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University communities for the green/digital renovation of public buildings

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Abstract
In the face of climate change and energy crises, the renovation of existing buildings is an adaptation imperative. Despite ambitious policies, effective progress is hindered by a limited focus on financial returns, neglecting the broader social and environmental dimensions of renovations. This paper presents a university-driven Living Lab methodology experimenting with Digital Twins to foster collaboration and engagement in the co-design of ambitious renovation projects. Tested in a pilot project site in a historical context, the collaborative digital methodology demonstrates the potential to optimize renovation processes and scenarios. Results highlight the transformative impact of the methodology, while addressing challenges for scaling up and replication.

Keywords: Public buildings renovation; Digital twin; Living lab; Community; Awareness.

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Introduction

In the global context of correlated insecurities arising from climate change and energy crises, the critical objective of renovating existing buildings can be considered as an adaptation strategy, given their well-documented and substantial adverse impacts. Despite the broad perspective of the European Union policies, building renovation efforts remain limited when translated to national and local scales. Here, while rainfall incentives are provided to economically support the renovation effort, the prevailing approach remains focused on the quantitative return on investments, impeding taking into account the wider social and environmental benefits (Fingleton and Jammet, 2021). This approach prevents the development of a comprehensive long-term vision, and the cultural transformation to achieve the necessary radical green transition. In the run toward adaptation, if predominant top-down and technocratic approaches are revealing shortcomings (Selje *et al*. 2024), alternative community-driven, needs- and place-based and participatory models are offering promising transformative and regenerative pathways. In the maturity context of building renovations' discourse (Liao *et al.* 2023), although "energy efficiency first" is the imperative of EU policies, the turn towards "beyond energy efficiency" concepts appears ready to support more qualitative, effective and future-oriented strategies.

The recently concluded EU co-financed Med-EcoSuRe project[1] (Mediterranean University as Catalyst for Eco-Sustainable Renovation) investigated innovative approaches for the renovation of public buildings, by accounting the social aspects related to the role, influence and impact of the wide range of building actors, and the opportunities of an improved collaboration. In this context, the paper focuses on the Italian contribution led by the University of Florence, in charge of defining a dedicated Living Lab (LL) methodology, and testing it in the local pilot experience. In particular, the local LL experimented with Digital Twins (DT), as the best path to support more collaborative processes.

Initially constrained due to the overlap of the project's launch with the Covid period, the methodology resulted in line with the EU initiatives emerging in those years in the context of the ambitious green transition of the Green Deal. Launched by the EU Commission in 2021, the New European Bauhaus initiative promotes sustainable solutions for transformation of the built environment by "engaging people at a grassroots level", "incorporating the views of various stakeholders into the process of design and implementation" and "prioritising people". These human-centric and social priorities are fully integrated within the Living Lab approach.

Key initiative to drive energy efficiency in the building sector, the Renovation Wave Strategy sets out measures to increase the rate and depth of renovations. In particular, it promotes "digital friendly renovations", suggesting the simultaneous addressing of "the twin challenges of the green and digital transitions". In the context of limited implementation of the BIM to DT nexus (Daniotti *et al.*, 2022), this call for the exploration of advanced digital technologies finds in LLs the ideal context for experimentation, enhancing the opportunities to improve renovation practices from the bottom.

Synchronizing a virtual replica to the physical building by evolving the game-changer building information modelling BIM towards IoT, sensors and AI, DT is a key enabling technology to foster, beyond enhanced prediction and analysis capacities, interaction, comprehension and communication. In the case of building renovation, DTs can serve as catalysts to stimulate a collaborative and dynamic exploration and optimization of renovation scenarios, maximising energy performance and minimizing environmental impact, by fostering community-driven co-design processes for a shared and common vision of sustainable built environments.

Methodology

Building on the LL approach, the methodology is grounded on the idea that universities are micro-societies oriented towards the future, where the development and testing of innovative solutions is ideal, given their roles in education, research & development and the third mission.

Initially designed to address the Med-EcoSuRe project's main objective - to reinvigorate the role of university managers in building renovations, the methodology unveiled the advantages of sharing knowledge and fostering collaboration among a diverse range of actors. Adopted to advance the renovation processes of public building "beyond energy efficiency", the LL approach was intended to create a favorable environment where interdisciplinary and collaborative teams can work together to drive innovation, and efficiently tackle the challenges of renovation.

The Living Lab approach

Although there is no single universally accepted definition of "Living Lab", from the review of previous literature, Hossain *et al.* (2019) identifies two main paradigms in the LL approach, consisting of open innovation and user innovation. The European Network of Living Labs (ENoLL) describes LLs as "open innovation ecosystems in real-life environments based on a systematic user co-creation approach that integrates research and innovation activities in communities, placing citizens at the centre of the innovation process"[2].

