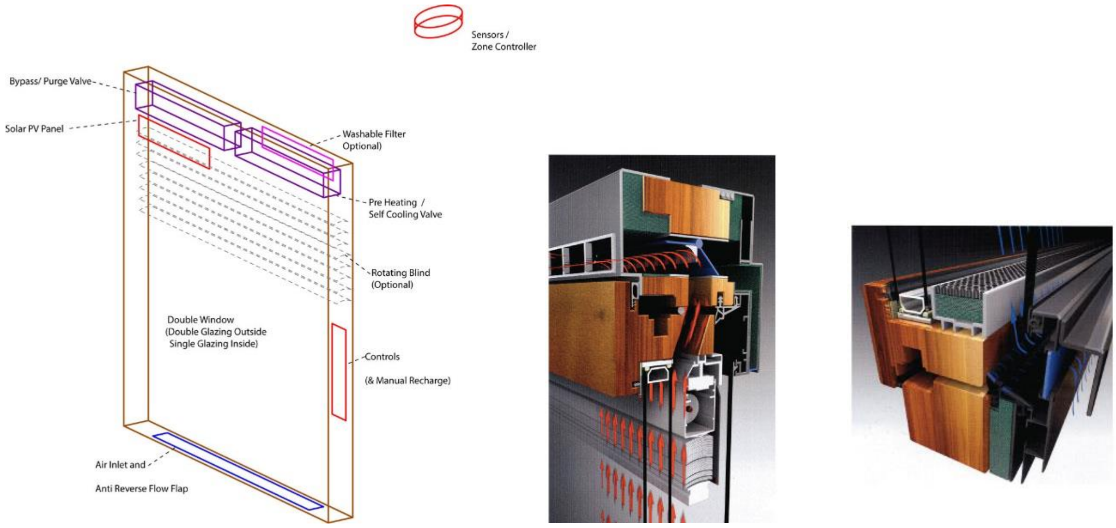

Figure 20: Climawin product presents an advanced ventilation window system [18].

Product's website: http://climawin.eu/ (commercial product on the market)

2.2.3 MEM4WIN (FP7)

MEM4WIN project introduces a development of an advanced technology of smart window having integrated quadruple glazing with ultra-thin glass membranes. The aim of this project is to develop adjustable and affordable window system that enables the erection of zero-energy buildings [19].

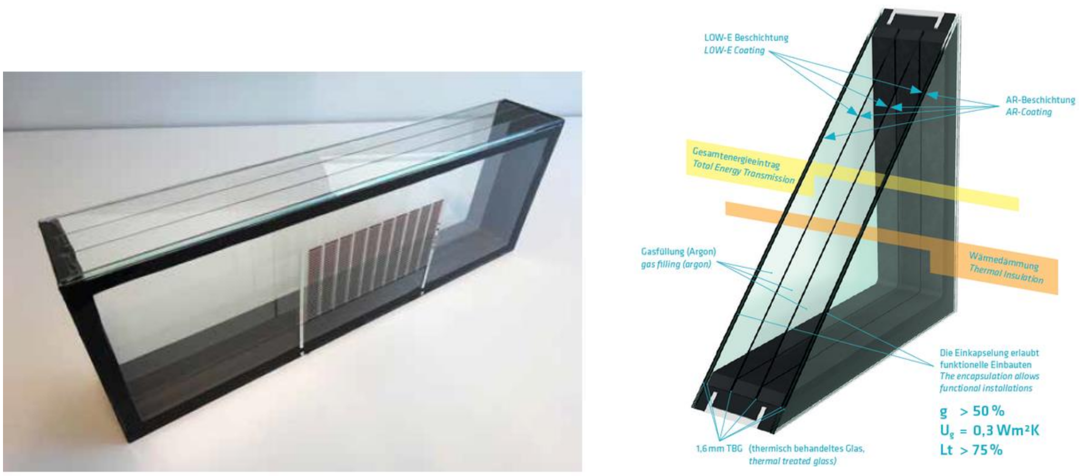

Figure 21: The quadruple IG-unit with Integrated Photovoltaic (left) and section of the novel IG-unit (right) [19].

The objectives of the MEM4WIN window are:

- 50 % weight reduction by using ultra-thin glass membranes.
- 50 % heat loss reduction by introduction of quadruple IG-unit (envisaged Ug value: 0.3 W/m²K).
- 20 % cost reduction (compared to a conventional window with the same functionalities) by advanced fabrication technologies and replacement of cost intensive materials.
- Modular solutions for energy harvesting with smart window: in-line printed Organic Photovoltaic (OPV) for power generation; fully integrated solar-thermal collector for warm water supply.
- Modular solution for control of solar radiation and light guidance with switchable micro-mirrors (envisaged range of transmission between 75 % and 2 %) [19].

Project's website: http://mem4win.eu/index.php?id=1 (Finished in 2016)

2.2.4 WINSMART (FP7)

The main goal of the WINSMART project is to develop a smart window system that will contribute to meeting the energy efficiency targets of the building industry by 2020. The goal is to develop a smart, lightweight, cost-effective and energy efficient window based on novel material combinations: vacuum insulation glazing (VIG) combined with robust switchable glazing systems mounted in durable and energy efficient sash and frame. The WINSMART windows objectives are:

- Reduce the U-value from 0.8 to 0.3 W/m²K;
- Reduce the weight of the window by 50 %;
- Reduce the window's overall energy consumption (embodied energy) during the manufacturing process and disposal/recycling by 50 %;
- Use new materials and new technology to improve the construction of the window frame and framework, the vacuum window and the glass coating;
- Develop smart technologies to control the solar radiation through the window [20].

Project's website: http://winsmart.eu/

2.3 Prefabricated renovation modules for roofs with integrated RES

2.3.1 MORE-CONNECT modular roof elements

The project MORE-CONNECT aims to develop roof modules with integrated RES and combined heat units. The first prototypes are already developed and applied in Heerlen, the Netherlands. Hence the full testing on demonstration sites will start in 2017 and 2018. The Dutch dwellings (prototype) from the 60's are fully retrofitted with modular prefabricated integrated roof. The facades include integrated combined heating units (convectors) with decentral demand and CO2 controlled mechanical ventilation units with heat recovery. The roof elements have 40.0 m2 PV panels for 6.4 kWp. A fully prefabricated installation box (engine) contains an air-to-air heat pump, boiler, mechanical exhaust fan and PV converters. This box is placed in the roof and can be accessed an replaced from the outside. In case of maintenance or replacement no access or activities in the dwellings are necessary, thus minimizing the disturbance for occupants [8].

Figure 22: Prefabricated installation platform placed in an integrated PV roof [8].

2.3.2 iNSPiRe roof elements and solar panels (FP7)

For the demonstration site of iNSPiRe project in Ludwigsburg, Germany two large modules of 2.2 x 5.6 m were transported to the building site and craned on to their final position on the roof. The two parts were connected on site by the producer of the collector. In this case a well-insulated collector was used, enabling ventilation between collector and roofing membrane without a loss of productivity to the collector. Ventilation tiles above the collector allow for a free airflow behind the panels, transporting water vapor away from the construction. The even surface produced by the lower height of the collector in relation to the roof produces a good aesthetical result, and was mounted in a minimal amount of time [15].

Figure 23: Installation of the solar collector (right) and final view of the surface-integrated solar collector [15].

Project's website: http://inspirefp7.eu/

2.4 HVAC solutions

HVAC systems installed in the existing buildings are often difficult to retrofit since the installations are spread through the whole building having indoor and outdoor components. As an alternative, different projects are trying to develop breakthrough smart optimized HVAC packages that allow for easier and more efficient improvement of the existing HVAC installations. The developed prefabricated modules often include certain HVAC components (ventilation with heat recovery, DHW with solar panels etc.).

2.4.1 MORE-CONNECT HVAC Engine (H2020)

MORE-CONNECT aims to develop a packaged HVAC solution minimizing the required space for the installations. In order to minimize installation costs and time as well as to ensure installation quality and simple modernization during lifetime, the multifunctional modular HVAC unit "house engine" should be introduced. Figure 24 presents a modular HVAC installation unit implemented in the Netherlands.

Figure 24: Example of modular HVAC unit (left), modular HVAC unit with heat pump and ventilation heat exchanger (middle), and gas boiler installation (right) [8].

Furthermore, prototype presented in Figure 22 (paragraph 2.3.1) includes a fully prefabricated installation box (engine) mounted on the roof of the dwelling containing an air-to-air heat pump, boiler, mechanical exhaust fan and PV converters. This box is placed on the roof and can be accessed an replaced from the outside. In case of maintenance or replacement no access or activities in the dwellings are necessary, thus minimizing the disturbance of the occupants [8].

