The ePopzeb project: an innovative prototype of an NZEB construction system with a smart monitoring IoT platform

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Abstract

In Europe the building sector is responsible for nearly 40% of the total energy consumption, and more than 75% of the building stock is inefficient in light of current standards. The EU and the Member States have targeted existing and new buildings through various policy instruments, from normative through informational and to market-based policies, building codes and appliance standards have had profound market transformational effects across the EU. In this paper the state of the art of the EU building sector is presented and the main results of a 2 years R&D project implemented in Italy are illustrated.

Keywords: Building Renovation and Regeneration, Decarbonization of buildings, Near Zero Emission Buildings, Smart building technologies IoT Platform

1. INTRODUCTION

Energy-related CO2 emissions from buildings have risen in recent years after flattening between 2013 and 2016. Direct and indirect emissions from electricity and commercial heat used in buildings rose to 10 GtCO2 in 2019, the highest level ever recorded. Several factors have contributed to this rise, including growing energy demand for heating and cooling with rising air-conditioner ownership and extreme weather events. Enormous emissions reduction potential remains untapped due to the continued use of fossil fuel-based assets, a lack of effective energy-efficiency policies and insufficient investment in sustainable buildings. Increasing the building sector's energy efficiency while reducing CO2 emissions, constitute the main challenge that most European cities need to tackle. As described in the EC COM 662, A Renovation Wave for Europe, in Europe the building sector is responsible for nearly 40% of the total energy consumption, and more than 75% of the building stock is inefficient in light of current standards. The EU and the Member States have targeted existing and new buildings through various policy instruments, from normative through informational and to market-based policies, building codes and appliance standards have had profound market transformational effects across the EU. However, most of the building stock in 2050 will be composed of buildings that already exist today, therefore the improvement of existing buildings has become an urgent pre-requisite for the road to decarbonisation. At the current average ca. 1% annual renovation rate, it would take around a century to decarbonize the EU building stock to modern, low-carbon levels. Therefore, to achieve a number of the Green Deal's objectives simultaneously, including drastic improvements in the overall energy and resource performance of the building stock, more attention and accelerated actions are needed to increase the rate and depth of renovation of existing buildings in all EU Member States. At the same time, having better and more energy efficient buildings will improve the quality of citizens' life and alleviate energy poverty while bringing additional benefits to the economy and the society, such as health and better indoor comfort levels, green jobs. Several legislative frameworks have been established by the EU to boost energy performance of buildings including the Energy Performance of Buildings Directive 2010/31/EU and the Energy Efficiency Directive 2012/27/EU. Together, the directives introduced the need to transform buildings to nearly zero energy (NZEB) promoting policies to achieve a highly energy efficient and decarbonised building stock by 2050 and creating a stable environment for investment decisions and enabling consumers and businesses to make more informed choices to save energy and money.

In 2018 both directives were amended with the EPBD 2018/844/EU directive as part of the Clean energy for all Europeans package, introducing new elements and sending a strong political signal on the EU's commitment to modernise the buildings sector in light of technological improvements and to increase building renovations. In October 2020, the Commission presented its Renovation wave strategy, as part of the European Green Deal which contains an action plan with concrete regulatory, financing and enabling measures to boost building

