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Technical, Financial, and 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 an insufficient rate of existing building renovation, there is the need to step up the pace of building renovation with ambitious performance targets to achieve European Union (EU) climate change policies for 2050. However, innovative technologies, including, but not limiting to, plug and play (PnP) prefabricated facades, information and communications technology (ICT)-support for building management systems (BMS), the integration of renewable energy systems (RES), building information model (BIM) and building performance simulation models (BPSM), advanced heating, ventilation, and air conditioning (HVAC), advanced geomatics, 3D-printing, and smart connectors, cannot alone solve the problem of low renovation rates of existing buildings in Europe that is hindering reaching of EU-wide targets. A workshop was held at the Sustainable Place Conference 2018 to present, with an integrative approach, the experiences from four H2020 innovation actions, i.e., 4RinEU, P2ENDURE, Pro-GET-OnE, and MORE-CONNECT, which were united by their central aims of improving building energy performance through deep renovation practices. This article presents the outcomes of the joint workshop and interactive discussion, by focusing on technical, financial, and social added values, barriers and challenges, in the context of the building renovation processes tackled by the four projects. Conclusive remarks converge on the identification of open questions to address future innovation opportunities, as well as some recommendations to be used at a policy level and/or in future implementation projects.

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

1. Introduction

Europe aims at bringing about drastic greenhouse gas emission reductions in the building sector, i.e., 80% [1] compared to 1990 by 2050. However, a major portion of European buildings (built from 1960–1970) present poor thermal insulation of the opaque and transparent building envelope, poor indoor environmental quality, poor performance in terms of seismic and structural safety, and low system efficiency and renewable energy systems integration [2]. In fact, it is widely acknowledged that building renovation is driven by local needs that go beyond the desire to reduce energy consumption, as in cases of renovation works that coincide with structural repairs [3].

Yet, despite EU energy-efficiency nZEB targets [3], and although the improvement of building quality due to renovation has been demonstrated by several EU initiatives [4] (i.e., aesthetic enhancement of the building exterior façade, system components energy savings, increased thermal comfort, 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 processes, with an insufficient renovation rate of 1% for existing buildings [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, the installation of photovoltaic panels, installation of heat recovery and efficient HVAC systems, etc. Conventional state-of-the-art energy retrofits focus 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 mostly effectual in their anticipated goals, and are simple and fast to deploy; however, they often miss the opportunity for saving more energy in a cost-effective manner. Furthermore, traditional renovation techniques require extensive labor to be done on site and must assume larger risks due to human errors and damages from exposure to different conditions (outdoor forces, weather conditions, etc.) [4].

Until now, deep renovation has often been approached as a technological challenge; therefore, many research and innovation projects are developing new construction techniques, or have already done so. However, social and financial barriers have been overlooked, and specific attention is also needed on these questions in order to unlock the market. Some initiatives are already in place [5], and some specific measures can favor the market; yet, they are usually not integrated approaches, nor replicated schemes.

As regards financial support, there is a clear lack of options to motivate long-term investment in the residential market. Concerning social aspects, traditional renovation approaches do not usually take into account individual needs or expectations from users using a participative way. Instead, regulations and common methodologies are applied. New approaches will probably need to integrate technical, financial, and social aspects from the beginning to take into account the specificities of each situation, making use of creativity.

1.1. Deep Renovation

The Energy Efficiency Directive 2012/27/EU [4] introduced the concept of deep renovation as a "refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels, leading to a very high energy performance". Implementing a deep energy renovation means adopting an integrative approach at the whole building level, allowing for a more cost-effective process and for a higher energy savings in comparison to the adoption of separate energy retrofit measures [4,5]. Although the EU Directives [6,7] do not provide a quantitative definition of a deep renovation, it is possible to link the concept to the major renovation, introduced by the EPBD 2010/31/EU [7], as a set of interventions fulfilling one of the following conditions:

(1) either more than 25% of the surface of the building envelope undergoes renovation
(2) or 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].

The EED does not provide a quantitative energy saving target for deep renovation, but has stated that it represents a solution which is able to reduce both the delivered and final energy consumption of a building by a significant percentage compared with pre-renovation levels [8]. On the other hand, the European Commission promotes several funding programs (e.g., Horizon 2020, Life, etc.)

aimed at finding effective solutions for deep renovation, and has set, as a reference value, a minimum primary energy saving objective of 60% compared to pre-renovation [8]. This background opens a new, dedicated research topic for the definition and analysis of deep renovation packages.