Project website: http://www.more-connect.eu/ (product in a research and development phase)

2.4.2 NANO-HVAC solution (FP7)

Poorly insulated HVAC ducts can lose through conduction up to 50 % of the energy used to heat and cool the indoor environment. The main goal of the NANO-HVAC project is a new innovative development of ducts insulation.

Safe, high insulating HVAC-ducts enabling minimization of heat/cool losses: cost-effective, safe and extremely thin insulating duct layers that can be applied both to circular ducts (wet-spray solutions) and to square ducts (pre-cast panel). Insulation is obtained using sprayable aeroclay-based insulating foams that can be automatically applied during manufacturing of ducts, avoiding manual operation needed for conventional materials. Such technologies, coupled with advanced maintenance systems can guarantee a 50 % saving in energy losses compared with conventional ducts. The whole system aimed to be developed with a requirement of service life of the building of 25 years.

The full scale demonstrator was developed and installed on an existing commercial demo building in Spain. The installation was used to measure and evaluate the performance of the system to be installed in HVAC system, regarding the low energy consumption in combination with the high antimicrobial capability [21].

Figure 25: Preparation of the demonstration site in Spain [21].

Project's website: http://www.nanohvac.eu/Default.aspx (finished in 2015)

2.4.3 E2vent system (H2020)

The technical objectives of the E2vent ventilated facade system are to:

- Develop an adaptable smart modular heat recovery unit (SMHRU) adjustable to work into the ventilated façade cavity, and able to recover heat from ventilation air, preheating the ventilation air in winter and precooling it in summer.
- Study the energy recovery potential of the SMHRU, as well as its use for free-cooling and thermal storage strategies.
- Develop a latent thermal heat energy storage system (LTHES) based on phase change materials fitting in the cavity and complementary to the SMHRU.
- Allow effective photovoltaic technology adaptation for the ventilated façade system, ensuring adaptability of PV modules in the external cladding, analyzing sun-tracking technologies and integration of PV inverters in the cavity of the ventilated façade, to improve the modularity of the system [12].

Project's website: http://www.e2vent.eu/ (2015-2018)

2.4.4 REnnovates Energy module (H2020)

Energy module contains appliances and measurement and control infrastructure required to provide energy services for tenants. Essentially it is a skid where all installations necessary for heating/cooling, ventilation, domestic hot water, monitoring and inverter for the solar panels are integrally combined so it is to be prefabricated (test-run off site), easy to transport, easy to install and easy to maintain.
The energy-module is a skid where all installations necessary for heating/cooling, ventilation, domestic hot water, monitoring and the inverter for the solar panels are integrally combined.

The energy module is to be prefabricated (test-run off site), easy to transport, easy to install and easy to maintain. The skid is slightly insulated and waterproof. The following components are integrated in the energy module:

- Air-water based heat pump with buffer vessel for space heating and domestic hot water use. Because of the climate conditions in the Netherlands cooling is not applicable. The existing radiators in the house are used as a heat emission system.
- Balanced ventilation system with heat-recovery for ventilation. Air supply in living-room, sleeping rooms and kitchen, air exhaust in toilet, bathroom and kitchen.
- Inverter to convert DC (unidirectional flow produced by PV-panels) to AC (alternating flow, form in which electric power is delivered to residences)
- To monitor the energy performance of the house a monitoring system is integrated in the energy module. Energy use for space-heating, hot-water and ventilation is measured as well as the actual performance of the PV-panels.

Project website: http://rennovates.eu/ (2015-2018)

2.5 Smart connectors

2.5.1 MORE-CONNECT smart connectors

MORE-CONNECT project aims to develop smart connectors to limit the actual renovation time on site. It is believed that by adopting high level of prefabrication and the use of smart connectors (mechanical, hydraulic, air, thermal, electrical, ICT), the actual renovation time on site can be decreased to a maximum of 5 days with a goal for an average of two days, including the complete or partial removal of the existing facades and roofs or other elements. Such smart connectors should give the modular elements a ‘plug and play’ character.

The main objective for the air connectors and hydraulic connectors is to allow for integrated air ductwork and for the connection of integrated heating/cooling emission systems to the MORE-CONNECT HVAC Engine (chapter 2.4.1). Airtightness of prefabricated modules is ensured by frame prefab airtight joints for the connections between the elements using airtight click systems.

Mechanical connectors’ main purpose is fixing the panel to the substructure. The connectors have to ensure a tight connection to withstand the expected load and have to allow for fast and flexible mounting on the existing constructions. Electric and ICT connectors are applied as connectors for power connection if necessary in the elements (power plugs or integrated appliances). These connectors also cover the needed communication connectors (including cables, communication bus etc.) [8].

Figure 26: Socked connectors with sealing element [8].

Figure 27: Example of connections between panels: push-fit connectors [8].

Figure 28: Connections inside panels: pressed connectors [8].

3. Integrated design: On site technologies and BIM application

Advanced BIM technology plays an important role during deep renovation process since it allows remote analysis of building performance and optimization of renovation design solutions from a computer. In order to increase the automation of the renovation process and decrease the renovation time, BIM technology needs to be integrated and so called BIM management carefully established.

3.1 On-site surveying for building documentation

Utilizing cutting edge-techniques as on-site 3D laser scanning of the building and the point cloud conversion to a 3D model can serve as an input for BIM model (existing building model). Such on site surveying technologies allow 3D measurement of the existing building and assessment of the building's pre-renovation performance.

Before the building is renovated, a detailed survey of the building by adopting complete digital measurement of the building allows a correct geometrical description of the building (used for design and thermal analysis). Windows, doors, balconies, etc. have an effect on the renovation design since they act as constraints in a modular design. The scanning of the building allows computer analysis and visualization of building appearance, irregularities and distortions. Two surveying technologies are commonly used: laser scanning and photogrammetry. Whether using photogrammetry or laser scanning depends on the project specifications and requirements [8, 9].

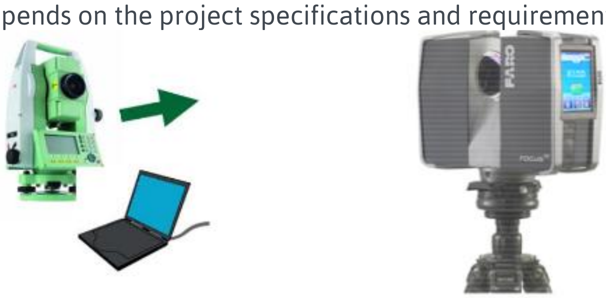

Figure 29: 3D laser scanning used for rapid detailed model acquisition of dense cloud points to be processed for a detailed building model [9].

Laser scanning process is the fastest method of 3D data acquisition for the existing buildings. The selection of the scanner type and scanning setup depends on the architecture or geometric complexity of the building elements. The primary product of the laser scanning is a point cloud, a set of data points in a user defined coordinate system that represents an external surface of the measured object.

Together with a scanning system is normally supplied also a software for pre-processing and point cloud export. In general, digital photogrammetry is simpler than laser scanning where the building is photographed by a good digital camera and pictures are combined with reference measurements. Normalization of the picture is done using certain software developed for creation of such 3D measurements [8].

Use of Ground control points (GCP) is recommended for higher accuracy demands (<5mm) and when larger objects (residential houses) are of interest. The accuracy of a manually traced BIM model of the building highly depends on the accuracy of point cloud and the experience and the skills of the modeller [9].

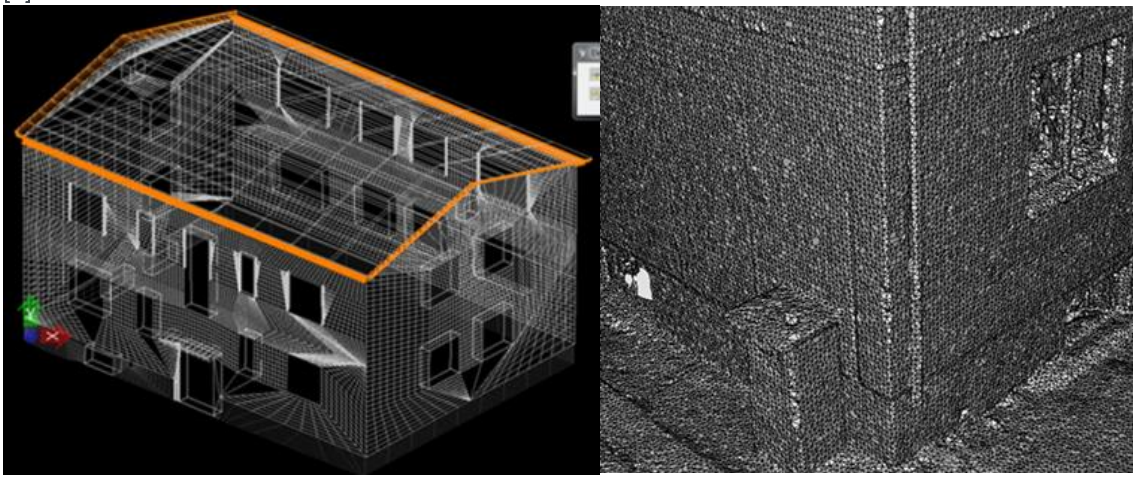

Figure 30: The Smart Surface model of the building generated with Bentley software (left) and the triangulated surface of the corner of building walls generated with 3DReshaper software (right) [8].

