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Technical, financial, social barriers and challenges in deep building renovation: integration of lessons learned from the H2020 Cluster Projects

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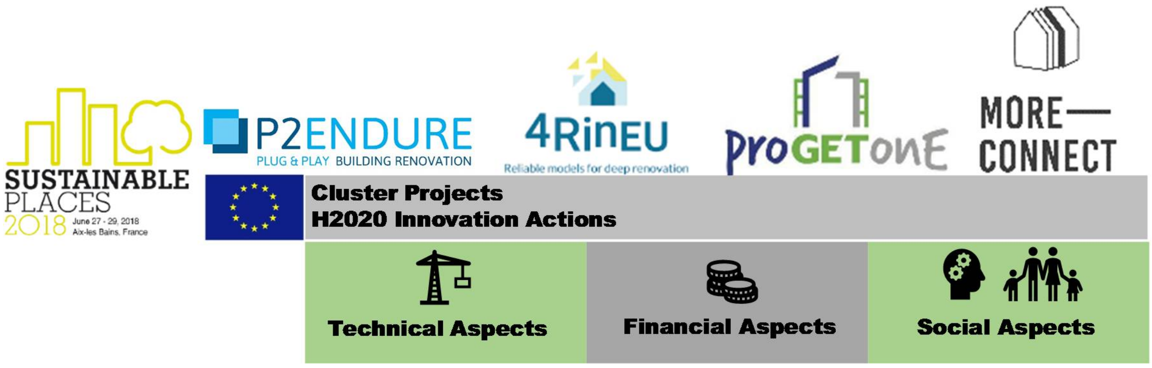
Abstract: With a low rate of new building construction and insufficient rate of existing building renovation, there is the need for stepping up the pace of building renovation with ambitious performance targets to achieve EU climate change policies. However, effective technologies alone cannot solve the low renovation rate of existing buildings in Europe that is hindering the reaching of EU-wide targets. A workshop was held at the Sustainable Place Conference 2018 to present successful experiences with an integrative approach from H2020 innovation actions (4RinEU, P2ENDURE, Pro-GET-OnE, MORE-CONNECT) aiming at improving building energy performance through deep renovation. This article presents the outcomes of the joint workshop and interactive discussion, by focusing on the different technical, financial and social added values, barriers and challenges in building renovation as well as on the identification of open questions to address future innovation opportunities.



Keywords: building deep renovation, energy performance, renovation rate, prefabrication, Plug-and-Play solutions, review, innovation action, H2020, social acceptance

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1. Introduction

Europe aims at bringing about drastic greenhouse gas emission reductions in the building sector of 80% [1] compared to 1990 by 2050. However, still, a major portion of the European building stock (built from 1960-1970) presents poor thermal insulation of the opaque and transparent building envelope, poor indoor environmental quality, poor performance in terms of seismic and structural safety, scarce system efficiency and renewable energy systems integration [2]. In fact, it is widely acknowledged that building renovation is often driven by local needs that go beyond the desire to reduce energy consumption, as for the case of renovation works that coincide with structural repairs [3]. Yet, despite EU energy-efficiency nZEB targets [3], and although the improvement of the building quality due to the renovation demonstrated by several EU initiatives [4] (i.e. aesthetic enhancement of the building exterior façade, system components energy savings, increased thermal comfort, including reduction of CO_2 related emissions, and enhancement of the quality of the overall built environment), the European building sector has not been able to adopt large-scale retrofitting process, with an insufficient renovation rate of 1% for the existing building stock [1].
Most common renovation technologies and practices include installing external/internal insulation and improving the airtightness of the transparent and opaque building envelope, roof retrofitting, installation of photovoltaic panels, installation of heat recovery and efficient HVAC systems, etc. Conventional state of the art energy retrofits focuses on isolated system upgrades (i.e. façade, lighting and HVAC equipment), usually with traditional technology solutions (i.e. without industrialized and prefabricated solutions) and without considering an integrated renovation approach [3]. These retrofits are most largely effectual in their anticipated goals, simple and fast to deploy, but they often miss the opportunity for saving more energy cost-effectively. Furthermore, traditional renovation techniques require an extensive labour work to be done on the site and must assume larger risks due to human errors and damages from exposure to different conditions (outdoor forces, weather conditions, etc.) [4]. Finally, traditional approaches do not usually consider individual needs or expectations by the users in a participative way. Instead, regulations and common methodologies are applied. New approaches will probably need to integrate both technical and social aspects from the early beginning making use of creativity.

1.1. Deep Renovation

A deep energy retrofit is a cost-effective whole-building process that employs an integrative design to attain larger energy savings compared to the ones achieved through the adoption of separate energy retrofit measures [4]. According to the EU Energy Efficiency Directive [5], the deep renovation process represents a solution able to reduce 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, while increasing user comfort and indoor environmental quality (IEQ) levels. The definition of deep renovation applies within the framework of major renovations, under two conditions: 1) either more than 25% of the surface of the building envelope undergoes renovation or 2) the total cost of the renovation of the building envelope or the technical building systems is higher than 25% of the overall value of the building [2, 3].
Progressing past traditional approaches, state of the art whole deep renovation packages includes integrated solutions combining sets of renovation measures [6]. These include i.e. the integration of energy efficient envelopes with improved insulation, high airtightness, solar control, moisture management, controlled ventilation and equipment, HVAC systems with

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heat recovery ventilation sized and integrated within the opaque envelope and walls, active energy components incorporating RES (Renewable Energy Sources) in the building envelope and energy harvesting equipment [4].

Compared to traditional solutions, the adoption of prefabrication systems for deep renovations has several advantages. Fabrication in a factory is demonstrated to be more accurate, secure and easier than on site. Components' quality control is performed in the factory, where the use of standard products (for dimensions and shapes) minimizes the design and production process faults (i.e. thanks to optimized automated production line). Using a high level of prefabrication can decrease the assembly risks on site (most of the work is made in the factory) and reduces the renovation process to the assemblage time of the prefab components on site, with consequent less intrusiveness and disturbance for the inhabitants, as well as reduced costs and less waste produced.

Despite these evident advantages, a general distrust and reluctance of the traditional building industry in adapting prefabricated solutions are observed in common practices. Several reasons can be highlighted, mainly connected to a perceived lower quality of the assembled components compared to singular elements alone, complex installation systems, as well as the need for optimized computerized production lines requiring detailed planning and coordination and innovative business models. More importantly, a generalized lack of knowledge on innovative deep retrofit design methodologies including the adoption of prefabricated systems is hindering the wider market adoption of such highly promising technological solution.

Apart from the appointed technical and industry barriers, the social environment and the citizens' expectations and needs are other key factors, that jointly to financing supporting schemes, need to be addressed for deep renovation deployment. Actually, the intense intervention that is needed by the building industry, to offer and implement competitive solutions to face the challenges in climate change we have at a common level, is not always aligned with individual and local priorities. Therefore, the success on upscaling deep renovation depends on optimized industry solutions and more prepared local communities at a time.