The literature presents a variety of definitions, reflecting the multifaceted and evolving nature of this concept. However, it is possible to identify some common elements that characterize LLs (Malmberg *et al.* 2017).

LLs take place in real-world settings, such as neighborhoods, cities, or university campuses, allowing solutions to be tested under realistic conditions and their social impact to be assessed through iterative user feedback. They represent a promising tool to stimulate co-creation of tangible (e.g. products, systems, etc.) and intangible (e.g. knowledge, value, services, etc.) innovation outcomes by including diverse users in all stages of design and commercialization processes, recognizing their ability to develop solutions that meet their target needs.

To foster the process and actively engage stakeholders, LLs can use a variety of methods (multi-method approach) such as workshops, focus groups, and online collaborative platforms. Finally, LLs are characterized by the presence of multiple stakeholders working together to achieve common innovation goals. The literature highlights the importance of public-private-people partnerships (4Ps), in which universities, companies, governments and citizens actively participate in innovation activities (van Geenhuizen, 2016). This collaboration takes the form of a "quadruple helix", which encompasses user-oriented innovation models, to take advantage of the hybridization of ideas that leads to experimentation, and to prototyping in a real-world setting (Compagnucci *et al.* 2021).

Living Labs have proven to be one of the most promising approaches to engage and stimulate stakeholders in co-creating innovative solutions for green energy and sustainable growth (Marksel *et al.,* 2024). The growing interest in applying this approach in various sectors, including energy efficiency and sustainability, can facilitate collaboration among citizens, businesses, institutions and other stakeholders, accelerating the development and adoption of innovative technologies and practices.

Living Lab for building renovation
The innovation development phases of the LL methodology, based on exploration, experimentation and evaluation (Malmberg *et al.* 2017), have been adapted to the building renovation, which is simplified into five stages (Trombadore *et al.,* 2024). The exploration phase can be considered as the 'pre-measurement' before the intervention, with the collection of data and information describing the knowledge framework of the building and the analysis of criticalities. The experimentation phase corresponds to the planning and designing of renovation scenarios (mix-of-technologies) and the intervention on the existing building. Third and final phase refers to 'post-measurement' after the intervention, and the post-management stage (Fig. 01).
From a strategic point of view, the setting up of the local LL (called beXLab - building environmental eXperience) required the definition of a common mission for renovation. Looking beyond energy efficiency, the mission of the local LL is to consider renovations holistically, also accounting for their environmental impact (focusing on the integration of renewable energies and NBS), the social aspects of comfort and wellbeing, and architectural quality.
From a more practical point of view, the setting up of the LL required the selection of a physical space for the pilot building renovation, as well as the creation of a virtual space for the DT experimentation. The strategic location of the LL in an historical heritage context and in a School of Architecture, has been calibrated in the project targets that strongly emphasize socio-cultural aspects while respecting the architectural integrity of the site (Fig. 02).
In line with the LL features, the methodology is multi-actor, accounting for the involvement of a wide set of actors in the renovation process. The adopted engagement methods and tools are the object of the following paragraph.
The methodology has been iteratively adjusted/adapted across the project thanks to the partners contribution and the implementation of the pilot project, serving as official trial to validate its effectiveness. The tested methodology has been capitalized in a dedicated project's output for the further scaling up and replication (Renovation Toolkit[3]).

Methods and tools
Various methods and tools have been established to engage diverse actors in the LL activities (Fig. 03), facilitating collective exploration of the DT within the context of the real-case pilot project, and contributing to the definition of an innovative renovation, as detailed below.

Researchers
As LL promoters, researchers (Phd, post doc, senior) led the design and management of all the LL activities, as well as the operative development of the pilot project. To initiate these activities, the first group of researchers (architects, energy engineers and information engineers) focused on the following tasks:

- developing the BIM model of the pilot building to renovate;

- designing a protocol for a real-time monitoring system (IoT sensor networks) to collect data on a specified set of environmental parameters influencing indoor comfort, and installing it within the LL spaces;
- customizing the DT into an ICT hosting platform (Snap4City[4]).

Beyond the exploitation for the definition of the ambitious pilot project, the DT continues to stimulate cross-disciplinary collaboration (for example, service designers are working on the definition of user-friendly interfaces for Digital Twin platforms).
It is important to highlight that the establishment of the LL would not have been possible without the collaboration of building and energy managers (e.g. providing physical spaces and existing data for the DT) and private companies (e.g. innovative monitoring technologies).