renovation with the objective to at least double the annual energy renovation rate of buildings by 2030 and fostering deep renovation.
To achieve these results it will be fundamental to adopt new measures like the gradual introduction of minimum energy performance standards to trigger renovation of the worst performing buildings, a new standard for new buildings and a more ambitious vision for buildings to be zero-emission, define enhanced long-term renovation strategies to develop national Building Renovation Plans, increased reliability, quality and digitalisation of Energy Performance Certificates, a definition of deep renovation and the introduction of building renovation passports, modernisation of buildings and their systems, and better energy system integration (for heating, cooling, ventilation, charging of electric vehicles, renewable energy, monitoring and control smart platforms). The directive, which is now being considered by the Council and the European Parliament, will contribute to set cost-optimal minimum energy performance requirements for new buildings and for existing buildings undergoing major renovation, and for the replacement or retrofit of building elements like heating and cooling systems, roofs and walls boosting energy performance of buildings and improving the existing building stock.
Energy performance of buildings standards
Existing buildings represent the majority of the building stock and the challenge is to transfer it toward Near Zero Emission Buildings (NZEB) considering that, as of 2021, all new buildings must be NZEB and since 2019 all new public buildings should be NZEB. Energy retrofit is even more significant in Mediterranean EU countries like those participating in this project (Italy, Spain and Portugal) where existing buildings stock is also historic, subject to environmental constraints or architectural-artistic value, and it's influenced by specific regulations and methods of intervention for refurbishment. Furthermore, the energy and environmental performance of this kind of buildings are very low (with an average energy consumption of 430 kWh/m2/year and 30 kgCO2Eq/m2/year of emissions) and the challenge to reduce energy consumption, to minimize CO2 emissions and maximize the use renewable energy sources becomes even more important. As described above, buildings are responsible for approximately 40% of EU energy consumption and 36% of the energy-related greenhouse gas emissions and therefore they represent the largest energy consumer in Europe. Heating, cooling and domestic hot water account for 80% of the energy that citizens consume. At present, about 35% of the EU's buildings are over 50 years old and almost 75% of the building stock is energy inefficient. Investments in energy efficiency stimulates the economy, especially the construction industry, which generates about 9% of Europe's GDP and directly accounts for 18 million direct jobs. At the same time, only about 1-1.5% of the building stock is renovated each year and in particular, Small and Medium Enterprises benefit from this renovation market, as they contribute more than 70% of the value-added in EU's building sector as described in the European Green Deal factsheet "Building and renovating".

Currently Europe counts with 160 million buildings, one-quarter of them built between 1970 and 1990. Considering that new buildings represent only 1-1.5% of the building stock, in order to achieve substantial impact in terms of energy savings and greenhouse gas reduction, renovation and retrofitting of existing buildings become a very important challenge. Although the large variety of existing buildings does not allow to have a unique retrofitting approach, in the EU, the EPDB includes the major aspects of renovation of existing buildings and the technical elements and/or systems of retrofitting. In order to meet the 2050 long-term target for reducing EU GHG emissions by 80%, it is necessary to dramatically increase the yearly buildings renovation rate from the current level to at least 2.3%. Meeting this objective requires the utilisation of innovative financial schemes involving financial institutions and private investors who are sometimes resistant, due to their unfamiliarity with the technical aspects of energy saving solutions, the small average size of these investments and due to difficulties in attributing energy savings to their respective impact on cash flows.

The first area that deserves specific attention is that of older, worst performing buildings that also include non-energy related typical burdens for the citizens like bad accessibility, higher exposure to heat waves or cold spells, toxic materials, bad indoor air quality, lack of daylight etc and that can be tackled together with energy renovations in one go.

State-of-the art of the buildings sector
Standards for new buildings and specific end-uses have improved significantly during the last 20-30 years. As a result, the theoretical consumption of a new building today is about 40% less than for dwellings built before 1990. Yet the overall stock of existing buildings remains very inefficient and progress of improvement is slow due to a number of reasons:

1. The large majority of the building stock is inefficient (Figure 1). Large majority of the building stock was built before thermal requirements and energy related building codes. The generally accepted rate of inefficient buildings is 75% (e.g. in the EPBD Impact Assessment (EC (2016)), while a study by BPIE showed that only 3% of all the buildings qualify for "A" labelled Energy Performance Certificates (EPC), thus around 97% of the building stock needs energy renovation (BPIE (2017)).