There are several works dealing with the evaluation of the energy and economic performance of deep renovation that identify common cost-benefit benchmarks [9–11] or that compare different scenarios and provide optimization approaches [12]. Compared to traditional solutions, the adoption of prefabrication systems for deep renovations has several advantages. These advantages include achievements on energy efficiency and comfort of existing apartments which are comparable to new, advanced low energy buildings (i.e., 30–50 kWh/m^2 year), optimized high quality and low cost constructions, presenting an opportunity to create new, attractive living spaces.

Fabrication in a factory has been demonstrated to be more accurate, faster, and more secure than fabrication on site. In the MORE-CONNECT project, prefabricated modules are produced with high precision for about 1 mm accuracy. We estimated that pre-fabrication in a factory can bring about shortened construction time by, on average, 18% compared to state-of-the-art deep renovation practices (Table 1). The reduction has been calculated through a comparison with current industrialized construction practices in the residential sector, including the impact of off-site manufacturing and on-site assembly on the overall time required for new buildings and deep retrofitting.

Table 1. Estimation of reduced construction time of pre-fabricated solution compared to state-of-the-art deep renovation practices.

	Time (h/sqm)			**Construction Time (days)**			
	Off-Site Manufacturing	**On-Site Assembly**	**Total Assembly**	**Off-Site Manufacturing**	**On-Site Assembly**	**Total Construction**	
				DEEP RETROFIT			
Traditional Glass Facade system	0	0.6	0.60	0	15	15	
Plug and Play Transparent Module	0.06	0.09	0.15	2	2	4	
						−25%	
Traditional prefabricated facade panel	0.05	0.05	0.10	31	31	63	−18%
Plug and Play solution	0.05	0.04	0.09	31	25	56	
						−11%	

Furthermore, pre-fabrication brings direct advancements [13] including:

- Fewer builders needed on site: Installation time is 1 prefabricated module element (20 m^2) per hour (with 3 installation crew member employed on site);
- Faster lead time: the total installation time will be cut to 1 day for the deep retrofit of the façade of the demo building (200 m^2) and maximum 31 days for the intervention of an entire apartment block;
- Use of BIM in the construction process that will reduce errors and clashes;
- Use of Plug&Play HVAC and ICTs integrated in the prefabricated modules.

It is important to define the tolerance in the design phase and the accurate mounting of the modules [14]. Quality control of components is performed in the factory, where the use of standard products (for dimensions and shapes) minimizes design and production process faults (i.e., thanks to optimized automated production line). Prefabrication technologies require additional planning efforts and accurate measuring, but the construction process has proven itself to be efficient [14]. In recent years, the production of spatial modules with a high level of prefabrication is getting more and more extended. Rationality and precision determine the manufacturing process. Standardized, optimized, and monitored processes from the inventory management to production allow for a high standard of quality [15].

One of the big advantages of prefabrication is the rational production of these components based on a controlled workflow from the design process to the execution. Building materials are used more efficiently and less waste is produced. Machines and controlled conditions during the production phase increase the precision and rationality of production. Production quality standards secure an accurate execution and ensure the result of the product [16]. Additionally, using a high level of prefabrication can decrease assembly risks on site (most of the work is undertaken in the factory), and it reduces the renovation process to the assemblage time of the prefab components on site, which creates a fast renewal process with minimal intrusiveness and disturbance for the inhabitants.

Despite these evident advantages, a general distrust and reluctance of the traditional building industry in adapting prefabricated solutions are observed in common practice. 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 a promising technological solution.

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

1.2. State-of-the-art Deep Renovation Solutions in EU Funded Projects

In the context of the H2020 project ProGETone [4,17], 31 EU-relevant (FP7, H2020) funded projects (2008–2020) have been revised (Figure 1). As a general criterion for project 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 used during the design, execution, and maintenance phases of the retrofit process (see details in Table 2).

The analysis was intended to deliver insights on the advanced integrated design method, including production, monitoring, control, and operation of smart components and systems (Table 3). Since one of the main barriers to adopting deep retrofit measures is 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.