1.2. State of the art deep renovation solutions in EU funded projects

In the context of the H2020 project ProGETone [4] [7], 31 EU-relevant (FP7, H2020) funded projects (2008-2020) have been revised (Figure 1). As a general criterion for the projects' selection, the review focused on projects that deal with state-of-the-art solutions for deep renovations and prefabricated systems, including advanced technologies and systematic renovation strategies and smart services exploited during the design, execution, and maintenance phases of the retrofit process (see details in Table 1).

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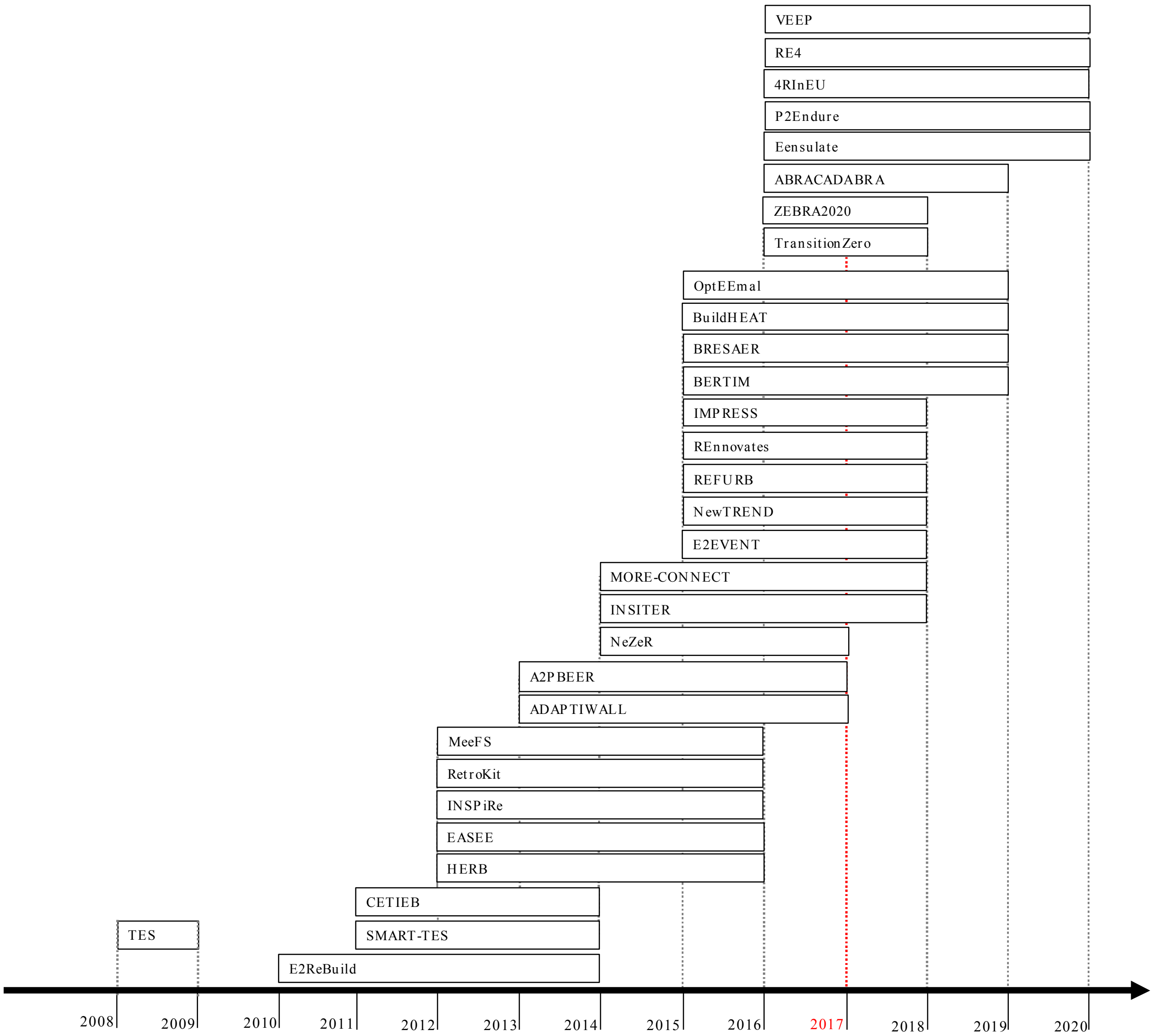

Figure 1: List of the 31 reviewed EU-funded projects that deal with state-of-the-art deep renovations [3]

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Table 1: Deep renovation solutions of state of the art EU-funded projects

Funding Scheme	Type of Action	Project Name	Solutions
FP7	CP-TP – Collaborative Project targeted to a special group	A2PBEER (2013-2017) www.a2pbeer.eu/	Retrofitting methodology for public buildings including existing available and newly developed innovative solutions.
H2020	CSA – Coordination and Support Action	ABRACADABRA (2016-2019) http://www.abracadabra-project.eu/	Renovation strategy coupling Adore, Assistant Building unit(s) – like aside or façade addictions, rooftop extensions or new building construction, with a densification retrofit policy
FP7	CP-FP – Small or medium-scale focused research project	ADAPTIWALL (2013-2017) www.adaptiwall.eu/	Nanotechnology-based, multi-functional and climate-adaptive panels consisting 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.
H2020	IA – Innovation Action	BERTIM (2015-2019) www.bertim.eu/	High energy performance timber prefabricated modules, a tool for mass manufacturing and holistic methodologies for the renovation process, from data collecting to installation.
H2020	RIA – Research and Innovation action	BRESAER (2015-2019) http://www.bresaer.eu/	Coupled cost-effective, adaptable, low-intrusive and industrialized envelope (for façades and roofs) with an innovative Building Energy Management System
H2020	IA	BuildHEAT (2015-2019) http://www.buildheat.eu/	Standardised approaches and products for the systemic retrofit of residential buildings, focusing on heating and cooling consumptions attenuation.
FP7	CP-FP	CETIEB (2011-2014) http://www.cetieb.eu/SitePages/Home.aspx	Monitoring, control systems and modelling tools of retrofitted indoor environments.
H2020	RIA	E2VENT (2015-2018) www.e2vent.eu/	A systemic retrofit solution including the use of ventilated façade system, heat recovery units, photovoltaic cells, natural lighting and envelope insulation strategies.
FP7	CP-IP – Large-scale integrating project	EASEE (2011-2014) www.easee-project.eu/	Toolkit for envelope retrofit in existing multi-story and multi-owner buildings combined with novel design and assessment strategies, with scaffolding-free installation approaches.
H2020	IA	EENSULATE (2016-2020) http://www.eensulate.eu/	Curtain wall system with lightweight (35% weight reduction) and highly insulating energy efficient glass modular components
FP7	CP-IP	HERB (2012-2016) http://www.euroretrofit.com/	Holistic energy-efficient retrofitting of residential buildings
H2020	IA	IMPRESS (2015-2018) www.project-impress.eu/	Pre-fabricated retrofitting modules supported by a BIM-based Iterative Design Methodology (IDM)
H2020	RIA	INSITER (2014-2018) www.insiter-project.eu/	Intuitive self-inspection techniques using augmented reality for construction, refurbishment and maintenance of energy-efficient buildings made of prefabricated components
FP7	CP	iNSPiRe (2012-2016) www.inspirefp7.eu/	Systemic renovation packages for residential and tertiary buildings
FP7	CP-IP	MeeFS (2012-2016) http://www.meefs-retrofitting.eu/	Multifunctional energy efficient facade system for residential buildings' retrofits
H2020	IA	MORE-CONNECT (2014-2018) www.more-	Prefabricated, multifunctional renovation elements for the total building envelope (façade and roof) and installation/building services.