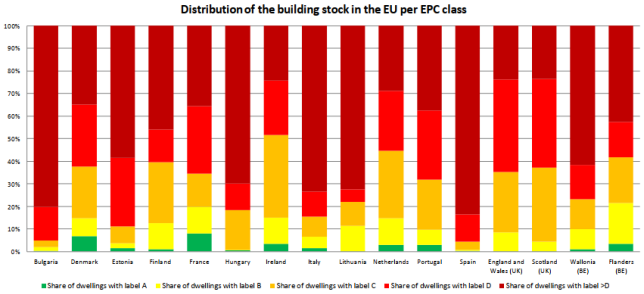


Figure 1. Distribution of buildings along the EPC categories. Data

from the EU Building Stock Observatory, national databases and reports by the Concerted Action EPBD. The sample compares Italy, Portugal and Spain with other main EU countries.

2. The share of new buildings is around 0.68% per year. Assuming the same construction rate, a maximum of 25% of the building stock will be new in 2050. If compliance is maximal, these buildings will be built as nearly-zero energy buildings. But still, 75% of the buildings in 2050 are already built today with the current average rate of energy performance (Figure 2).

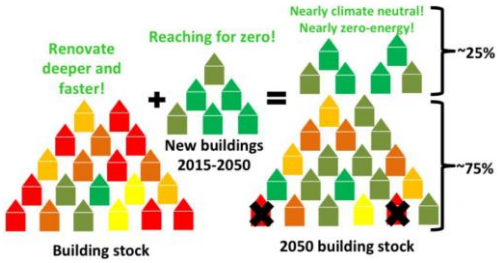


Figure 2. Building stock composition forecast in 2050.

3. At the current (less than) 1% average annual renovation rate it would take around a century to decarbonise the EU building stock.
4. Only 12% of all residential building renovations can be considered as "deep renovation".

The residential building stock represents around ¾ of the total building stock in the European Union. The size of the residential building stock is large: over 120 million residential buildings exist in the EU, consisting of three fourth of single buildings and one fourth of multifamily buildings. Estimates about the full renovation market size of the EU revolve around 100 billion EUR per year, concentrated in Germany, Italy, France, and the UK, and huge disparities across Member States (see Figure 3).

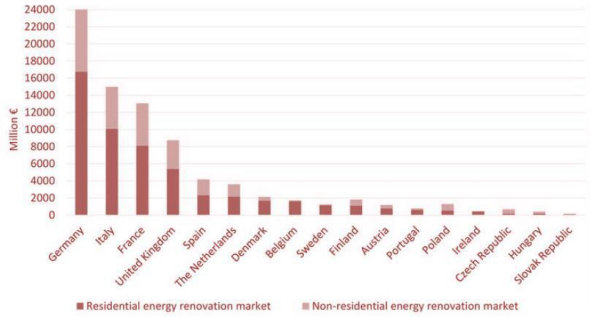


Figure 3. Estimated value of the renovation market in selected Member States.

According to the Buildings Performance Institute Europe (BPIE), deep renovation of buildings in the EU could cut 36% of their energy consumption by 2030, while reducing EU energy import dependency, creating growth, innovation and employment, reducing fuel poverty and resulting in more comfortable and healthier buildings. Public policies are able to move the market beyond the regular market forces, and thus are required to ensure a higher rate and a more comprehensive renovation strategy across all Member States.

In summary, the energy performance of the EU building stock is dominated by the existing buildings and shallow renovations, which has important implications for the 2030 and 2050 building stock. Focus on existing buildings must grow, and 90% of the building stock should be renovated deeply or demolished by 2030, in order to achieve a climate-neutral building stock. This means a rate of 3-4% of the buildings should be (deep) renovated per year.

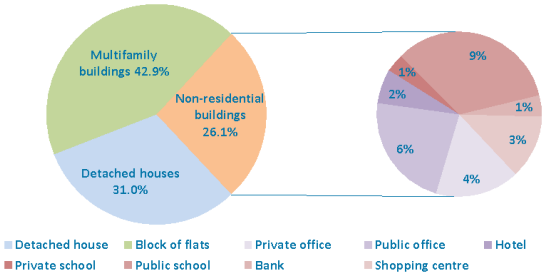


Figure 4: Building share in Italy by type of use (multifamily buildings, detached houses and non-residential buildings). 6% is represented by public offices.