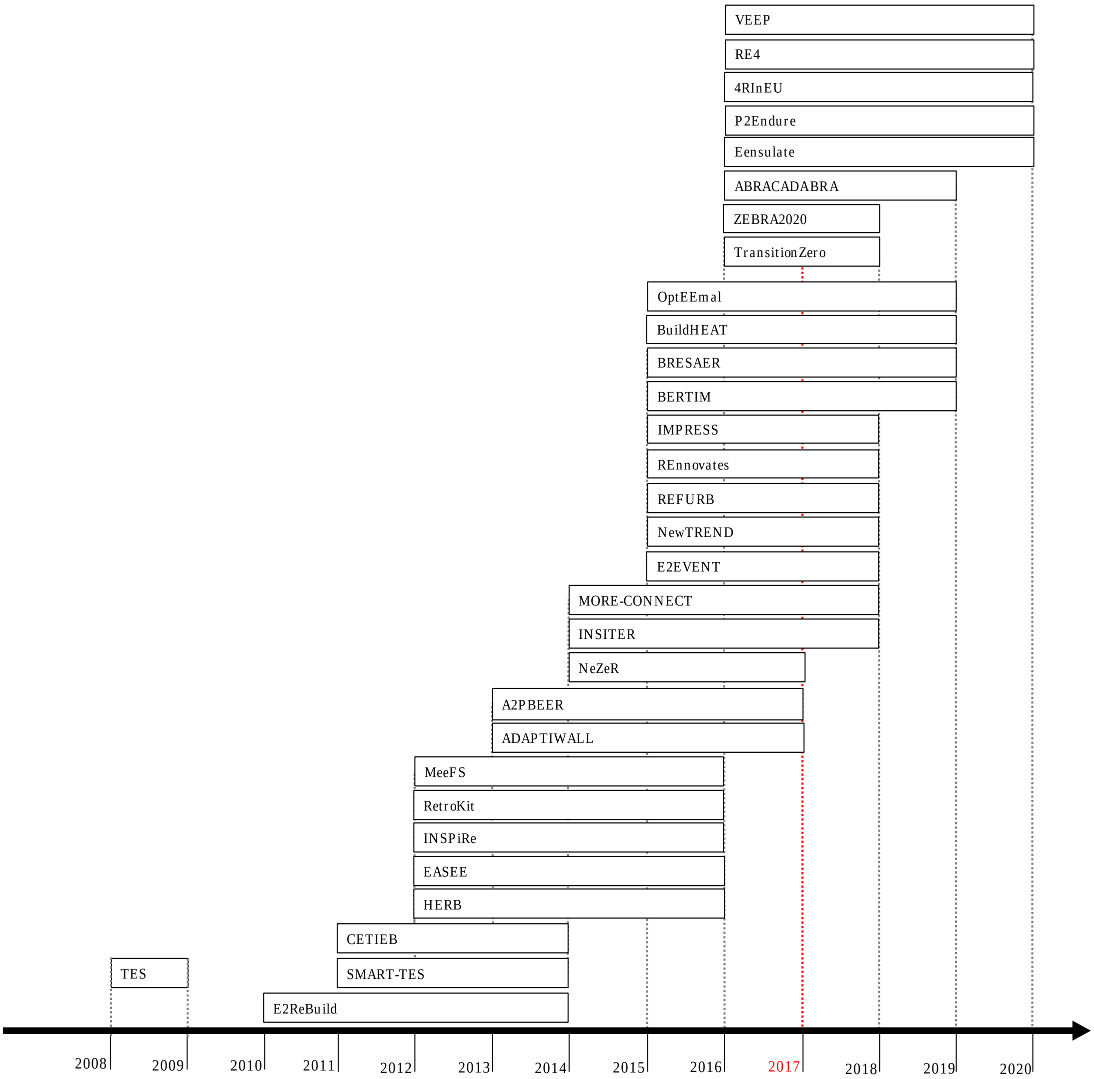

Figure 1. List of 31 reviewed EU-funded projects that deal with state-of-the-art deep renovations [3].

Table 2. 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.

Table 2. *Cont.*

Funding Scheme	Type of Action	Project Name	Solutions
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/	Standardized 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 modeling 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-connect.eu/	Prefabricated, multifunctional renovation elements for the total building envelope (façade and roof) and installation/building services.
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

Table 2. *Cont.*

Funding Scheme	Type of Action	Project Name	Solutions
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.

Table 3. 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 systems 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. Building Information Modeling (BIM) and the exchange information with building performance simulation models (BPSM) emerged significant enabling technologies in state-of-the-art solutions for deep retrofits towards nZEB, oftentimes in combination with advanced geomatics (3D scanning), as for the cases of BERTIM, EASEE, MORE-CONNECT, NewTREND, REnnovates, and OptEEmal projects, and 3D printing techniques (MORE-CONNECT, P2ENDURE, IMPRESS, and 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 in the cases 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-benefit 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 illustrated by 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 closer to 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 and 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.