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H2020	IA	NewTREND (2015-2018) http://newtrend-project.eu/	Integrated design methods
IEE		NeZeR (2014-2017) http://www.nezer-project.eu/	Smart and integrated NZEB renovation measures for nZEB
H2020	IA	OptEEmal (2015-2019) https://www.opteemal-project.eu/	Optimised Energy Efficient Design Platform for Refurbishment at District Level
H2020	IA	P2Endure (2016-2020) https://www.p2endure-project.eu/en	Prefabricated Plug-and-Play (PnP) systems enabled by 3D printing, laser, and thermal scanning integrated with Building Information Model (BIM) for deep renovation of building envelopes and technical systems.
H2020	CSA	REFURB (2015-2018) http://go-refurb.eu/	One-stop-shop model for energy renovations
H2020	IA	REnnovates (2015-2018) www.rennovates.eu	Smart services, technical solutions, energy-based communities
FP7	CP-IP	RetroKit (2012-2016) www.retrokitproject.eu	Multifunctional, modular, low cost and easy to install prefabricated modules
H2020	RIA	RE4 (2016-2020) http://www.re4.eu/	Reuse and Recycling of CDW materials and structures in energy efficient prefabricated elements for building refurbishment and construction
Public funding from Wood Wisdom-Net Research.		SMARTEST	Innovation in timber construction for the modernization of the building envelope
		TES	Systematically process of surveying, renovation planning, construction and maintenance of the building stock using prefabricated large sized timber frame elements. targeted at the refurbishment of the existing building stock built from 1950's to 1980's.
H2020	RIA	VEEP (2016-2020) http://www.veep-project.eu/	Cost-Effective Recycling of CDW in High Added Value Energy Efficient Prefabricated Concrete Components for Massive Retrofitting of our Built Environment
H2020	CSA	TransitionZero (2016-2018) http://transition-zero.eu/	Net zero refurbishment solutions integrating standardized design of pre-fabricated technological modules and mass-production with innovative business case for housing associations
IEE		ZEBRA 2020 (2014-2016) http://zebra2020.eu/	Monitoring system of market uptake of refurbished nZEB including data collection and recommendations
FP7	IA	4RinEU (2016-2020) http://4RinEU.eu/	Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU.

The analysis was intended to deliver insights on advanced integrated design method, including production, monitoring, control and operation of smart components and systems (Table 2). Since one of the main barriers to adopting deep retrofit measures is the guaranteed high efficient performance, against the high capital investment cost and complex operation, the pre-fab system is oftentimes supplemented by smart building management systems (BMS) and ICT. This is the case, for example, of several EU funded H2020 projects, including the A2PBEER, BRESAER, CETIEB, E2EVENT, MeeFS, MORE-CONNECT, REFURB, REnnovates, RetroKit, 4RinEU, BuildHEAT, OptEEmal and RE4projects.

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Table 2: Key state of the art technologies for the reviewed EU-funded projects that deal with pre-fab systems for deep renovations.

Project	Pre-fab	BMS - ICT	RES	BIM BPSM	Multi-benefit	HVAC	Advanced geomatics	3D print	Smart connector
A2PBEER		✓							
ABRACADABRA	✓		✓		✓				
ADAPTIWALL	✓								
BERTIM	✓			✓			✓		
BRESAER	✓	✓	✓						
BuildHEAT	✓	✓	✓		✓	✓			
CETIEB		✓							
E2ReBuild	✓								
E2EVENT	✓	✓	✓			✓			
EASEE	✓			✓			✓		
Eensulate	✓								
HERB	✓		✓			✓			✓
IMPRESS	✓							✓	
INSITER							✓		
INSPiRe	✓		✓						
MeeFS	✓	✓	✓						
MORE-CONNECT	✓	✓	✓	✓	✓	✓	✓	✓	✓
NewTREND				✓					
NeZeR					✓				
P2ENDURE	✓			✓		✓	✓	✓	
OptEEmal	✓	✓		✓	✓		✓		
REFURB		✓	✓		✓	✓			
REnnovates	✓	✓	✓	✓	✓	✓			
RetroKit	✓	✓	✓			✓			
RE4	✓	✓		✓			✓		✓
smartTES	✓		✓			✓			
TES	✓		✓			✓			✓
TransitionZero				✓	✓		✓	✓	
VEEP	✓						✓		✓
ZEBRA 2020					✓				
4RinEU	✓	✓	✓	✓	✓	✓			

The modular nature of pre-fab system allows seamless integration with active system for production from renewable energy sources (RES) such as solar panels and photovoltaic (PV) systems, as for the ABRACADABRA, BRESAER, E2ReBuild, E2EVENT, HERB, INSPiRe, MeeFS, MORE-CONNECT, REFURB, REnnovates, RetroKit, SMART-TES, TES, 4RinEU and the BuildHEAT projects.

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Building Information Modelling (BIM) and the exchange information with building performance simulation models (BPSM) emerged significant enabling technologies in state of the art solutions for deep retrofit towards nZEB oftentimes in combination with advanced geomatics (3D scanning), as for the case of the BERTIM, EASEE, MORE-CONNECT, NewTREND, REnnovates, and OptEEmal projects, and 3D printing techniques (MORE-CONNECT, P2ENDURE, IMPRESS, TransitionZero).
Several EU-funded projects focus on innovative optimized HVAC packages integrated with pre-fab deep retrofit packages that allow for easier, less intrusive and more efficient improvement of the existing HVAC installations, as for the case of the BuildHEAT, E2EVENT, MORE-CONNECT, P2ENDURE, REFURB, REnnovates, and RetroKit projects. One of the latest developments in the renovation process, is the adoption of co-benefits solutions coupled with energy-saving measures. Moreover, taking into account in the business plan the advantages of an integrated renovation will help to overcome the barriers in adopting innovative technologies and will foster the market update of building renovation, as for illustrated for the ABRACADABRA, MORE-CONNECT, NeZeR, REFURB, REnnovates, TransitionZero, 4RinEU, BuildHEAT, OptEEmal and ZEBRA 2020 Projects. MORE-CONNECT emerges as the only recently EU-funded project moving one step forward a full integration of the most advanced state of the art technologies and approaches combined with prefabricated modular systems for deep retrofit (as shown in Table 2). Significantly, integrated wide implementation of prefab principles (platforms, modularity) and its correlated state of the art technologies brings significant advantages to the renovation market:

- Development of an assessment approach, enabling the development and the testing of technical progress of state of the art technologies;
- Development of guidelines, including the transfer of knowledge and skills, to be delivered and disseminated among all the EU community (researchers, practitioners, building industry, technology vendors, and producers, etc.)
- Better knowledge understating for the building industry on properties and duration of advanced materials, to enhance the performance of their products/concepts, as well as calculation methodologies, assessments, and testing procedures.
- Benefits for the industry sector include the validation of integrated solutions enabling better collaboration among companies supplying different technologies to be integrated and utilization of each other's competencies, products, and experiences.