Using BIM technology throughout the renovation process can be used during the automated production of prefabricated building components, building design, for on-site 3D printing and post-renovation life-cycle data management. By adopting semi-automated approach existing problems can be resolved in the BIM model.

3.1.1 INSITER (H2020)

The key innovation of INSITER is the intuitive and cost-effective Augmented Reality (AR) for self-inspection. The use of AR –that connects virtual and physical buildings in their environments at real-time– will ensure that the targeted performance in the design model is realized. INSITER aims to eliminate the gaps in quality and energy-performance between design and realization of energy-efficient buildings based on prefabricated components.

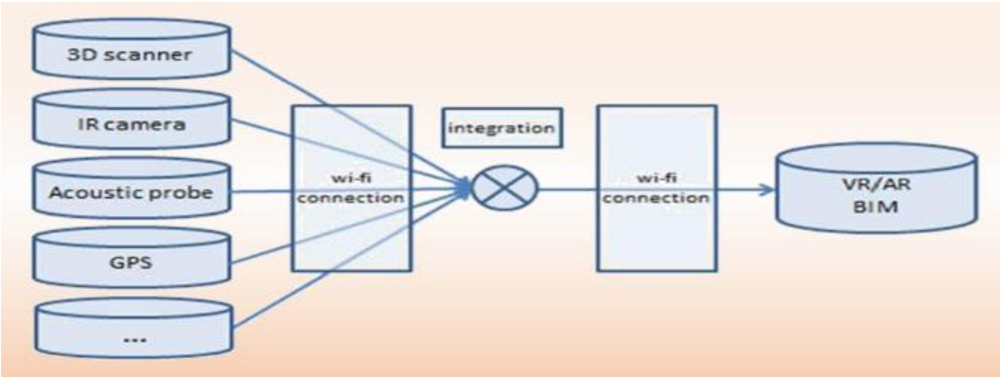

Figure 31: Data integration with a cloud based Building Information Model (BIM) [22].

The key innovation of INSITER is the intuitive and cost-effective Augmented Reality that connects the virtual model and the physical building in real-time. INSITER will substantially enhance state-of-the-art measurement and diagnostic instruments with wireless and easy-operation facilities through users' mobile devices. During the project, a new methodology for self-instruction and self-inspection by construction workers, subcontractors, component suppliers, and other stakeholders during on-site working processes, supported by a coherent set of hardware and software tools will be developed. Triangulation of Geospatial Information, Global and Indoor Positioning Systems (GIS, GPS and IPS) will support the 3D accuracy of these instruments. The data will be integrated in cloud-based BIM that evolves throughout the building's lifecycle [22].
Project's website: http://www.insiter-project.eu/ (2014-2018)

3.2 Integrated design and BIM technology used during renovation

The ambitious EU projects strive to optimize the automated production of the developed products by making use of BIM technology. Once having the in-situ measurements and 3D documentation of the building, this can be combined in one BIM model to support further renovation measures. As such, BIM model serves as a shared knowledge resource for information about a building forming a reliable basis for decisions during its lifecycle from inception through renovation onward leading to integrated design.

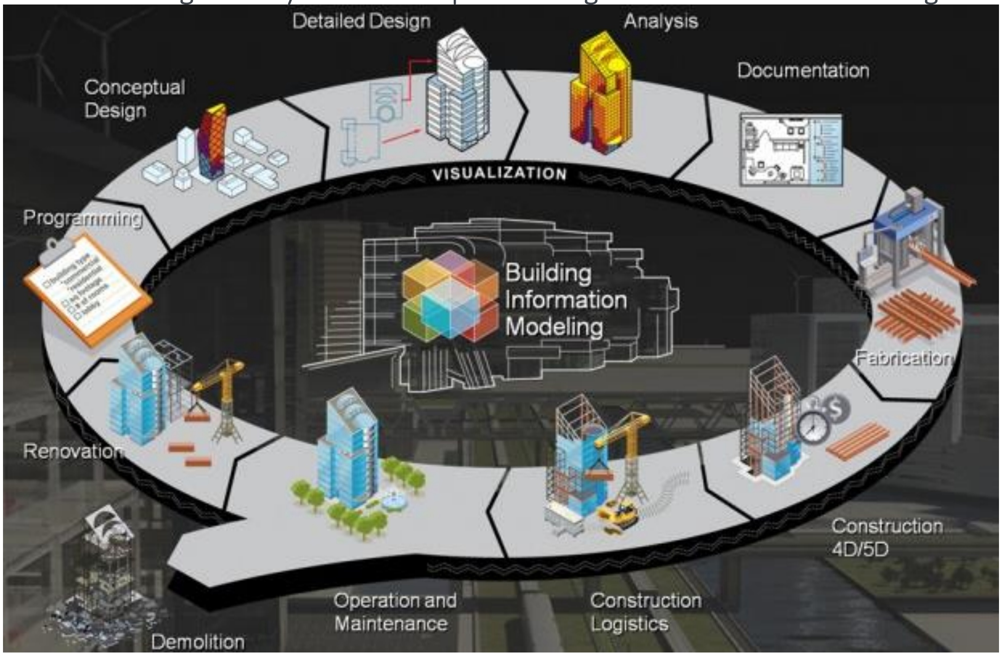

Figure 32: Building Information Models (BIM) illustration [23]

3.2.1 MORE-CONNECT deep renovation decision support software tool

Inside the MORE-CONNECT project, a tool will be developed that allows for modelling of different building renovation configurations based on information obtained through on-site surveying and creation of a BIM model. Furthermore, the end-users profiles in terms of end-users requirements and favourable choices of the modular renovation concepts by the end users will be included in the developed decision support tool. The MORE-CONNECT decision support tool will include:

- Design user profile options and characteristics.
- Design building profile options and characteristics.
- End-users choices and configurations.

The final output of this decision support tool will be used as an input for a seamless integration of BIM with integral computerized numeric control prediction where BIM is used to steer and to control the production line [8].

3.2.2 RenoBIM tool (BERTIM project)

Partners in the BERTIM project will develop a new platform targeted to mass manufacturing methodologies applied to the whole renovation process of a timber-based building. Two main innovations are envisaged in this approach, which enable the complete data flow from reality capture to manufacturing orders:

- A methodology and support tools to capture real building data (using laser scanning techniques) transferring it to a BIM-based Web3D environment.
- Building renovation project definition and communication with CNC manufacturing machines by means of BIM application.

In parallel, an additional innovation is related to the integration of BIM-IFC viewing and editing support inside Web3D based configurators. This new tool will comprise three main blocks:

- Data gathering and building model template: from the 3D laser scanning methodology to the development of the building 3D template for renovation. This methodology will provide an added value to the companies currently working only in data acquisition.
- The developed modules will be described in BIM (IFC) for future use in any software compatible with BIM.
- The renovation project will be defined in BIM, so that any sectorial software (thermal, structural, fluid, etc.) importing BIM will directly have the building model and will be able to carry out the required analysis [10].

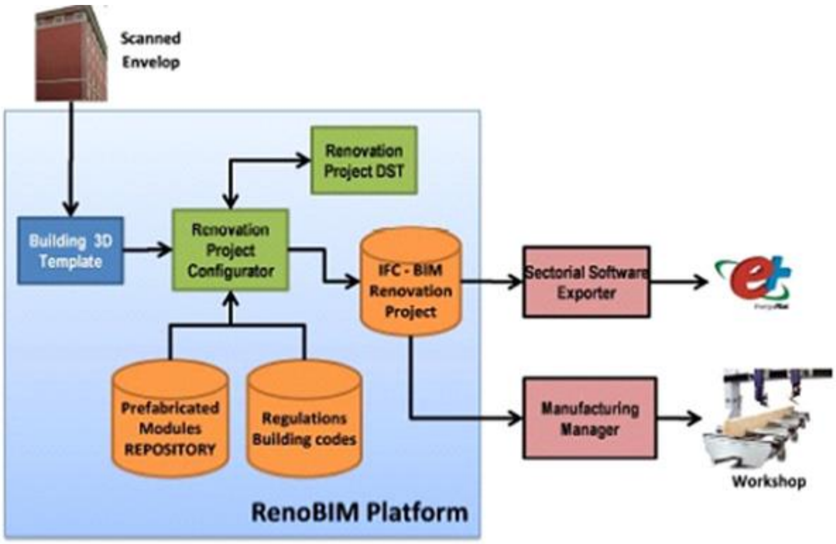

Figure 33: RenoBIM tool Architecture [10].