Considering the slow rates of constructing new buildings, a lot of attention needs to be paid to the already existing building stock and to historic buildings, since their significant cultural and historic values make their refurbishment and retrofitting process more complex. Currently the EU-27 counts with 160 million buildings, one-quarter of them built between 1970 and 1990 and more than 40% of the residential buildings have been constructed before the 1960s. In order to achieve substantial impact in terms of energy savings and greenhouse gas (GHG) reduction, renovation and retrofitting of existing buildings become a very important challenge as well as the construction of new efficient buildings.

Smart building technologies IoT Platform

One of the objectives of the revision of the Directive on the energy performance of buildings EPBD is to bring it up to date with technological developments such as smart building technologies. Smartness in buildings is an essential part of a decarbonised, renewable-intensive and more dynamic energy system geared to achieving the 2030 EU targets on energy efficiency and renewable energy, and a decarbonised EU building stock by 2050. An IoT smart monitoring platform will be implemented with the aim of:

- achieve high energy efficiency by optimal operation of the building and facilitate the maintenance of technical building systems;
- strengthen the role of demand-side flexibility in increasing the share of renewables in the energy system and making sure that the benefits are cascaded down to consumers;
- ensure that the building users' needs are covered and they can effectively interact with the building;

- contribute to the establishment of well-connected buildings, and smart communities also supporting citizen-centric and open standard based solutions for smart cities.

2. THE EPOPZEB PROJECT

In this paragraph the main results of the 2 years ePOPzeb project will be illustrated. The project, named ePOPzeb, was an R&D project funded with structural funds under a regional call "Green and Smart Building" in the framework of the 2014-2020 Operative Programme. An innovative prototype of an NZEB modular wooden construction system, economically advantageous, with very low environmental impact, rapid installation and integrated with a smart monitoring IoT platform for the control and management of several parameters related to the efficiency and internal comfort of the building, has been developed during the project. The final prototype is shown in Figure 6. The prototype is characterized by:

- Passive envelope: annual energy requirement below 15 kWh/m2/year.
- Wooden construction system with a wide variety of finishes.
- Integration with renewable source system and energy saving solutions.
- NZEB (Near Zero Energy Building), certified in class A4.
- Anti-seismic: designed and tested against seismic events according to current Italian legislation.
- Acoustic comfort: 80% absorption of acoustic emissions.
- Thermal comfort: high insulation that minimizes thermal systems.
- Flexibility and modularity
- Recyclability: all materials are 100% recyclable.
- Reduction of construction times: 5 days per 100 square meters of closed enclosure in class A4.
- Simplicity of construction: dry and dust-free, construction site with low environmental impact.
- Reduction of construction costs and operating costs of the building-technological system.
- Prepared for green roofs and for rainwater treatment.

During the project a series of sustainable technological solutions have been analysed, studied and compared with traditional solutions:

- **Innovative materials for the structural building components (i.e., column and beams, structural external and internal walls, non-structural walls and slabs)**
  - poplar wood,
  - EPDM Ethylene-Propylene Diene Monomer,
  - EPS Expanded polystyrene,
  - CBPB Cement bonded particle panel, composite material panel, consisting of a mixture of compressed and dry wood and concrete particles
  - OSB Oriented Strand Board
  - Laminated veneer lumber LVL is one of the most innovative wood-based materials offered by contemporary construction
  - innovative wooden foundations with metal cages
- **Technological systems**
  - double flow Controlled Mechanical Ventilation (VMC) system to ensure winter heating, summer cooling and dehumidification and optimal air exchange.
  - A photovoltaic system integrated with a lithium ions storage system that makes it possible to achieve 100% self-consumption and the exchange of excess energy in a smart-grid logic
  - Solar thermal system integrated with high performance heat pump.
  - IoT Smart Monitoring platform

The project has been developed by a partnership including private partners (3 SMEs and 1 private university), public partners (1 municipality and 1 public university), the municipality of Colleferro and its citizens and a Regional Agency for the management of structural funds. In addition, numerous stakeholders from the construction and IT sectors were involved during the execution of the project. The prototype has been installed in a public urban disused area made available by the municipality of Colleferro. The used technology has been first validated in lab (TRL4) and validated on field (TRL5) and the system prototype is now being demonstrated in an operation urban environment (TRL7). Next steps will be to reach a complete and qualified system (TRL8) fully proven in operational environment and ready for the market.