All combined, these advantages are foreseen as enabling factors for a deeper market (and user) acceptance of the highly promising state of the art solutions for deep retrofit at the EU level.

1.3. Review of social approaches to deep renovation

In the framework of ProGETonE project [7], a review of best practices and lessons learned from different user approaches has been done at the European level. In addition, specific surveys within the ProGETonE case studies communities have been undergone.

Main findings related to social aspects in ProGETonE point out the difficulty to scale results for target groups given the intrinsic reality of needs of each community, depending on a lot of variables (year of construction, constructive solution of the envelope, dimension of the dwellings, orientation, installed system, previous rehabilitation, main type of occupant,

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culture, climate, etc.). For this reason, there is a need to start identifying specific problems/needs/possibilities/types of users first, and to treat case per case, without generalizations. In order to understand the motivations and trigger points of a target group, it is very useful to investigate these aspects:

- what is relevant for people in their homes;
- why they decide to renovate and what are their expectations;
- their awareness of seismic safety and energy efficiency issues;
- the added value in terms of real estate increase of the building after the renovation to counterbalance the economic costs of investment.

As a general conclusion for the case studies of ProGETonE, safety, space, comfort and money, meant to come from energy savings and for building value enhancement, are the main trigger points for the inhabitants of multi-family buildings to decide to renovate their home. An important aspect for occupants to be motivated to renovate in terms of seismic safety and energy efficiency is the awareness of these trigger factors. This last point is where ProGETonE can give an added value, by answering the need of making training workshops or similar on seismic safety, energy efficiency, space extension and aesthetical improvements with the occupants of the buildings to renovate. In particular, the space addition and the aesthetical improvements are also essential to emphasize how seismic safety, which is not so "visible" as energy efficiency, can be integrated with other triggering aspects which are directly connected to energy expenses, added real estate value and comfort. In addition, it has been raised the need to create trust among the community as regards the renovation process.

In a more general context, it can be stated that renovation projects are complex to carry out, because of many actors involved and diversity of aspects that are tackled. Many barriers are still present; however, ProGETonE has come up with a set of aspects that may help to unlock social-related barriers. The main ones are pointed out below.

- Building confidence and having enhanced communication possibilities among the involved actors and inhabitants. In addition, early users' involvement and personal contacts are key aspects to consider.
- Taking into account the users' needs and motivations as well as the site social climate.
- The renovation should imply more building value and improved aesthetics.
- It is important to explain and put in value the benefits in health and wellbeing.
- It is useful to set up training or education programs to increase awareness about climate change, energy efficiency and seismic safety. More mature communities in terms of sustainability awareness may engage easier in a deep renovation process.
- Leadership inside the concerned community may inspire others, so an already trained and trusty person can unlock some resistances.
- Increase in rent is not well perceived, especially when vulnerable homes are concerned.

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2. The H2020 Cluster Projects Initiative

The Cluster Projects initiative brings together four ongoing H2020 Innovation Action projects focusing on improving building energy performance through deep renovation:

- **4RinEU:** Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU (http://4RinEU.eu/)
- **P2ENDURE:** Plug-and-Play solutions for Energy-efficiency deep renovation of European building stock (https://www.p2endure-project.eu/en)
- **Pro-GET-OnE:** Integration of Plug-and-Play solutions and users' centered approach to solving both energy and seismic requirements during deep renovation of residential buildings (https://www.progetone.eu/)
- **MORE-CONNECT:** Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTions (https://www.more-connect.eu/)

The H2020 Cluster Projects initiative is an interest group formed by professionals involved in at least one of the 4 aforementioned projects with the following objectives:

- To share barriers and strategies to overcome with respect to deep renovation in EU;
- To keep up to date with knowledge, practices and learn among each other;
- To co-create new approaches, project ideas;
- To enhance knowledge and technology transfer, as every partner is not only involved in EU projects but also in the implementation of the latest developments;
- To identify synergies among projects that may lead to specific collaborative work.

The space to share the knowledge and progress is allocated through teleconferences, joint workshops and webinars. Some of them will have a clear purpose to be open to professionals that are not directly involved in the projects.
An interesting step further would be to create a living community, beyond projects' extinction, to contribute to the development of the market of deep renovation, while keeping an independent view on it.

The Cluster Projects Initiative brings experts from the field of Architecture, Urbanisms, Building Engineers, experts in user-centric approaches and Sociology, together with product developers and manufacturers and representatives of public bodies, universities and research centres, and provides them with an occasion for sharing experience and discussing example projects that embody such kind of multidimensional questions.

The ultimate objective is to co-create a multidimensional and cross-disciplinary platform and a knowledge-based agenda that can steer the evolution of innovation actions under the H2020 umbrella. This community platform will allow researchers and interested stakeholders to perform contextualized analysis of concrete examples and to share lessons learned, with the inclusion of multiple perspectives from the different related fields of expertise and disciplines involved over the entire renovation process (from co-design of solutions, to off-site manufacturing, on-site installation up until operation, maintenance and performance certification).

3. The Projects Cluster Workshop

On June 27th and 28th INES Research & Development premises in Aix Les Bains (France) hosted the Sustainable Places Conference 2018. A workshop was held in the context of the H2020 Cluster Projects Initiative to present and interactively discuss ongoing H2020 innovation actions aiming at improving building energy performance through deep renovation.

The gathering workshop aspired to reach three specific goals: 1) to identify unaddressed questions, challenges and opportunities; 2) to collaboratively develop guidelines of future research and innovation action agendas, which are shared and commented among the workshop participants; and finally 3) to consolidate a European- centred pool of experts that will act on the identified guidelines through steering future funding streams (i.e. new H2020 projects).

This article presents the outcomes of the joint workshop with an integrative approach. The analysis first focuses on the technical, financial, and social added values, barriers and challenges in building renovation, pointed out within the clustered projects, in order to further identify untapped open questions to address future innovation opportunities.