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 retrofits at the EU level.

1.3. Main Barriers Encountered in EU Deep Renovation Projects

In recent years, numerous EU projects have tackled the main barriers of deep-renovation through the search for innovative technological solutions to overcome the obstacles present in the market of energy requalification. We classify the main barriers that have been found in the deep renovation processes as the following macro-groups [18]:

- Technical barriers;
- Financial barriers;
- Social barriers.

Key technical barriers include: (i) A lack of consistent and standardized solutions or integrated solutions to comply with new and different building standards requirements on energy saving; (ii) Lack of skilled workers to carry out the work; (iii) Shortcomings in technical solutions, and long processes discouraging owners; (iv) Safety/seismic risk connected with the deep renovation processes (damages can be done to the homes while retrofitting or unsure perception of the current safety of the existing buildings); (v) End users' and owners' lack of technical expertise and trust in effective energy renovation savings.

As for the financial barriers, they are essentially due to (vi): (i) high up-front costs and owners reluctant to borrow funds for energy renovation purposes; (ii) Long pay-back times of retrofitting interventions; (iii) Lack of confidence of the potential investors; (iv) Insufficient and instable available funding; (v) Lack of attractive financing for homeowners with low to medium incomes who are usually not eligible for regular bank loans; and (vi) The fact that existing financial tools are insufficient and unattractive.

Finally the main social barriers include: (i) Decision-making processes that are long and complex, especially in cases of multi-owner houses (condominiums); (ii) The lack of consensus, understanding, and support from the inhabitants that often hinder the effective approval of the interventions; (iii) The problem of disturbance during site works and/or relocation (in case owners/users need to leave their homes during the process); (iv) Low awareness about energy efficiency and non-energy benefits of renovation; and (v) Lack of dialogue between the different stakeholders.

As a consequence, there is a strong need to create a demand both from the market and the final users to strengthen investors' confidence and accelerate the market of deep renovation.

1.3.1. Review of Technical Challenges

The technical feasibility of deep renovation measures is of great importance for the achievement of proven-quality results [19]. Yet, the purpose of many reviews on technical challenges is to assess what is feasible or technically suitable in specific cases [13]. Several works in the recent literature have focused on the investigation of technological solutions for deep renovation [20,21]. In particular, the focus is usually on integrated packages aimed at improving performance while reducing the time and complexity of the interventions, combining a set of renovation measures for the envelope and the HVAC system [22]. These include e.g., the integration of energy efficient envelopes with improved insulation, high airtightness, solar control, moisture management, controlled ventilation and equipment, HVAC systems with heat recovery ventilation sized and integrated within the opaque envelope and walls, and active energy components incorporating RES [23].

1.3.2. Review of Financial Challenges

Financial aspect are among the highest barriers for owners and co-owners when it comes to renovations [24–26]. Payback and up-front costs are crucial in this context.

Return of investment. The time taken for the initial outlay to be recouped is one of the major barriers [27]. Users and owners are not likely to consider investments that do not pay for themselves within 3–7 years. Therefore, the profitability of renovation in terms of building life cycle costs and long-term maintenance costs that can be avoided, thanks to energy efficiency deep retrofitting, should be evident. The initial investment costs can be high, and this is seen as an obstacle to consumer investment decisions. The most ambitious retrofits will undoubtedly require considerable upfront funding.

Funding schemes. Lack of funding opportunities and/or inability to secure finance on acceptable terms is generally one of the most cited barriers to investing in energy efficiency measures [28]. This applies at all the levels of ownership (from the level of the individual householder to the small landlords, to the case of fragmented ownership in condominiums and, finally, in the renting market, i.e., tenants).

With the reduction of public spending, funding opportunities became scarce, and the uncertainty and volatility of the schemes proposed increases. Policy-makers at the European level are increasingly encouraging the reduction of grants, and instead promoting revolving financial support that combine public and private resources, including the procedure of the Public Private Partnership (PPP) for large redevelopment. Yet, grants remain a significant argument to incentivize users and owners to renovate [18].

1.3.3. Review of Social Challenges

In the context of innovative deep renovation practices, it is more urgent to understand what is relevant when it comes to technological aspects for *end users*, including how property owners perceive technological changes and how they assess their benefits and potential disadvantages [29,30]. Some of the revised social challenges are listed as follow.