After the end of the project, the experimental prototype is been managed by the same temporary business association that developed the prototype thanks to the free concession of the area where it has been built and owned by the municipality of Colleferro. The project represents an example of practical application of the 5P model. The 5P concept (Public–Private–People-Policy-Partnership) is an emerging way of highlighting the need for developing the involvement of private actors and the general public in a joint process with policy makers. EU cities emphasise the importance of citizen participation in their planning legislations and policies. At the same time, they continuously need to develop new models in order to make private companies more involved in planning processes through different types of public-private partnerships and cooperation modes. Typically, city administrations' cooperation with companies on one hand and citizen participation on the other hand is discussed separately although they both are expected to influence the same planning process. The concept of Public-Private-People-Policy-Partnerships (see Figure 4) has emerged as a way to address the problems related to public-private

partnerships by bringing the general public ("people") into the partnerships alongside with public and private actors and with the strategic local policies like regional development agencies. There are also other new policy concepts with an aim to create more inclusive governance involving different actors, but the 5P-approach specifically targets attention to adding the general public and the citizens to public-private partnerships and particularly addressing the problems of exclusion and lack of transparency. There is no single model or definition of the concept, and its principles can be adapted in different ways case by case. In general, however, 5P approaches focus on developing planning processes that can be both efficient and open by including both private actors and citizens. Practices of stakeholder involvement stem from legislation and local and national planning cultures, and can thereby be difficult to influence by individual planners. By pointing attention to the in-built imbalances in terms of positions and influence between private actors and the general public, however, the concept of Public-Private-People-Policy partnerships could at least be a first step of helping planners to become aware of, and address the differences in resources and influence between actors, and also to find ways to utilise the strengths of the different actors to comply with specific policies.

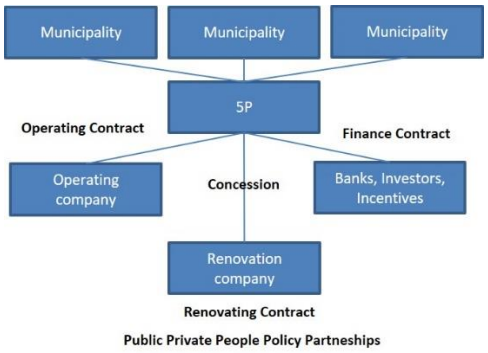


Figure 4: The 5P model.

Currently the building is used as an experimental living lab where local citizens can carry out joint research projects and training activities. The laboratory, called Smart City Lab of Rome and Lazio, is managed by the same consortium that built it, thanks to free loan agreements that are renewed every year and it represents a user-centered, open-innovation ecosystem operating in the territorial context, integrating research and innovation processes. The lab is based on a co-creation approach integrating research and innovation processes. These processes are integrated with the co-creation, exploration, experimentation and evaluation of innovative ideas, scenarios, concepts and related technological artefacts in real life use cases. This approach allows all stakeholders involved to consider both the global performance of a product or service and its potential adoption by users. The lab is based on:

- Co-creation: bring together technology push and application pull into a diversity of views, constraints and knowledge sharing that sustains the ideation of new scenarios and concepts and contributing to local policies.
- Exploration: engaging citizens, innovators and all stakeholders at the earlier stage of the co-creation process for discovering usages and behaviours in real or simulated environments.
- Experimentation: implement the proper level of technological artefacts to experience live scenarios with a large number of users while collecting data. Evaluation: assess new ideas and innovative concepts as well as related technological artefacts in real life situations and evaluating also socio-economic aspects.

Figure 6: the TRL6-Prototype of the ePOP-zeb project.