This position paper classifies values and barriers for deep renovations among the four Clustered Projects, taking into account the critical parameters and conflicting requirements and the possible mutual solutions to achieve energy and safe buildings within a socially acceptable environment and technical and economic feasibility. The main objective of this paper is to highlight critical positive and negative aspects that are key in deep renovations, which can imply an important impact on the development of future solutions.

3.1. Technical Aspects

Traditional renovation techniques require extensive labour work to carry out on the construction site. On the one hand, with a traditional renovation, the users are forced to leave their homes during the most invasive works, and have to bear the prolonged disturbances during of construction site activities. On the other hand, the traditional approach presents high risks for the implementation, due to human errors and damages from exposure to different conditions (outdoor forces, weather conditions).

In particular, several studies **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** pointed out that there is an embedded cost of failures during the construction on a traditional building site, and it has been estimated an impact around 20% of the whole construction cost. The cost of failures is related to human error (54% of failures), material defects (12%) and errors during the construction (34%).

A prefabricated approach copes with this problem, since it can:

i) decrease the assembly risks on site and the impact of human error, since most of the works are made in the controlled environment of the factory
ii) enhance the level of performance of the technologies installed (in comparison to the predicted ones), since the quality control of the components is performed in the factory

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iii) minimizes the design and production process faults thanks to standard products (dimensions and shape) and optimized automated production

Moreover, a prefabricated renovation will reduce the number and duration of construction and assembly processes on-site, with consequent less intrusiveness and disturbance for the inhabitants. The project 4RinEU estimated, for a theoretical building archetype (i.e. a detached house with a façade surface to be renovated around 380 m^2) that it is possible to save 52% of the construction site duration by applying a multifunctional prefabricated façade integrating PV system and HVAC components with the technology solutions introduced by the project.
The P2ENDURE project provides tools and methodologies to evaluate the effectiveness of the renovation solutions and to verify the expected building performance in terms of energy, environmental impact, Indoor Environmental Quality (IEQ), time and cost efficiency. The preliminary results of the project indicate that by implementing Plug-and-Play prefabricated solutions it is possible to achieve at least 15% cost-saving and 50% time saving of installation work as well as to reduce disturbance on-site significantly during construction.

In order to significantly reduce energy consumption in building stock, Europe has to focus on scaling up the process of energy retrofitting of existing buildings. So far, business as usual practices includes energy retrofitting step-by-step, building-by-building. This building retrofitting process is indeed labour-intensive and lengthy – it usually takes several weeks or even months to replace old windows by new, install new thermal insulation layers on the external walls and roofs of buildings and, renew the heat distribution systems or to attach renewable energy sources on the building's envelope. In order to overcome these historical inefficiencies, several innovation and research actions have been initiated under the H2020 program. The workshop organized at the Sustainable Places Conference 2018 highlighted the technical values introduced by the results of the 4 Cluster Projects, in order to overcome the above-mentioned barriers. Moreover, it was the occasion to identify the still existing drawbacks of a prefabricated renovation approach.

Table 3 illustrates in details the key technical added values and barriers for deep renovation emerged from the 4 Cluster Projects.

One of the key results of the project 4RinEU [12,13] is a prefabricated multi-functional façade integrating active components (e.g. ventilation devices, photovoltaic and solar thermal systems, components of the HVAC plants), that allows for a plug and play installation on the existing construction without the use of scaffoldings. The project deals with all the phases of the renovation process and, in particular, concerning the design it introduces a tool named EarlyReno, aimed at supporting the user in the early design of the renovation in order to maximize the exploitation of renewables on site (i.e. ventilation and daylighting potential as well as solar energy potential). This tool is strategic, since it provides inputs also for the best integration on the façade systems. The project takes care of the replicability of the solutions, by investigating three demo cases in different contexts (i.e. Norway, Spain and The Netherlands) where the results will be implemented in a real renovation, three early adopters, where 4RinEU will be implemented as a feasibility study and a set of representative building archetypes across Europe, adopted for a theoretical renovation.

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Table 3: Key technical added values and barriers for deep renovation emerged from the 4 Cluster Projects

	Values	**Barriers**
4RinEU	• Prefabricated renovation of the envelope without scaffolding – significant time reduction • Integration of functions and elements in the façade (ventilation, ducts, RES) • Optimization tool for Early Design and RES integration • Plug&Play energy hub for controlling the heating and cooling fluxes within the HVAC system • Replicability potential based on shared technical specifications	• Prefabrication does not suit all the buildings: technical constraints (nodes, balconies) • Speed mounting VS dimension of the elements • Integration of components allows to speed-up the process but is a complex problem • The accurate design would need detailed inputs – lack of information on the energy profiles
ProGETonE	• Deep renovation driven by seismic reinforcement and space extension • The increase of the real estate value of the original building • Aesthetic improvements • Increased comfort	• Integration of different solutions • Legislative barriers since additions are not always admitted by current regulations • Integrated energy-seismic renovation offer is not common, lack of reference actors
P2endure	• 4M modular process for preparing and implementing deep renovation measures: Mapping – Modelling – Making – Monitoring [8] • Easy to install Plug-and-Play (PnP) innovative prefab solutions for retrofit of building envelopes and MEP systems [9] • Deep renovation aiming at achieving at least 60% energy-, 15% cost- and 50% time saving compared to traditional renovation • Monitoring system before and after renovation with the Comfort Eye - a low-cost sensing device for the real-time monitoring of Indoor Environmental Quality (IEQ) [10] • BIM-based energy analyses of different renovation strategies [8] • BIM Parametric Modeller and e-Marketplace for local renovation factory to display information on costs and energy performance of different renovation strategies [11]	• Managing dynamics of real renovation projects related to creating/choosing and executing the best renovation strategy, delays in the realization of renovation plans • Integration of different PnP solutions • Finding methodology for BIM-based energy analyses • Lack of data on building energy performance and operational costs of buildings • Unknown feasibility of the developed methodology • Gathering building data in a coherent way • Creating BIM models with available software • Specific requirements for BIM models of buildings and building solutions for energy analyses • Restrictions of implementation of innovative façade and roof solutions to historical buildings and therefore, improving the energy performance of these buildings
MORE-CONNECT	• Smart connectors: air, hydraulic, mechanical, and ICT • New advanced geomatics technologies applied and tested in demos • Role of innovative industrial partners i.e. 3D printed facades etc. • Scaffold less renovation demonstrated as an effective technology • New BIM controlled automated production lines • Morphological design procedures	• Sizing of prefab elements needs attention. • Elements are still too big and too heavy: miniaturization of elements is needed • Gauging in practice • HVAC platforms still need a redesign and miniaturizing • Point cloud to BIM is the main technical barrier : the process is still too complicated

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Anyway, there are still several barriers affecting the process, since the prefabrication is influenced by several constraints (e.g. balconies, specific building features, nodes) and it is still quite expensive in comparison to a traditional renovation. Moreover, the larger the façade element, the quicker is the installation, but the more difficult and expensive is the transportation.