Lack of education and confidence in construction professionals. Latent mistrust toward professionals, the lack of properly trained energy efficiency professionals—in particular in local areas—or, on the contrary, the overwhelming number of offers can weigh heavily in the balance when it comes to the final decision to renovate or not. Individual homeowners and users do not know where and how to find reliable experts and professionals and ask for advice and assistance. Taking such an important decision as a deep renovation is, for many, the second most important investment—after buying their home—that they will undertake in their lifetime. As a consequence, they demand some guarantees that the work will be done appropriately, and that the given advice is neutral and does not favor particular technologies or services. They are looking for long-lasting solutions that will be both economically and practically viable.

Consumer acceptance of new technologies and innovative renovation solutions. Users and owners often feel distrust towards new technologies. This phenomenon, that can also be referred to as 'consumer acceptance', has been widely documented [31]. It corresponds to behavioral aspects towards available technological solutions and the possibility of purchasing and using new products. It is mainly due to a lack of knowledge about issues and technologies, the perception, feelings, and interpretation of information, and finally, the fear, i.e., worry, risk, and inconvenience that people may feel regarding new energy technologies. Training and awareness-raising activities are key elements for the acceptance of innovation; they are the first crucial step to providing knowledge on the importance of improving buildings' energy efficiency through the application of the respective innovative technologies.

Lack of knowledge of available solutions and customizability. The lack of knowledge about available solutions is a major obstacle. This is particularly relevant for energy efficiency solutions [29,30,32].

Disruption factor. The disruption factor is also fundamental and needs to be assessed, especially in cases of deep renovations. It refers to all the troubles linked to refurbishment work for the occupant, which might impact on the decision to renovate. This aspect is confirmed by extensive literature and research that has pointed out that one of the main barriers to retrofitting is the disruption caused to users [33,34]. Favoring 'Plug-and-play' type solutions that limit the intervention on site should help to overcome occupants' reluctance to face renovation work. Major dissatisfaction can be avoided if the owners (occupant and landlord) have been sufficiently informed of the renovation plan and the possible disruption [13].

Decision-making in condominiums. A significant part of the existing building stock in many Member States is composed of multi-apartment buildings, often with multiple owners, and decision-making rules on necessary majorities can be complex. Making a decision for energy retrofits in condominiums requires a majority in some countries, while in others, the consensus of owners should exceed 75% according to the national condominium laws, and can even require unanimity [35]. Another aspect influencing consensus building is a potential uneven distribution of benefits and costs of an energy retrofit to the individual apartments [31]. Making easily-understandable information from the start of the renovation process could facilitate the complex decision-making process and consensus building in condominiums. The provided information should focus on the benefits in terms of energy efficiency, housing quality, and indoor conditions, but should also specifically address condominium concerns relating to individual owners' rights.

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 further step would be to create a living community beyond the project's extinction, to contribute to the development of the market of deep renovation, while keeping an independent view of 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 centers, and provides them with the chance to experience and discuss example projects that embody such 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 27th and 28th June, 2018, INES Research & Development premises in Aix Les Bains (France) hosted the Sustainable Places Conference. 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 on by the workshop participants; and finally (3) to consolidate a European-centered 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, as identified within the clustered projects, in order to further identify untapped open questions to address future innovation opportunities.

This paper classifies values and barriers for deep renovations among the four Clustered Projects, taking into account the critical parameters and conflicting requirements and possible mutual solutions to achieve energy and safe buildings within a socially-acceptable environment and with 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 have an important impact on the development of future solutions.

3.1. Technical Aspects

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

In particular, several studies [17,21,36] have pointed out that there is an embedded cost of failures during the construction on a traditional building site; this has been estimated an impact of around 20% of the global construction cost. The cost of failures is related to human error (54% of failures), material defects (12%), and errors during construction (34%).

A prefabricated approach addresses this problem, since it can:

(i) decrease the assembly risks on site and the impact of human error, since most of the work is done 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
(iii) minimize the design and production process faults thanks to standard products (dimensions and shape) and optimized, automated production.

Moreover, prefabricated renovation will reduce the number and duration of construction and assembly processes on-site, with consequent reduced 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 reduce by 52% the construction site duration by applying a multifunctional prefabricated façade integrating a 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 renovation solutions, and to verify the expected building performance in terms of energy, environmental impact, Indoor Environmental Quality (IEQ), and 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 significantly reduce disturbance on-site 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 include step-by-step, building-by-building energy retrofitting. This building retrofitting process is indeed labor-intensive and lengthy—it usually takes several weeks or even months to replace old windows, install new thermal insulation layers on the external walls and roofs of buildings, and renew the heat distribution systems or attach renewable energy sources to 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 existing drawbacks of a prefabricated renovation approach.