3.2.3 EASSE Retrofitting planner and design tool

The Retrofitting Planner and Design Tool developed inside EASEE project consists of:

- Building envelope assessment using 3D laser scanning techniques.
- The 'computer based procedure' utilizing IES's Virtual Environment software otherwise known as the VE. The VE software is an advanced simulation tool designed to analyze building performance and for the purpose of EASEE project to test and validate retrofitting solutions developed by the manufacturing partners within the EASEE project.
- The 'Design Tool' module sometimes referred to as EASEE Editor, providing the manufacturers of the prefabricated elements the technical specifications for the customized component fabrication [9].

3.3 3D printing and robotics

Over the past few years it has become increasingly evident that 3D printing and robotics technologies will have a big impact within the field of construction.
P2ENDURE further develops and implements robotic technologies for on-site 3D printing for façade retrofitting. This solution works with various sorts of materials, yet a mix of Thermosilit and limestone is currently preferred to create effective layers of insulation. 3D printing is primarily used to create plastering with special limestone material on concrete walls, ventilation ducts, or water pipes. It gives a 3D design exterior finishing in combination with painting. 3D printing is also used to create a façade layer with any kind of materials suited for the new or retrofitted building structure. In combination with robotic technologies, mounting of windows or other Plug-and-Play (PnP) prefab components can also be done very effectively and efficiently on-site.

3.3.1 Robot@Work

Robot At Work's 3D facade solution is a combination of known insulating materials with a new finishing method performed with the robot, which makes it possible to obtain 3D facades, with high quality envelopes in focus. The Mulitpor insulation panels should be installed traditionally by craftsmen from the lift. The remaining work will be done by Robot At Work's robot solution such as trimming, 3D milling and spray plaster and facade paint to the finished envelope appears as desired with or without 3D design [24].

Figure 34: Robot at work 3D façade solution on site with Multipor façade insulation panels [24].

Table 3 present the characteristics of a robot solution and identified differences according to the traditional approach.

Robot at Work	Traditional
New 3D design opportunities, cultural and social boost to the building area	Traditional 2D/even surfaces
Less hard manual labour on site	Severe tough on craftsmen doing plaster work
The Robot performs mortar envelope on the 3D design which is not otherwise possible	Many man hours spent on site
The Robot performs 100% compared to the craftsman 30% efficient work	Craftsmen works effectively 30% of the actual execution and 70% on logistic and preparation, etc.
The envelope is performed with higher precision and with brand new control and quality assurance capabilities: moist, temperature, weather etc.	Scaffolding placed long periods in the façade, even during bad weather.

Table 3: Characteristics of a traditional and Robot At Work solution [25].

Company's website: http://www.robotatwork.com/

3.3.2 IMPRESS(H2020)

The aim of the IMPRESS project is to develop prefabricated panels for buildings (described in Chapter 2.1.3) based on innovative nano/micro particle based coatings, suitable for 3D printing.

The panels will be manufactured using the following approach:

- Standard panels to suit the majority of the façade will be created using a standard formwork approach where generic shapes and sizes will be created from existing machinery, equipment and methods,
- 3D printing coupled with 3D laser scanning will be used to create customized panels which fit exactly to the existing building, and can take into account windows and junctions for example,
- Reconfigurable Moulding will be employed to product customized shapes where a curved or irregular surface is required or where an aesthetic finish is desired and
- 3D printed coatings will be applied to the panel to provide an aesthetic finish to match the building to its surroundings, along with other surface enhancements [11].

Project website: http://www.project-impress.eu/

4. Building monitoring and smart control system (ICT based solutions)

4.1 Monitoring and controlling the indoor environment

Energy efficiency should not be reached on the expense of indoor environmental quality. Therefore, during the deep building retrofit it has to be ensured that reducing building-s energy consumption and using new materials will not compromise occupant's health and wellbeing. A number of cost-effective, easy-to-use devices for indoor climate monitoring were developed in the recent years and are offered on the market. These devices include infrared sensors to monitor temperature and energy fluxes, and commercial sensors for carbon dioxide, ultraviolet light and air velocity and advanced sensors to detect volatile organic compounds and light. Furthermore, comprehensive monitoring systems are offered on the market to the users to monitor and control the indoor environment.

4.1.1 CETIEB (FP7)

The refurbishing to an energy efficient standard leads to tight buildings (whole envelope: windows, walls, etc.) and affects the indoor climate. In case of refurbishing the inhabitants or users are not adapted to this new situation. Therefore, the air exchange rates could be lower than required if no mechanical ventilation is installed or the system performance is not optimised. Then, in trying to increase the energy performance of buildings, the indoor environment quality is often degraded due to the lack of exchange with the outdoor environment. People in Europe spend more than 90% of their time indoors (living, working, and transportation). In more than 40% of the enclosed spaces, people suffer from health- and comfortable related complains and illness. Already in 1984 the WHO reported an "increased frequency in buildings with indoor climate problems". The complexity of the problem and the fact of building related symptom clusters were later described as "Sick Building Syndrome". The CETIEB (Cost-Effective Tools for Better Indoor Environment in Retrofitted Energy Efficient Buildings) developed innovative solutions for better monitoring the indoor environment quality and to investigate active and passive systems for improving it. The focus lies on cost-effective solutions to ensure a wide application of the developed systems. The project is based on three main objectives:

- Development of monitoring systems (wireless and/or partly wired) to detect insufficient comfort and health parameters. Among the technologies, the Comfort Eye prototype, which will be used in P2ENDURE, has been developed within the CETIEB project:

- Development of control systems for indoor environments which could be based on passive elements like cost effective photo catalytic materials or PCMs and active systems which control the air flow rates based on the monitoring data.
- Modelling of indoor environments for the assessment and validation of monitoring data and to optimise with respect to energy efficiency the control parameters and systems [26].

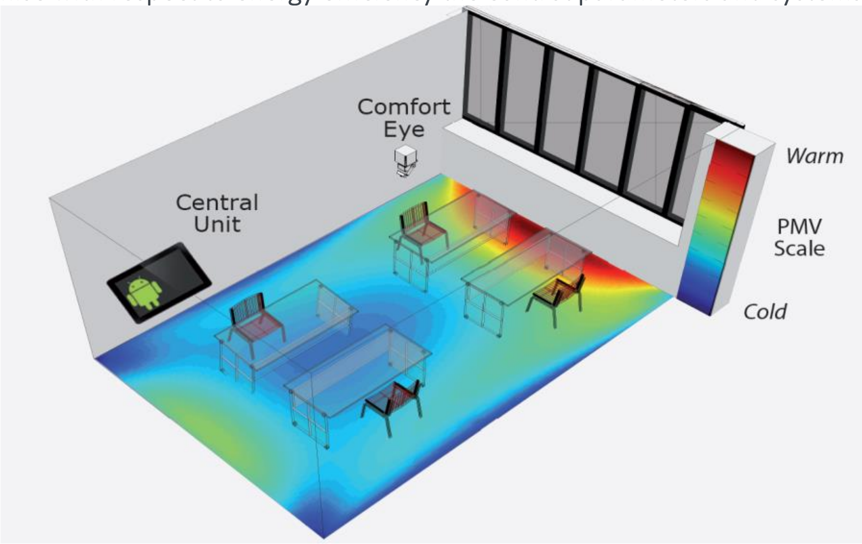

Figure 35: Scheme of the low-cost sensor, Comfort Eye, for the monitoring of thermal comfort in indoor environments [26].

Project website: www.cetieb.eu

4.1.2 INTASENSE (FP7)

Tightly sealing a building to reduce air exchange rates as a means of increasing energy (and noise) efficiency inevitably also increases the impact of any indoor emissions of air pollutants to its occupants. Emissions of air pollutants from building, decorative materials and from furnishings may contribute to Sick Building Syndrome (SBS), the poorly understood phenomenon in which building occupants suffer a range of symptoms of poor health. With the increasing recognition of the need to reduce the energy use of buildings, together with the need to safeguard the health and wellbeing of occupants, ensuring the balance between energy efficiency and good indoor air quality is an important challenge.