In P2ENDURE, the 4M modular process clarifies the stepwise PnP approach for preparing and implementing the deep renovation followed by real monitoring of the resulting performance improvements [8]. During "Mapping", As-Built BIM derived from '3D scan to BIM' is created to combine the necessary building information and improve communication between different actors. During "Modelling", various innovative solutions can be implemented in BIM in order to make simulations of different renovation strategies to compare capital and operational costs as well as possible energy performance after renovation. During "Making", the deep renovation is performed based on the most optimal design with the chosen PnP products. Finally, during "Monitoring", an IEQ monitoring tool is deployed [9]. There are still certain limitations in all the 4Ms, for example in "Mapping", there is no fully-automated procedure yet to create BIM based on a point-cloud derived from 3D scanning. In "Modelling", there are interoperability issues related to BIM formats and BEM tools. In "Making", as mentioned before, the building owners and providers of various PnP renovation products have limited willingness to investigate new deep renovation measures and integration of PnP solutions. In "Monitoring", the constraints are related to the data exchange due to the incompatibility of smart meter standards in different countries as well as the ongoing discussions on data privacy [7, 10].

The objective of the H2020 project 'MORE-CONNECT' is to develop and to demonstrate technologies and components for prefabricated modular renovation elements in five geo-clusters in Europe (The Netherlands, Denmark, Estonia/Latvia, Czech Republic, Portugal). MORE-CONNECT is based on three main innovations: product, process and market innovation. Product innovation includes prefabricated innovative, modular composed building envelope elements, including the integration of multifunctional components for climate control, energy saving, building physics and aesthetics, with advanced plug & play connections (mechanical, hydraulic, air, electric, prefab airtight joints) for ultrafast installing, limiting the total renovation time of 5 to 2 days. Process innovation includes a fully automated productions process, starting with digital imaging using advanced geomatics, the on-line configuration of the renovation concepts by end-users and a fully automated BIM controlled production process. This process offers the possibility to produce 'series of one' in a mass production process. Market innovation includes the offering of a one-shop-stop concept to the end-user, i.e. the end-user deals with only one responsible party organizing the design, production, installing, financing, performance contracting and aftercare. A performance guarantee is offered for individual energy use and the quality of the indoor environment. Web-based tools will link building characteristics, building energy potential and end-users demands [14].

The MORE-CONNECT project has developed a system of prefabricated retrofitting modules, that enables to cut primary energy consumption of a typical residential building by 80%, reduces on-site installation time bellow two weeks and improves the indoor environment for the tenants [15]. Indoor climate and energy calculations were made based on national energy calculation methodologies in six countries: Denmark, Estonia. Latvia, Czech Republic, Portugal, and Netherland. Requirements for heat loss of building envelope vary

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depending from requirements on indoor climate and energy performance in the specific country, outdoor climate, availability of renewable energy, and building typology [16]. Furthermore, results show that simple thermal insulation of building insulation can ensure 50% reduction of building heat consumption, while, practical measurements have shown a significant increase of indoor air relative humidity and CO2 concretion level [17].

Going forward, MORE-CONNECT focused on significant improvement of pre-production and production process of the developed solutions to advance the overall production efficiency and reduce the production costs [18]. The main tools to achieve this goal include automated 3D scanning of buildings, fully digitalized pre-production process and IT-supported the creation of data describing the automated fabrication of the modules. At the same moment, the project implemented a systemic quality control over the whole design, pre-production, production and installation process in order to significantly reduce the number of warranty claims by the clients [19].

The growing attention to improving the building's thermal performance has initiated an increasing demand for innovative remodelling solutions for existing houses. This modelling problem is being studied in MORE-CONNECT through innovation in industrialized building renovation to reduce energy consumption. Advancements in contemporary CAD and CNC manufacturing technologies brought by MORE-CONNECT allow the use of modular prefabricated insulated wood frame panels for this purpose as one of the possible solutions. More and more widely used Building Information Modelling (BIM) concept with its' parametric modelling capabilities allows to assess the outcomes of the results of preliminary building energy performance analysis and later coordinate these complex and time-consuming processes much easier, faster, and cheaper [20]. As one of the key components in the solution of this problem is the fast and precise acquisition of geometry of the building. This research was aimed towards the reconstruction of BIM compatible 3D geometric model from laser scanned data that captures the building's external envelope with main openings. The research in MORE-CONNECT focused on the capture of building 3D data in a BIM compatible format, which later may be used for both an energy analysis and a structural design of insulation systems. A raw laser scan data captured at the building site was later post-processed with dedicated software to comply with import options for BIM software. Furthermore, using a point cloud data as a reference a 3D geometry of the building was traced [20].

Despite these evident advantages, there is a general reluctance of the traditional building industry in converting the renovation into an industrialized process, where the building components are prepared and combined in a production line within the factory. This lack of trust has an impact on the construction workers, that are not usually skilled in the installation of such technologies, and only specialized companies have the right competencies for managing a prefabricated construction site. Consequently, also a generalized lack of knowledge of the designers on innovative deep renovation methodologies, including the adoption of prefabricated systems, is hindering the wider market adoption of such highly promising technological solution. These factors contribute to reducing the use of such technologies, and consequently the cost for the design/production/installation is still not competitive with a traditional renovation and, since the main driver for the users is money, the high investment cost represents one of the most significant barriers.

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3.2. Financial Aspects

Most of actual Europe's residential building stock is due for deep energy renovation. The motivation is set by the EU's environmental goals, together with the users' demand for the energy and costs savings. However, the building sector is currently not able to offer an integrated solution for deep renovation toward nearly Zero Energy Building (nZEB) for reasonable costs [21]. Deep retrofits are often associated to the concept of "cost-effectiveness" [22,23] since higher energy performance is resulting in the lowest cost during the estimated economic lifecycle of the building, and quicker Return on Investment (ROI) for implemented solutions through energy savings. However, cost-effective direct economic payback is not universally applicable for all cases – i.e. in Mediterranean regions energy consumption is generally lower than expected and already lower than the EU average [24]; this fact, alongside to fuel poverty cases [25], make it difficult to pay back the interventions in energy savings terms.

Table 4 illustrates in details the key financial added values and barriers for deep renovation emerged from the 4 Cluster Projects.