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

One of the key results of the project 4RinEU [37,38] 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 plug-and-play installation of 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 input also for the best integration on the façade systems. The project takes into account 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, and 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.

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 the installation, but the more difficult and expensive the transportation.

Table 4. Key technical added values and barriers emerged from the 4 Cluster Projects.

	Values	Barriers
4RinEU	• Prefabricated renovation of the envelope without scaffolding—significant time reduction	• Prefabrication does not suit all the buildings: technical constraints (nodes, balconies)
	• Integration of functions and elements in the façade (ventilation, ducts, RES)	• Speed mounting vs. dimension of the elements
	• Optimization tool for Early Design and RES integration	• Integration of components allows to speed-up the process but is a complex problem
	• Plug&Play energy hub for controlling the heating and cooling fluxes within the HVAC system	• The accurate design would need detailed inputs—lack of information on the energy profiles
	• Replicability potential based on shared technical specifications	
ProGETonE	• Deep renovation driven by seismic reinforcement and space extension	• Integration of different solutions
	• The increase of the real estate value of the original building • Aesthetic improvements • Increased comfort	• 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 [39] • Easy to install Plug-and-Play (PnP) innovative prefab solutions for retrofit of building envelopes and MEP systems [40] • 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) [41] • BIM-based energy analyses of different renovation strategies [39] • BIM Parametric Modeller and e-Marketplace for local renovation factory to display information on costs and energy performance of different renovation strategies [42]	• 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

Table 4. *Cont.*

	Values	Barriers
MORE-CONNECT	• Smart connectors: air, hydraulic, mechanical, and ICT	• Sizing of prefab elements needs attention.
	• New advanced geomatics technologies applied and tested in demos	• Elements are still too big and too heavy: miniaturization of elements is needed
	• Role of innovative industrial partners i.e., 3D printed facades etc.	• Gauging in practice
	• Scaffold less renovation demonstrated as an effective technology	• HVAC platforms still need a redesign and miniaturizing
	• New BIM controlled automated production lines	• Point cloud to BIM is the main technical barrier: the process is still too complicated
	• Morphological design procedures	

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 [39]. During Mapping, an As-Built BIM derived from '3D scan to BIM' is created to combine the necessary building information and improve communication between the different actors. During Modeling, 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 [40]. There are still certain limitations in all the 4Ms; for example in Mapping, there is no fully-automated procedure 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, 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 installation, reducing the total renovation time from 5 to 2 days. Process innovation includes a fully-automated production 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 [13].

The MORE-CONNECT project has developed a system of prefabricated retrofitting modules that makes it possible to cut primary energy consumption of a typical residential building by 80%, reduces on-site installation time to below two weeks, and improves the indoor environment for the tenants [43]. Indoor climate and energy calculations were made based on national energy calculation methodologies in six countries: Denmark, Estonia. Latvia, Czech Republic, Portugal, and The Netherlands. Requirements for heat loss of building envelope vary depending on the requirements for indoor climate and energy performance in the specific country, outdoor climate, availability of renewable energy, and building typology [44]. Furthermore, results show that simple thermal insulation of building insulation can ensure a 50% reduction of building heat consumption, while practical measurements have shown a significant increase of indoor air relative humidity and CO_2 concretion levels [45].

Going forward, MORE-CONNECT focused on significant improvements of pre-production and production processes of the developed solutions to advance the overall production efficiency and reduce production costs [46]. The main tools to achieve this goal include automated 3D scanning of buildings, fully digitalized pre-production process, and IT-supported of the creation of data describing the automated fabrication of the modules. At the same moment, the project implemented 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 [47].

The growing attention to improving the building's thermal performance has initiated an increasing demand for innovative remodeling solutions for existing houses. This modeling problem is being studied in MORE-CONNECT through innovation in industrialized building renovation to reduce energy consumption. Advancements in contemporary 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 Modeling (BIM) concept with its parametric modeling capabilities makes it possible to assess the outcomes of the results of preliminary building energy performance analysis, and later, coordinate these complex and time-consuming processes more easily, rapidly and cheaply [48]. 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 models from laser-scanned data that captures the building's external envelope with its main openings. The research in MORE-CONNECT focused on the capture of building 3D data in a BIM compatible format, which may be later used for both an energy analysis and a structural design of insulation systems. 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 [48].