One of the main objectives of the lab is to apply the Living Lab approach to the demand side of regional policy, building on concrete pilot projects to construct a multi-level governance network for territorial innovation. A series of pilot projects that link transnational R&D and regional innovation strategies with specific development needs will be identified and developed to create a permanent structure through which regional development authorities apply the Living Lab model in an increasing array of fields of territorial innovation.

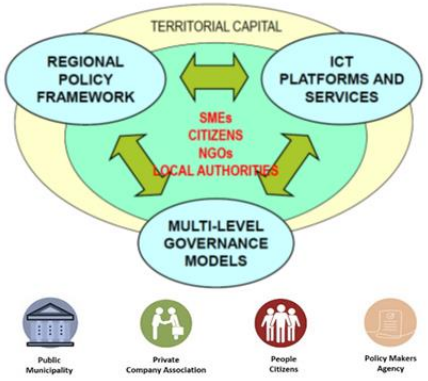


Figure 6: The Smart City Lab of Rome and Lazio multivel model.

The lab has a multi-level governance approach. Every governmental level – local, regional, metropolitan, national, European and global – has a specific responsibility for the future of our cities based on the principles of subsidiarity and proportionality. Complex challenges should be jointly tackled by all levels of urban and spatial policy and this requires the cooperation of all

societal actors, including civil society and the private sector. As recommended by the Pact of Amsterdam and the New Urban Agenda, vertical and horizontal multi-level and multi-stakeholder cooperation, both bottom-up and top-down, is key to good urban governance. The Figure shows the main elements for setting a user-driven innovation ecosystem.

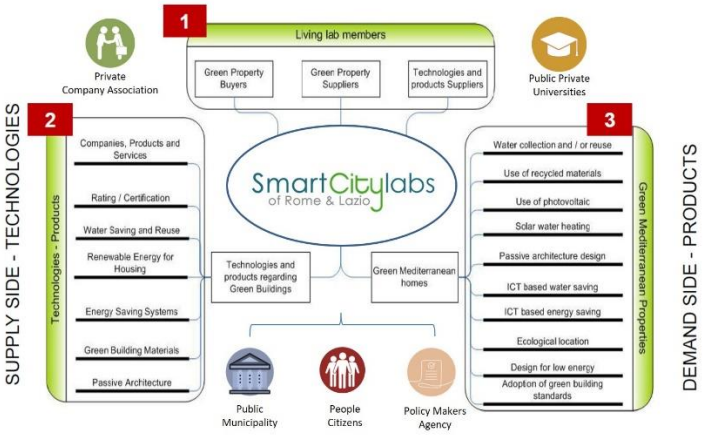
The lab focuses on green and smart building, the construction industry and the real estate sector with a specific attention to the Mediterranean countries. Construction and property development are an important sector of economic activity, ranging from 5-10% of GDP in MED regions. The sector is composed of hundreds of SMEs in construction, repair, marketing, real estate, and engineering and it is very important for the value chain of many other industries as well and to achieve a strong input-output chains and growth multiplication effects. Product innovation and access to global markets and market-related innovation is a major challenge for most companies in the sector.

The lab represents a physical place where new technologies can be showcased, demonstrated and presented to the public who can visit the laboratory, take an active part in the activities and acquire information relating to possible energy efficiency for their homes. this can also happen thanks to the activation of some activities such as:

- Learning about Green Building: Characteristics in selected technologies of interest, special features of green building, cost and benefits.
- Green Building Entrepreneurship: Sustaining companies producing Green Building products, materials and technologies.
- Green Building Collaboration: Platform with database with information about the local public real estate assets representing a social space of innovation within the ecosystem of the local construction industry and a tool for the participation of end-users and SMEs in the design of new products and services in the sector of Green Building and a digital space for the promotion of Green Property and building renovation and urban regeneration.

Topics of interest of the Living Lab are:

- Passive architecture
- Green building materials
- Energy saving systems
- Renewable energy for buildings
- Water saving and reuse systems
- Green building rating and certification
- Smart buildings and IoT Platforms



3. ACKNOWLEDGMENTS

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