Table 4: Key financial added values and barriers for deep renovation emerged from the 4 Cluster Projects

	Values	Barriers
4RinEU	• Reliable costs for the investment due to reduced failures during the renovation, guaranteed high performance during time • 4RinEU energy audit and Early RENo reduce the uncertainties in terms of performances (circular knowledge transfer) • Prefabricated façade systems allow increasing the building lifespan	• Investment for the renovation are still high for common users – mass production would be needed to reduce costs of prefabrication • Multi-functional façades have a complex maintenance management (general contractor and agreements are needed)
ProGETonE	• The increase of the real estate value • The increase of the expected lifetime of the buildings •	• Lack of investment • Higher up-front costs compared to standard renovation • Lack of supporting schemes (both legislative and financial) • Long payback or not directly paid back (need to include the benefits of the increased seismic security)
P2endure	• Faster RoI with innovative, energy-efficient technologies • LCC analyses proving lower operational costs of buildings after performing deep renovation [11] • Enhancement of the product value chain through the e-Marketplace financial mechanism	• Managing dynamics of real renovation projects related to financial issues, e.g. insufficiency/lack of available funds for renovation • Higher initial costs of the innovative solutions; reducing the production cost of the PnP solutions by increasing volumes of production
MORE-CONNECT	• Prefab renovation solutions should be able to offer significant cost reduction • Significant cost reduction is expected if Pointclouds2BIm is achieved	• Cost reduction still not achieved because of lack of scale (solutions are one-off test products, 2.0 version in development) • Although roadmap to pointclouds2BIM and steps to make are developed within M-C no one is able or willing to do this

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The aim of 4RinEU is to make the planning of the renovation as reliable as possible, by considering all the possible issues and uncertainties that can deviate the actual behavior from the predicted one, reducing the risks of the overall process. In this regards, starting from the very beginning, during the audit also an evaluation of the pre-bound effect (in order to estimate properly the energy savings). Moreover, a deep evaluation of the risks associated with the adopted technologies in the renovation and relative countermeasures is introduced, in order to improve the effectiveness of the implementation. Finally, the application of the prefabricated façade will enhance the building value and its lifespan, in comparison to a traditional renovation with a simple insulation. On the other hand, the cost of such technologies has still a low competitiveness in comparison to traditional techniques, thus the shifting to the mass production to increase the sustainability of prefabricated renovation is needed. In addition, the maintenance of a multifunctional façade is still an open issue, since several technologies from different companies integrated on a complex system, thus more detailed evaluations on site and agreement among producers are needed to provide the users with a durable solution.

In P2ENDURE a methodology and a tool for Life-Cycle Costs Analysis (LCCA) are further developed for deep renovation of buildings and tested on the real renovation projects [26]. Based on the gathered data cost calculations have been performed for three strategies: maintain-only, traditional renovation and P2ENDURE deep renovation. The preliminary results show that even though the initial costs of renovation with innovative technologies are higher than costs of traditional renovation, the Return on Investment (ROI) can be achieved faster and the operational expenses after performing deep renovation are significantly lower in long-term. Performing LCCA helps building owners and asset managers to understand the financial benefits and opportunities that can be achieved with deep renovation and in the result, overcome the barriers related to high costs of innovative technology, lack of awareness on costs of energy-efficiency measures and the benefits of deep renovation, including possible ROI [27].

MORE-CONNECT explored concepts for large-scale retrofit of housing with prefab panels, and analysed the environmental effects of these concepts. A graphics tool for design aid is developed to find the optimal solution, using embodied energy as the main parameter. One of the main conclusion is that the cost-optimum in deep renovations can only be found evaluating different combinations of energy reduction and production. The design aid also connects the outcomes to technical constraints (like roof surface available) as well as to cost optimization. Furthermore, the project outcomes argue on the importance of embodied energy, and the wider use as a general proxy for low energy/ low CO2 strategies, as an alternative for more broad sustainability assessments [28]. Furthermore, MORE-CONNECT investigated a solution for the cost-effectiveness problem by pushing forward the integrated modular renovation system closer to the mass production. The computer-aided models are used to control the production and reduce the price of the system by mass production [21]. The adjustments of the solution for particular Europe’s geo-cluster is the objective for the industrial and knowledge partners in the project. The end result is expected to be an energy renovation methodology reaching a plus-energy level at competitive costs [29]. The aim of MORE-CONNECT is to create a competitive solution consisting of a technology and processes which enable fast, cost-effective renovation with minimal difficulties to inhabitants. Significant cost savings in renovation costs lies in the usage of prefabricated elements and

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the reduction of construction works on site. The precision of the prefabricated element depends on the precision of the construction, project and building documentation. This project offers an overview of the possible methods for building documentation and spatial data transfer into BIM (Building Information Modelling) software. The description of methods focuses on laser scanning and photogrammetry (including RPAS based), its advantages, disadvantages and limitations according to the documented building, level of renovation, and situation on site [30].

3.3. Social Aspects

This chapter identifies values and barriers for deep renovations among the four Cluster Projects, taking into account the critical parameters and conflicting requirements and the possible mutual solutions to achieve energy and safe buildings within a socially acceptable environment.

Table 5: Key social added values and barriers for deep renovation emerged from the 4 Cluster Projects

	Values	Barriers
4RinEU	• Less disturbance of the inhabitants due to reduced time and complexity of the building site • User information about the building operation • Feasibility studies from early adopters	• Lack of trustiness in innovative technologies (and in general in renovation and changes)
ProGETonE	• Shorter time and less disturbance • User-oriented design (space and comfort increase alongside safety improvement) • Safer and climate-respectful buildings • Higher IEQ • Focus on user's willingness to pay	• Lack of awareness and trust in new technologies • Lack of awareness of seismic risk and in energy transition needs • Lack of communication channels and resources • Short-term oriented vision by both inhabitants and most of technical professionals • Lack of supporting funds • The mismatch between collective and individual needs
P2endure	• Shorter time of renovation and less disturbance on-site during renovation • Improved IEQ • Involvement of local communities through local renovation factory and e-Marketplace	• Managing dynamics of real renovation projects related to lack of commitment of the building owners/developers, lack of communication and lack of long-term vision on the building performance after renovation • Lack of awareness and trust in new technologies, especially from public clients and in public procurements
MORE-CONNECT	• Short time renovation and less disturbance is possible (proven in 'Energiesprong' already) • New VR technologies to show occupants 'what they get' and 'making own configurations' • Integrated tools to assess energy, embodied energy and costs	• Cost break down is: Prefab envelope: 1/3; Building services and PV: 1/3; Finishing, small works, failure costs: 1/3 • Earnings/earning model of traditional companies is often in extra work and failure costs • Technology is not the problem, but how to break through a traditional market, dominated by traditional (large) companies

	• One-stop-shop concepts	• Clients are still reluctant for innovations • Blueprints for new production processes/ factories but due to lack of market on hold

The main objective of this section is to highlight the critical promoting and preventing aspects that are key in socially acceptable deep renovations, which can imply important impact on the development of future solutions. Table 5 illustrates in details the key social added values and barriers for deep renovation emerged from the 4 Cluster Projects.

During the workshop's open discussion some recommendations and remarks appear recurrently and are worthy to be reported:

- There is the need of having a multiple solution approache to unlock the deep renovation market (residential) - political support (more obligation, more supporting schemes), proactive promoters (better offer), more aware occupants (knowledge about the co-benefits, engagement, etc.).
- There is the need for different approaches according to the users. If we deal with a social housing company, a housing company or a condominium it may be quite different to have the users' engagement. It would be particularly interesting to be able to identify the "early adopters", the most prepared / convinced communities, as the effort (in time and money) will be less. We may ask ourselves "How can we detect the most prepared occupants/owners?"
- Health is dependent on many aspects (food, lifestyle, environment, buildings, etc.). Certainly the population is not aware enough of the importance of "environmentally healthy buildings and cities". Effective practices to communicate with the users about the relative importance of these factors among other healthy aspects, still need to be isolated and studied.