Despite these evident advantages, there is a general reluctance of the traditional building industry to convert renovation into an industrialized process, where building components are prepared and combined in a production line within the factory. This lack of trust has an impact on 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 among the designers of innovative deep renovation methodologies, including the adoption of prefabricated systems, is hindering the wider market adoption of such a 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 that of traditional renovation; since the main driver for the user is money, the high investment cost represents one of the most significant barriers.

3.2. Financial Aspects

Most of 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 cost savings. However, the building sector is currently not able to offer an integrated solution for deep renovation toward nearly Zero Energy Building (nZEB) at a reasonable price [23]. Deep retrofits are often associated to the concept of "cost-effectiveness" [49,50], 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 [51];

this fact, alongside fuel poverty cases [52], makes it difficult to pay back the interventions in energy savings terms.

Table 5 illustrates in details the key financial added values and barriers for deep renovation which emerged from the 4 Cluster Projects.

Table 5. Key financial added values and barriers 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	• Investment for the renovation are still high for common users—mass production would be needed to reduce costs of prefabrication
	• 4RinEU energy audit and Early RENo reduce the uncertainties in terms of performances (circular knowledge transfer)	• Multi-functional façades have a complex maintenance management (general contractor and agreements are needed)
	• Prefabricated façade systems allow increasing the building lifespan	
ProGETonE	• The increase of the real estate value	• Lack of investment
	• The increase of the expected lifetime of the buildings	• 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]	• 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
	• Enhancement of the product value chain through the e-Marketplace financial mechanism	
MORE-CONNECT	• Prefab renovation solutions should be able to offer significant cost reduction	• Cost reduction still not achieved because of lack of scale (solutions are one-off test products, 2.0 version in development)
	• Significant cost reduction is expected if Pointclouds2BIm is achieved	• Although roadmap to pointclouds2BIM and steps to make are developed within M-C no one is able or willing to do this

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 cause the actual behavior to deviate from the predicted one, thereby reducing the risks of the overall process. 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 is still uncompetitive in comparison to traditional techniques; thus, shifting to 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 are integrated into a complex system; thus, more detailed evaluations on site and agreement among producers are needed to provide 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 [53]. 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 more rapidly, and the operational expenses after performing deep renovation are significantly lower in the 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 as a result, overcome the barriers related to high costs of innovative technology, lack of awareness of the costs of energy-efficiency measures, and the benefits of deep renovation, including possible ROI [54].

MORE-CONNECT explored concepts for large-scale retrofit of housing with prefab panels, and analyzed 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 conclusions is that the cost-optimal deep renovations can only be found by 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 for the importance of embodied energy, and the wider use as a general proxy for low energy/low CO_2 strategies, as an alternative for more broad sustainability assessments [55].

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 [23]. The adjustments of the solution for a particular European 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 cost [19].

The aim of MORE-CONNECT is to create a competitive solution consisting of a technology and a series of processes which enable fast, cost-effective renovation with minimal difficulties to inhabitants. Significant savings in renovation costs lie in the usage of prefabricated elements and the reduction of construction works on site. The precision of the prefabricated element depends on the precision of the construction, and 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 [55].

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 6).

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 have an important impact on the development of future solutions. Table 6 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 worth reporting here:

- There is the need for a multiple solution approach 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.

Table 6. Key social added values and barriers emerged from the 4 Cluster Projects.

	Values	Barriers
4RinEU	• Less disturbance of the inhabitants due to reduced time and complexity of the building site	• Lack of trust in innovative technologies (and in general in renovation and changes)
	• User information about the building operation	
	• Feasibility studies from early adopters	
ProGETonE	• Shorter time and less disturbance	• Lack of awareness and trust in new technologies
	• User-oriented design (space and comfort increase alongside safety improvement)	• Lack of awareness of seismic risk and in energy transition needs
	• Safer and climate-respectful buildings	• Lack of communication channels and resources
	• Higher IEQ	• Short-term oriented vision by both inhabitants and most of technical professionals
	• Focus on user's willingness to pay	• Lack of supporting funds
		• The mismatch between collective and individual needs
P2endure	• Shorter time of renovation and less disturbance on-site during renovation	• 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
	• Improved IEQ	
	• Involvement of local communities through local renovation factory and e-Marketplace	
MORE-CONNECT	• Short time renovation and less disturbance is possible (proven in 'Energiesprong' already)	• Cost break down is: Prefab envelope: 1/3; Building services and PV: 1/3; Finishing, small works, failure costs: 1/3
	• New VR technologies to show occupants 'what they get' and 'making own configurations'	• Earnings/earning model of traditional companies is often in extra work and failure costs
	• Integrated tools to assess energy, embodied energy and 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 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 which is required 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 [54]. The aim is to provide construction players and potential clients with information to quickly understand how to implement/replicate a similar 4M-based process in their projects, and at the same time, to raise awareness and trust in new technologies and deep renovation measures.