The INTASENSE project approached this challenge by developing a wireless indoor air quality monitor that could provide feedback to a building's HVAC system. Reliability and performance tests have been undertaken to assess the prototype's functionality. The findings showed that the unit is capable of detecting the target gases at specified levels of concentration while wirelessly communicating the results. The flexibility of the system also allows for a number of INTASENSE platforms to work simultaneously, as a network, within a room or a building [27].

Project website: http://www.intasense.eu/ (finished in 2014)

4.1.3 IAQSENSE (FP7)

The main aim of the IAQSENSE (Nanotechnology based gas multispectral sensing system for environmental control and protection) project is to develop new nanotechnology-based sensor systems to monitor indoor air quality (IAQ) in closed environments. The development of the system covers the development of the sensor, its integrated electronics and several wireless micro modules, validated with a set of the most common molecules present indoor.

In order to assure continued use of the project results, a spin-off company named IAQSense Ltd has been created. IAQSense Ltd will follow the trends towards IoT and pervasive sensing in the development of a complete range of environmental sensors for indoor, outdoor and wearables [28].

Project website: http://www.iaqsense.eu/ (finished in 2016)

4.2 Building smart system

In order to optimize building's performance, the modern buildings are most often equipped with smart control systems. Such building monitoring and control systems allow insight in building's energy consumption: how, where and when the energy is used. The monitoring itself does not lead to energy saving, however, translation of the measured energy data into useful information for the user can result in significant reductions.

The term smart meter is often referred to an electricity meter hence it can also refer to different IEQ sensors, devices measuring gas, water consumption etc. They allow real time measurements and enable two-way communication between the senor (measuring device) and the central unit. Smart meter allow for remote monitoring and they are based on the connection network (wired, wireless). They provide the building manager or end-user information on how and when was used energy for a particular building component or appliance.

Several projects (BERTIM, E2vent, iNSPiRe, RetroKit) comprise also design and development of the building monitoring system that allows users interaction, control in operation and communication requirements for sensors and hardware [10, 12, 15, 29]. A real time intelligent management system and control strategies aim to control operation of the developed system and provide an optimized building performance and ensuring the availability of the captured information for a detailed building supervision. For further information and monitoring system guidelines, it is referred to the deliverables of the above described projects [15, 29].

European Commission has acknowledged that such ICT based innovations as smart control systems can help member states achieve 2020 targets. Several EU-funded projects are besides focusing on smart building controls also focusing on how to translate this building captured data in user attractive information and how to establish an effective communication with end-users.

4.2.1 SportE2 (FP7)

SportE2 is an EU-Cofounded FP7 project, involving a group of 9 partners from Europe to develop energy efficient products and services dedicated to needs and unique characteristics of sport facilities. In short, SportE2 excites the sport facility community about energy efficiency and develop ICT related energy consultancy services, hardware, and software to reduce energy consumption and emissions production by 30% in these facilities with a 5 year ROI. To do this, the project developed an integrated, modular, and scalable ICT system to manage energy consumption, generation, and exchange locally and within the larger context of the smart grid/ neighbourhood [30].

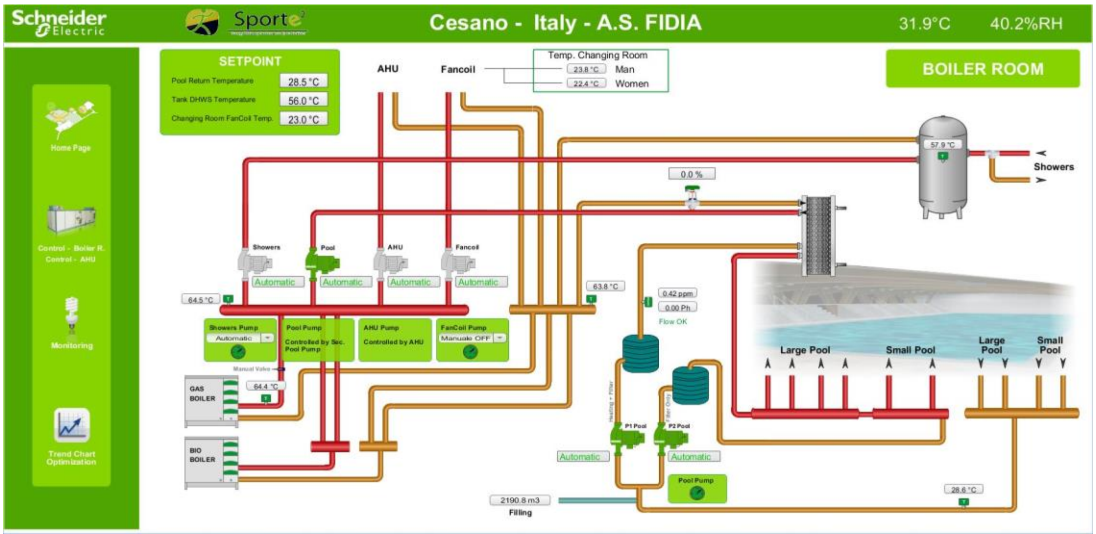

Figure 36: User interface of the SportE2 system [30].

The four modules developed are:

- How: smart metering system
- When: integrated control system
- Why: Intelligent and optimal decision making
- Where: multi-facility management portal

SportE2 has been applied and validated in 3 sport facilities (Italy, Spain, Portugal), where the average energy saving registered was about the 30% with respect to the situation before the installation [30].

Project website: www.sporte2.eu

4.2.2 BeAware (FP7)

BeAware project was concentrated on reducing the energy consumption in homes by investigating next generation ICT tools. During the project, solutions were created that motivate and empower citizens to become active energy consumers, by offering them the opportunity to raise awareness of their own power consumption in real time. These solutions include:

- Energy life: a mobile phone application.
- Watt-lite twist: an ambient interface that makes use of the home lighting and lamps as a means to communicate with the user.
- Service layer: a solution providing data to the interfaces.
- Sensor layer: a solution containing sensor network installed in the users' homes and data storage and handling massive amounts of recorded data [31].

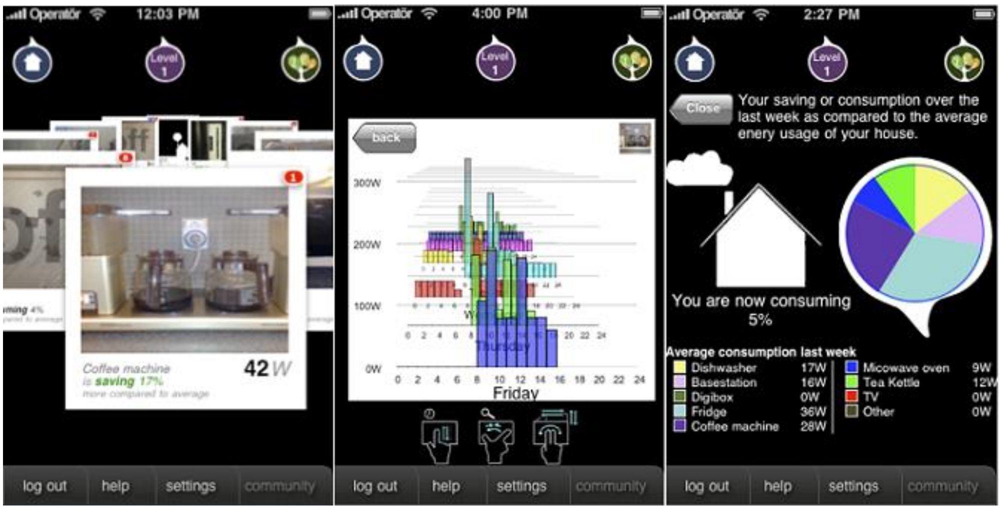

Figure 37: Example of the graphical user interface Enegry Life mobile application [31].

Project website: http://www.energyawareness.eu/beaware/ (finished)

4.2.3 MOBISTYLE (H2020)

One of the core objectives of the new H2020 project MOBISTYLE is to develop easy to use, tailor-made ICT-based tools which will make energy monitoring a well-accepted and attractive 'daily activity' (routine) for different end-user groups (archetypes) as well as for professionals (building managers).

User-friendly ICT tools will be developed that comprise:

- Robust and cost-effective sensing technologies that can be deployed with minimal setup in small and large-scale installation spaces;

- An integration platform with modular configuration for data and software interoperability, inter-connecting sensor networks for sensible environment that aims to improve the range and type of energy-efficient behaviours;
- A set of software applications and apps for mobile devices and wearables, to enable energy-efficient behaviours of the end-users.

The overall aim of MOBISTYLE is to raise consumer awareness and motivate behavioural change by providing attractive personalized combined knowledge services on energy use, indoor environment, health and lifestyle, by ICT-based solutions. Providing more understandable information on energy, health and lifestyle will motivate end-users to change their behaviour towards optimized energy use and provide confidence in choosing the right thing. It will offer consumers more and lasting incentives than only information on energy use [32].