The added value introduced by 4RinEU is the reduction of the impact on the occupants of the renovation process, by simplifying the construction site management and the implementation of the renovation packages. Moreover, an active involvement of the users is strategic for a successful intervention and for exploiting the energy saving potential after the renovation. Therefore, a building data handler (elaborated by IES) will be coupled to the monitoring system, in order to provide the users with real data and benchmarks on the building operation. This is a key issue needed to overcome the lack of trust in innovative technologies, that is still an influencing barrier.

P2ENDURE supports the involvement of local communities in the renovation process via an e-Marketplace, which will be set-up to be deployed on the existing e-Marketplace platforms operational within the EeB PPP programme and the research projects therein. The P2ENDURE e-Marketplace will facilitate the establishment of local factories for district-scale deep renovations by providing the local construction players with guidelines and franchise business models [27]. The aim is to provide construction players and potential clients with information to quickly understand how to implement / replicate a similar 4M based process on their projects and in the same time, to raise their awareness and trust in new technologies and deep renovation measures.

4. Open questions and future guidelines

What clearly emerges from this interactive workshop, finding the "composition" of the receipt of a successful deep renovation is a challenging task. Still at the current stage, several

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matters remain unresolved, that must be addressed by future initiatives and interdisciplinary projects:

- What ideas will encourage the owners to undergo a deep renovation process? Education/awareness programs are useful but not enough nor quick to implement... Other ideas?
- What trigger points will encourage inhabitants to take action beyond climate change?
- How to identify *early adopters*, i.e. the most prepared users, condominium, housing company to foster the innovation spill-over effect?
- To what extent can the existing technical solutions and current inhabitants' motivations respond to the need for a more resilient built environment (energy and/or seismic)?
- Are national/local political schemes needed to speed up deep renovation? If yes, what key issues should they include?
- What channels to reach out to demand-side and supply-side users for deep renovation technologies?
- What lessons have we learned that can contribute to transforming our findings into a successful commercial product?
- Do plug and play solutions actually work for deep renovation practices at the large scale? How much flexibility/freedom is needed/should be provided to end-users to ensure performance and effectiveness of interventions?
- What needs (of the different actors) in the deep renovation process are not covered yet?
- Do the trigger points change a lot among countries? Which ones are common?
- Which is the best way to involve the user? At which moment?
- How can we manage that users perceive the direct and indirect benefits of a deep renovation?
- Do you think it is needed a facilitator and an integrator? How do you imagine their roles?
- How can we distribute individual and collective benefits?
- Are an engaged team (including users) and technical solutions enough? To which extent do we need policy and financial support?

With these open questions still in mind, this article has been envisioned with the purpose of providing interdisciplinary knowledge-based guidelines for future EU-relevant projects, to fill in the gaps of untapped potential for deep energy renovation in the EU building stock. 10 final conclusive remarks are listed in the followings:

1. In general, deep energy renovation needs a participative approach with early involvement of the user. This means a higher cost in terms of integrated design and analyses dealing with social aspects, which are time-consuming. These costs need to be foreseen taking into account the starting situation. This means that a community already mature in terms of environmental motivations and social cooperation will be easier to integrate into the process, thus less costly in terms of investment costs.
2. Innovative technologies may cause reluctance from users. Additional communication effort is needed to build trust within residents and communities.
3. In terms of life-cycle cost, a higher investment in communication and social activities aimed at building trust and engaging the users may have a positive impact in both the designing and operation phase, because of fewer conflicts, blocking points and unexpected changes.

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4. Interest to shift from cost-optimal technologies to cost-optimal processes, including non-technological costs that may influence positively or negatively the adoption of innovative renovation technologies.
5. The point of renovating while keeping the users inside their homes seems interesting, but it has appeared to be conflicting in many cases (noise, disturbances) even for short renovation periods. The business plan of the renovation needs to consider the cost of relocating people, since it can have a huge impact according to the site location and residence availability.
6. Socially related costs in terms of initial investment in enhanced communication and similar are often taken in charge by research projects or by internal commercial/R&D budgets, because of promoting new markets or because of social interest. However, it may be considered a wider general need, instead of counting on specific punctual programs.
7. Aggregation of demand is a good strategy for both reducing investment and social costs.
8. Taking into consideration the initial motivations of owners and tenants as regards environmental, energy and safety issues represents a positive driver.
9. To include, in the renovation business plan, the costs needed to overcome social barriers such as lack of trust, lack of energy culture, lack of future vision. These costs may include training sessions, participative strategies, integrated design and many on-site visits to build a confident relationship between inhabitants and key stakeholders. These actions may need more or less effort depending on the initial situation and may need multi-disciplinary teams dealing with technical and social aspects at the same time.
10. A design approach in which the energy calculation is just one isolated step of the decision making process is no longer suitable in the concept of nZEB renovation. Energy and cost optimality calculations must be used in parallel with the definition of the technical solutions, already in the early stage of design.

5. Conclusive remarks

This paper intended to position a collection of knowledge to drive new effective methodologies and practices in order to overcome actual barriers and challenges.

To conclude, the need for a major renovation in EU is evident, but current innovation efforts to renovate the European building stock to the nZEB target have raised many new challenges. Somewhat surprisingly, the highlighted challenges were not so much related to the specific technical problems but more to the overall understanding of the concept of nZEB and managing the design process in order to guarantee that the result is an nZEB building, including social and financial aspects respectively. In general, building owners seem to be in favor of the nZEB concept, but nZEB renovation should not mean excessive investment costs. Therefore, designers have a new challenge to devise nZEB renovation in such way that it is not significantly more expensive than standard major renovation. Our experience revealed that designers have not yet fully understood the whole concept of nZEB buildings and have some difficulties managing the deep renovation process in parallel with the energy calculations and cost optimality calculations.

This paper aimed to highlight to which extent have the efforts and achievements of various H2020 projects resolved the “barriers to EE renovation” as pointed out by the EU. In this perspective, this paper is not only about the technological, financial and social barriers within

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the different research projects, but more importantly, it addresses the barriers of renovation in the EU at large.

Going forward, more work will be necessary to uncover to which extent have currently running EU projects, incentives and policies been able to resolve the most prominent barriers hindering large scale replication of deep renovation practices in the different EU countries. Forthcoming application of the knowledge gathered in this paper is envisioned to increase the capacity of public authorities at regional/municipal level to collect the necessary data to prepare realistic renovation strategies for both public building and private sector, as well as to analyse and identify cost-effective approaches to guide investment decisions and facilitate private and public sector investments.

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