In the framework of the ProGETonE project [17], the main findings related to social aspects pointing out the difficulty of scaling 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, culture, climate, etc.). For this reason, there is a need to start identifying specific problems/needs/possibilities/types of users first, and to treat each in a case per case manner, 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 to make training workshops or similar on seismic safety, energy efficiency, space extension, and aesthetical improvements with the occupants of the buildings to be renovated. In particular, the space addition and the aesthetic improvements are also essential to emphasize how seismic safety, which is not as "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, the need to create trust among the community, as regards the renovation process, has been discussed.

In a more general context, it can be stated that renovation projects are complex to carry out because of the 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 social climate at the site.
- The renovation should imply more building value and improved aesthetics.
- It is important to explain and emphasize the benefits to 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 more readily in deep renovation processes.
- Leadership inside the concerned community may inspire others, so an already trained and trusty person can reduce some resistance.
- Increase in rent is not well perceived, especially when vulnerable homes are concerned.

4. Open Questions and Future Guidelines

It clearly emerges from this interactive workshop that finding the "composition" of the receipt of a successful deep renovation is a challenging task.

Still, at the current stage, several matters remain unresolved that must be addressed by future initiatives and interdisciplinary projects.

On technical aspects:

- 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)?
- What channels to reach out to demand-side and supply-side users for deep renovation technologies?
- Do plug and play solutions actually work for deep renovation practices at the large scale?
- Are an engaged team (including users) and technical solutions enough?

On financial aspects:

- To which extent do we need policy and financial support to support penetration of deep renovation practices in the EU market?
- Are national/local political and financial schemes needed to speed up deep renovation? If so, what key issues should they include?
- What type of financial instrument will be most effective to encourage the owners to undergo a deep renovation process?
- What lessons have we learned from previous H2020 projects that can contribute to transforming theoretical findings into successful commercial products for the wider EU market upscale?

On social aspects:

- Education/awareness programs are useful, but not enough alone, nor quick to implement.
- 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?
- 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/drivers for renovation change a lot among countries? Which ones are common?
- Which is the best way to engage the building occupants? At which stage of the deep renovation?
- How can we manage that users perceive the direct and indirect benefits of a deep renovation?
- Is a facilitator or brokerage service between stakeholders involved in the renovation process needed?

With these open questions in mind, this article was 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. Therefore, 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.
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. Concluding Remarks

Although the need of renovation in the EU is evident, the implementation of deep renovation measures in the EU building stock is still reduced. This paper aims to provide a general overview on building deep renovation across Europe, identifying values and barriers through the experience of European Innovation Action projects.

As a starting point, the paper introduces the deep renovation as defined by the EU Commission and in literature, and provides a comprehensive list of the EU funded projects on the topic, identifying the main results, approaches and technological developments. To complete the overview, it presents the experience of four projects within H2020 innovation actions—4RinEU, P2ENDURE, Pro-GET-OnE, MORE-CONNECT/as collected during the cluster workshop within the Sustainable Places Conference 2018. The description of the technical, financial, and social aspects is strategic for describing the base knowledge to drive new effective methodologies and foster deep renovation overcoming the main barriers identified by the EU.

The experience gained through the implementation of the four projects highlights many new challenges for future developments and research activity. In particular, the main barriers are not related to specific technical problems, but deal with the deep renovation and nZEB knowledge, for both the building owners (i.e., awareness and commitment) and for the designers (i.e., managing properly the design process in order to guarantee the expected performances and targets). In general, building owners seem to be in favor of deep renovation towards nZEB, but they are not motivated by the excessive investment costs. Therefore, designers and technology providers have a new challenge to devise nZEB deep renovation in such a way that it is not significantly more expensive than standard major renovation.

Going forward, more work will be necessary to determining the extent to which currently running EU projects, incentives, and policies have 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 the regional/municipal level to collect the necessary data to prepare realistic renovation strategies for both the public building and private sectors, as well as to analyze and identify cost-effective approaches to guide investment decisions and facilitate private and public sector investments.

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