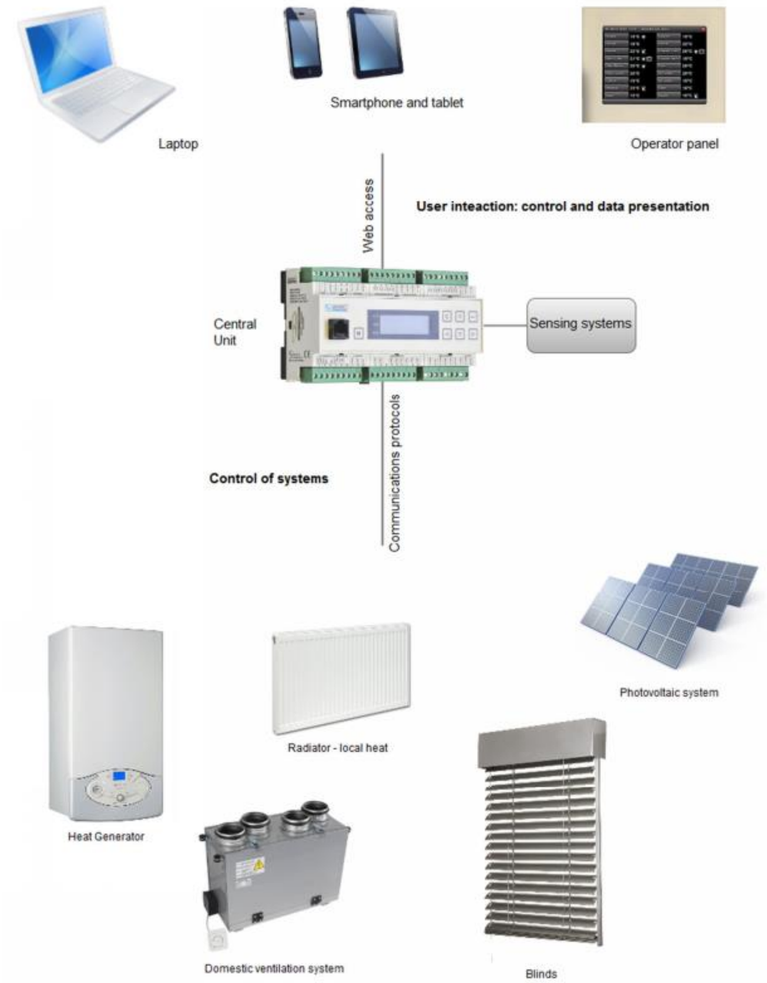

Figure 38: Illustrative diagram for user control of diverse systems [8]

Project website: http://www.mobistyle-project.eu/ (started October 2016)

5. Towards comprehensive renovation approach

5.1 Fragmentation of the current renovation techniques

Based on the performed research, it could be noted that these new ambitious projects (scheme H2020, FP7, IEE) are effectively developing and offering technologies allowing for advanced and efficient deep renovations to take place. Common characteristics of the presented state-of-the-art renovation solutions are:

- Adaptability to different building requirements and user needs.
- Efficient and fast implementation on site (minimized disturbance of building occupants).
- Flexibility in design: room for tailoring.
- Ensuring technical quality, desired performance (energy, IEQ) and aesthetics.

Hence, the review showed that currently these solutions are fragmented and the technologies are scarcely acknowledged and adopted at the demand side. Commonly, building owners need to 'patch' different renovation related sources themselves: looking for technical solutions, planning a complex and long renovation process, searching for building contractors, financial opportunities, legal and quality assurance etc. There is a variety of challenges that building owners are facing when considering renovation and often they dismiss the renovation due to the mentioned reasons. This leaves a considerable room for improvements in this new emerging renovation market and shows a need for an effective integral renovation approach.

Involved organizations (mostly SMEs) working on different EU projects are focusing on the development of the breakthrough technologies where execution of important parts of renovation measures is often forgotten or not completed thoroughly. Common products pitfalls are: mistrust in the modular prefabricated elements quality, limited owner's freedom of choice, unattractive solutions and high costs.

Due to budget and time constraints of these projects, the products are not necessarily brought to the market when the project ends and are still in research and development phase. Further development of the technologies (increasing TRL of the technologies) should be done, bringing together different solutions, combining know-how and proving their usability by applying the solutions at the different demonstration projects in order to launch products affordable and attractive for the different stakeholders.

In order to achieve good and wide-scale application of these solutions into the market, replication and repeatability of the innovative technology and developed concepts is needed. With such increased (industrial) replication of innovative solutions, not only energy requirements are satisfied but solutions present more affordable solutions attractive for the wider range of building owners (increased confidence and trust). Efficient funding models (subsidies, funding schemes), business models and supportive national legal frameworks would even further enhance deep renovation executions.

The observation is made that for the end-users to be convinced in these state-of-the art solutions, good examples (best practice) should be shown where dissemination of the lessons learned in the projects is essential. Most of the products are not widely reproduced and there is insufficient time spent on building the trust and confidence in these products. The translation of the knowledge and renovation concepts developed in these projects should be done to practice. Still, it seems there cannot be one-fit-all renovation concept for all possible building configurations. More personal approach is needed with more heterogenic solutions. Several of the reviewed projects (MORE-CONNECT, BERTIM, IMPRESS, iNSPiRe) are producing such tailor made configurations of the products (offering different packages according to different building types and climate), hence, marketing of these solutions is not yet sufficient [8, 10, 11, 15]. More should be done on presentation of these products to the clients where the client is stimulated and triggered to apply these solutions on his building instead being pushed by the supplier. The SMEs working on those EU-funded projects can use these products as a commercial tool to show their skills in the field of deep renovations EU wide.
Individual planning and long-term collaboration schemes between supply-demand side would also accelerate the deep renovation cases where sufficient individual planning is done to increase trust and avoid additional costs and unnecessary work. Potential client and a supplier should work together choosing the best solution, 'renovation package' where it is clearly presented to the client why this solution is best for his building case in comparison with other renovation solutions (compatibility with the current state, technical characterization, energy saving, CO_2 reductions, improved IEQ).
It is believed that Europe can benefit by bringing together these new state-of-the-art renovation solutions, but several important barriers need to be tackled simultaneously: technologies, renovation plan, demand-supply related issues, funding schemes, legal frameworks etc. in order to accelerate a large scale uptake of deep renovations and sufficiently achieve the EU energy targets.

5.2 New renovation strategies

Most of the described projects aim to develop innovative advanced solutions for energy retrofitting where the process is as much as possible automated and products prefabricated. These new renovation strategies are much different than traditional renovation techniques where most of the work is done on site. MORE-CONNECT project (One stop shop concept) [8], EASSE project (The Design Tool) [9], Retrokit (Retrokit Toolbox) [29] etc. present renovation packages that include similar renovation concept where the potential client can chooses the complete renovation solution at once (depends on costs and desired benefits) with minimized occupant disturbance on the actual building when the renovation takes place. Figure 39 shows such complete integrated renovation strategy adopted for several EU-funded projects.

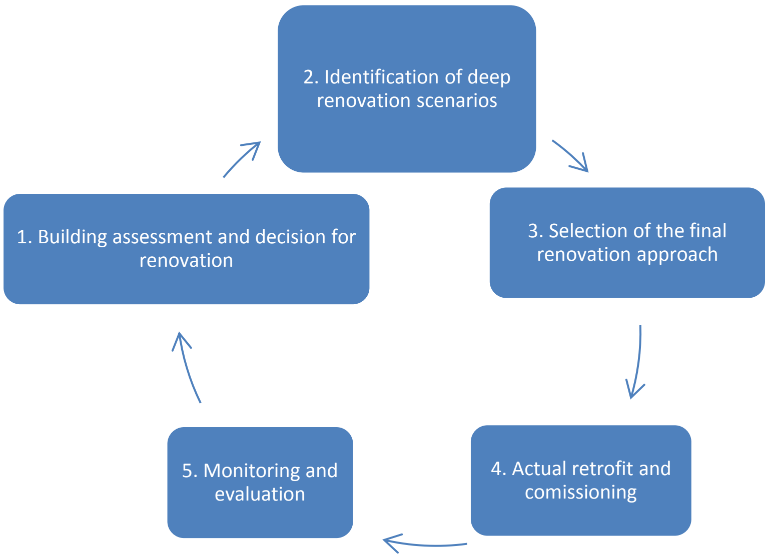

Figure 39: Common renovation strategy applied in several new innovation projects.

1. Building assessment:
   a. Define the aim of renovation, targets and resources.
   b. Scan to BIM approach (laser scanning, photogrammetry).
2. Identification of suitable deep renovation scenarios:
   a. Analysis of different potential renovation scenarios according to the renovation requirements, building characteristics and LCC analysis.
3. Selection of the retrofitting approach:
   a. Final solutions (prefabricated building modules with HVAC components) integrated in BIM model: digital workflow (integration of different parts, connections and detailing).
4. Actual retrofit on site:

   a. Site implementation using high level of prefabrication reducing the time and disturbance on site.
   b. Commissioning (performance evaluation of the retrofitted building).
5. Monitoring and evaluation:
   a. Continuous commissioning: measurements, verification, post-occupancy surveys etc.

By developing a common vision that facilitates these innovative renovation technologies and the renovation strategy presented in Figure 39, this would increase the possibility for wide adoption and application of deep renovation cases in general. Repeatability and reuse of the innovative technology is needed in order to increase the number of actual building retrofitting cases with the developed available technology and resolve the current main barrier: absence of solid empirical evidence.

5.2.1 NewTREND (H2020)

The NewTREND (New integrated methodology and Tools for Retrofit design towards a next generation of Energy efficient and sustainable buildings and Districts) project seeks to improve the energy efficiency and performances of the existing European building stock by developing a new participatory integrated design methodology specifically targeted to the retrofit of buildings and neighbourhoods, fostering collaboration of all the stakeholders in the value chain, engaging occupants and building users and supporting all the refurbishment phases towards whole life-cycle optimisation. The integrated design methodology for energy retrofit will be specified for use for individual buildings and at the district level. NewTREND will address all phases of the refurbishment process. To enable the effective application of the methodology, a toolkit will be developed to support each phase from concept design to implementation and operation, fostering collaboration among stakeholders, involving building inhabitants and users and establishing energy performance as a key component of refurbishments [33].

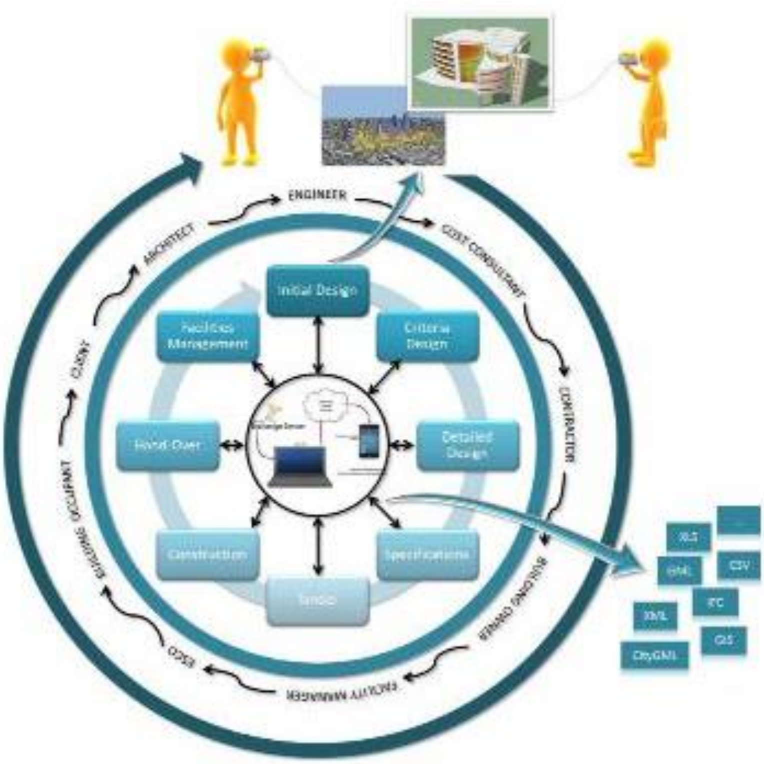

Figure 40: Overall concept of the NewTREND methodology [33].

The project will deliver a set of software tools to support the successful implementation of the methodology for each of the phases, from concept design, through to detailed design, implementation and post retrofit operation. This will contribute to new BIM standards for the installation of retrofit systems to ensure the renovated building operates as designed and is optimised to maximise efficiency. The approach includes modelling and simulation to ensure that the dynamic behaviour and response of the existing building integrated with potential neighbourhood energy systems, is taken into account [33]. Project website: http://newtrend-project.eu/ (Ongoing project 2015-2018)

5.2.2 REnnovates (H2020)

In REnnovates the potential of zero energy housing is investigated. The concept is based on the former concept “Stroomversnelling” in the Netherlands, which entails that energy use and energy generation should be balanced over a one year time period. Key in this concept is sharp reduction of energy demand for heating by insulation improvement and the added solar PV on the roof to fulfil the energy demand for domestic hot water and household electricity. In REnnovates this concept is taken further with the use of smart control and the interaction of building and district level controls. So besides using less energy and generate energy needed to become a zero energy building, the aim is to optimize the use of the generated energy in the building or district itself. To leverage these energy streams the expected new market structure (USEF) and use of smart energy controls is followed.

The new design consists of the following building components:

- Prefabricated energy module
- Prefabricated insulated roof
- Prefabricated insulated façade
- Insulation of crawlspace

Additional

- Bathroom with prefabricated glass panels, coated floor and new plumbing;
- Kitchen with prefabricated glass panels, new kitchen cabinets and equipment for induction cooking;
- Toilet with prefabricated glass panels, coated floor and new plumbing.

Ground floor

The reference house usually has a ground floor of wood or concrete with underneath a crawlspace of approximately 40-60cm. The crawl space is filled up with DROWA-chips (polystyrene). Under air-pressure approximately 40cm chips are blown into the crawl space.

<u>Rc 3,00 m2K/W</u>

Façade

The façade is insulated with a prefabricated insulated timber-framed construction. It is possible to apply a variety of finishing’s amongst others: brick strips, cladding and glass. The façade is mounted to the existing façade, demolition is limited to the removal of the old window-frames only.

<u>Rc 5,00 m2K/W</u>

Roof with PV panels

The roof is insulated with a prefabricated insulated timber-framed construction with a EPDM water-repellent layer. Mounting clips for the PV-panels are already in the factory made up. On average, a reference house gets 28 PV panels of 280 Wp each. The exact amount depends on the angle of the roof,

presence of roof lights, and the length of the building block and whether it is a corner or middle house. The amount can vary from 28 to 36 PV panels.
Rc 5,00 m2K/W 7840 Wp – 10080 Wp

Housing associations refurbish kitchen, bathroom and toilet on average every 15-20 years. Because some adjustments to the kitchen, bathroom and toilet are required anyway for the deep-retrofit to NetZero-energy, it is logical to also refurbish these elements. For example for ventilation and induction cooking it is obvious to refurbish kitchen, bathroom and toilet at the same time.
The refurbishment of the kitchen, bathroom and toilet is inconvenient for tenants. The period in which the kitchen, bathroom and toilet are out-of-use is minimized by the choice of materials and realization process. Demolition is limited.

- Polyuria floor coating, after application direct walkable. The floor coating is applied on top of the existing floor. Demolition is therefore minimized;
- Glass wall panels are applied on top of the tile layers on the wall. The glass wall panels are prefabricated;
- Kitchen cabinets are put together off site.

Figure 3-2 Drowa Chips

Figure 3-3 Timber-framed construction

Figure 3-4 Roof with mounting clips for PV panels

Figure 3-5 Energy module

Figure 3-6 Kitchen, mounting glass wall panels

Figure 3-7 Result, glass wall panels

Figure 41: REnnovates building components.

Creating a business model and setting guidelines and protocols is also part of the project REnnovates [34]. Traditionally, the market is organized top down with large, central energy plants producing all the energy and consumption downstream. Control of the supply/demand balance is also centralized via various mechanisms such as frequency control (primary control based on control power), frequency restoration control to resolve imbalance within a 'program time unit' (secondary control based on reserve power) and (dispatched) reserves/emergency power (tertiary control). Secondary and tertiary control power is bought by the TSO trough imbalance markets and/or bilateral contracting. A representation of the traditional and proposed system is included in the Figure 42.

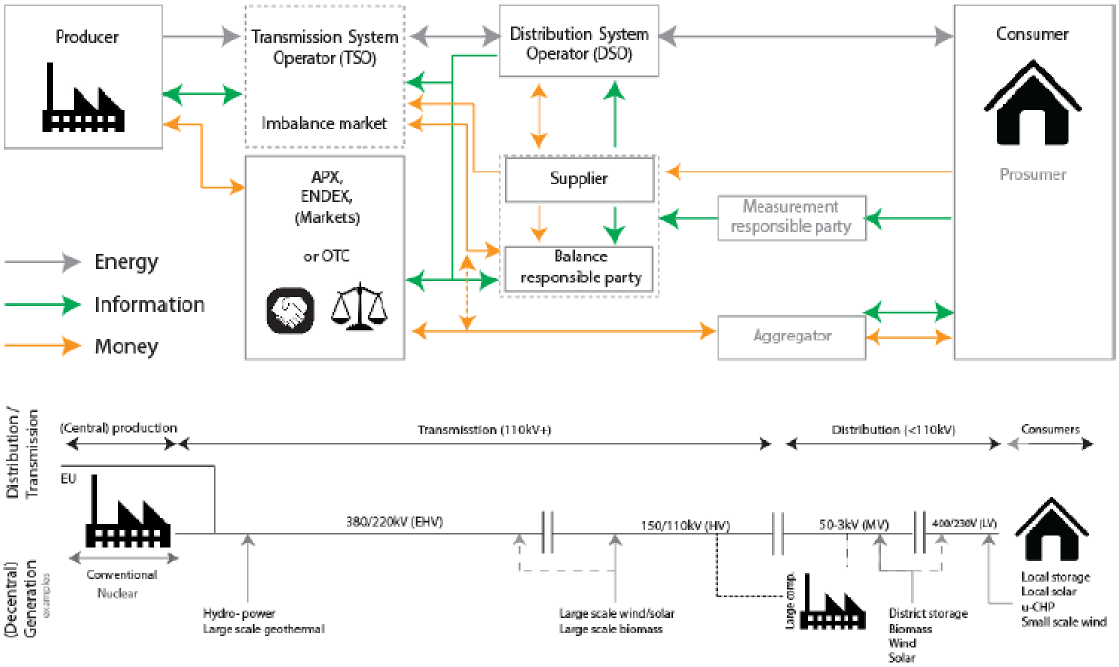

Figure 42: Top - classic physical system with new decentralized producers included.

Bottom - electricity market relations. Energy market relations including some Dutch trade mechanisms (wholesale markets). The grey entities are 'new market roles' [34].

The Universal Smart Energy Framework (USEF) is a market framework that introduces market mechanisms that allow energy trade, flexibility trade while maintaining robust energy control. One of the challenges resolved by USEF is that current grid control schemes do not facilitate small scale, local control and do not couple the intraday energy markets and the unbalance market during operation. USEF specifies trade mechanisms and stakeholders, it is a market framework that leaves room for various business models but does specify new energy market operation paradigms. In REnnovates the USEF framework will be implemented and USEF market role definitions will be used. USEF defines stakeholders, provides possible use cases and describes market interactions. USEF derives potential market relations based on use cases. An overview of possible use cases is given in Figure 43. Here, the 'prosumers' can be either the tenant, or, as is a possible case in REnnovates, be the party who operates the energy module. The benefit of which is that the tenant does not have to be concerned with flexibility, but only with comfort.

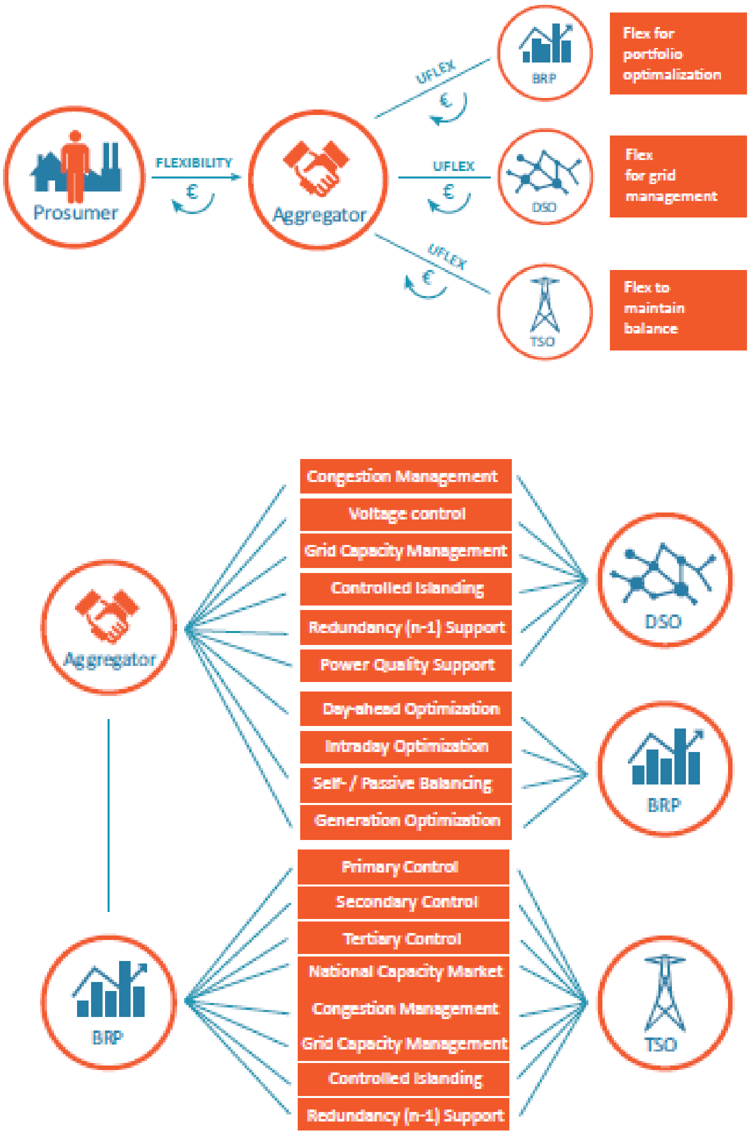

Figure 43: Added business cases. On the up, relation between prosumer and aggregator that aggregates flexibility and sells it to the BRP, DSC or TSO. On the bottom; overview of all possible cases via which an aggregator can create value from flexibility [34].

The REnnovates concept will be demonstrated within three demonstration sites in the Netherlands, Spain and Poland [34].

Project website: http://rennovates.eu/ (2015-2018)

5.3 Key innovation of P2ENDURE

What is urgently needed is to increase the scale and level of adoption through innovative combinations, processes and supporting ICT tools. P2ENDURE will resolve the main barrier for wide-scale implementation of innovative solutions: the absence of solid empirical evidence that such innovative solutions deliver the expected performance, both energetically and financially. P2ENDURE will also create the supply-chain infrastructure for large-scale commercial implementation and upscaling of prefab deep renovation solutions.

P2ENDURE will provide evidence-based innovative solutions for deep renovation that are applicable and replicable for the widest range of building typologies: public buildings, residential buildings, and transformation projects of public and historic buildings into dwellings. P2ENDURE takes on a progressive principle:

- Build further on credible state-of-the-art solutions of 3D scanning and printing technologies in combination with prefab renovation systems, which are derived from tested results of recent EU and national R&D projects;
- Develop modular processes for deep renovation through BIM-based design, engineering, production and installation for speeding up the implementation of the state-of-the-art solutions;
- Optimize and integrate the state-of-the-art solutions grounded in practical evidence of their performance through real deep renovation cases of public and residential buildings;
- Perform real deep renovation projects at a higher complexity level and with a larger performance impact than typical residential buildings through transformation of obsolete public and historic buildings.

P2ENDURE mainly aims to provide scalable, adaptable and ready-to-implement innovative PnP prefab solutions for deep renovation of building envelopes and technical systems. The innovative solutions will be complemented with a proof-of-performance, which is based on pilot implementation and monitoring in 10 live demonstration projects representing deep renovation characteristics in all main EU geo-clusters. Through this aim, P2ENDURE will ensure that the PnP solutions are ready for EU-level market upscaling by 2020.

The project demonstrates the most optimal solutions for deep renovation, which are characterized as affordable, eligible for rapid production and installation, as well as replicable, compatible and adaptable to the widest range of building types and geo-clusters across Europe.

The key innovation of P2ENDURE comprises the upscaling and EU-wide implementation of prefab PnP systems combined with 3D-printed components, 3D laser and thermal scanning integrated with BIM for deep renovation implemented through "4M modular processes"(Mapping – Modelling – Making –

Monitoring) for rapid and low-disturbance on-site assembly.P2ENDURE prioritizes prefab systems that are developed, manufactured and delivered by European SMEs. Thus, while tackling the real market demand for deep renovation, P2ENDURE also strengthens innovative European SMEs in the construction sector to become competitive and profitable after the economic crisis.

The ultimate success of deep renovation can only be proven in the building's long-term sustainability; and therefore, the energy performance goals of deep renovation are achieved when the building optimally fulfils its functional and user requirements throughout its lifecycle. P2ENDURE ensures that public and residential buildings are functionally, technically and socio-economically viable at all times: through transformation of the building's typology and function at deep renovation.

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