Building/energy managers
Customers of the LL's outcome as main responsible for the management of the university building stock, building/energy managers (from decision makers to technicians) have been involved since the beginning of the project through a dedicated survey (conducted at cross-border scale). This initial survey has been constructed to self-assess current facility management practices, giving particular attention to the identification of information and collaboration barriers. Findings revealed issues related to the uniformity and standardization of building data, as well as the fragmentation of management processes. Sharing these results served as an opportunity to raise awareness of the potential benefits of digital models, highlighting their value as tools for improving data reliability, fostering collaboration, and supporting informed decision-making. Moreover, they have been targeted by a training webinar series, organised online and at cross-border level given the Covid period, which provided an opportunity not only to acquire new knowledge on the project's key topics but also to exchange best practices with peers.
At the local scale, building and energy managers (mainly technicians) provided the initial data to initiate the construction of the DT. They actively participated in all the technical meetings for the definition of the pilot project, conducted around the DT. During these sessions, the potential of the DT was highlighted, emphasizing its capacity to enhance project management, stimulate innovative strategies and approaches while predicting renovation outcomes.
Considering the lengthy and complex administrative and procedural processes inherent to public procurement, technicians observed how the DT facilitated advanced project delivery. It enabled seamless collaboration among various professionals involved in the integrated project (architects, energy and structural engineers, and safety engineers), accelerated ongoing project updates, and ensured a fast development of the executive project and effective control over the construction process.
Even decision-makers were actively involved throughout the project. At its inception, they collaborated to strategically select the most suitable university building for establishing the LL, installing the monitoring system, and implementing the pilot renovation. Regularly updated on the progress of the DT and pilot project, they facilitated a smooth authorization process. By the end of the project, they committed to transitioning toward more digital and sustainable renovation practices. This commitment was formalized through the adoption of a long-term renovation strategy for the university's building stock and a short-term action plan to implement the project outcomes.

Companies
A variety of private companies contributed to the LL, each playing a key role in the DT experimentation and pilot renovation:

- IoT and software companies: the development of an experimental environmental monitoring system of the environmental required a close contact, support and communication with companies, in order to select the optimal set of sensors and activate the DT's data exchange;
- Manufacturing companies: designing and implementing a state-of-the-art pilot renovation involved the integration of innovative technologies and materials (notably, innovative photovoltaic panels). From the design phase, the DT was used both as a communication tool to engage with manufacturing companies and as an operational tool to manage customization;
- Construction companies: also the construction process had to be innovative. Given the location in an historical building, the continuity of university activities, and the innovative technologies adopted, the worksite required special features. The DT facilitated smooth communication between the contracting station and construction companies, while also supporting worksite organization;
- Consultancy companies: the adoption of innovative technologies necessitated expert guidance to manage procurement logistics and the proper installation, acting as a bridge between manufacturing companies and the contracting station.

*Public organizations and institution*s:
The experimental LL renovation process has been actively disseminated locally through dedicated events, targeting key organizations and institutions to showcase the potential of DT in driving sustainable and innovative renovation practices. The dialogue with the municipality, as the owner of the pilot building, and with the local cultural heritage superintendence, given the architectural constraints of the pilot site, has been stimulated by detailed technical reports, containing DT-generated data-rich renovation scenarios. This approach facilitated a favorable environment for obtaining necessary authorizations.

Students:
As special building's users, students of architecture have been involved in several LL activities, contributing and benefiting from the DT experimentation:

- dedicated seminars, also with international partners, advancing their knowledge on building renovation and DT, usually relegated to researchers;
- data collection to create the DT (building survey and energy audit);
- qualitative survey on the perception of indoor comfort in the LL (open space for students), stimulating a reflection on the importance of environmental indoor quality, and to retrieve qualitative data for the DT (matched with quantitative data);
- dedicated co-design workshop (see Trombadore *et al.* 2023), handling the BIM asset model of the pilot building to design, simulate and evaluate integrated renovation scenarios;
- direct observation of the pilot project's construction works, adopting advanced techniques (e.g. modularity, prefabrication);

- on site education, thanks to dedicated posters in proximity of the pilot project and the LL, where all the process, the technologies adopted and the obtained results are detailed in an easy form;
- perception surveys on the pilot project, for developing critical thinking about the architectural impact of innovative renovation measures (i.e. solar active structure, see results).

Beyond the project duration, the LL, the DT and the pilot project remain as a real-life/virtual learning resource at disposal for students, stimulating their interest in innovative, sustainable and digital practices.

Results, limits and discussion

Valorising the contribution of all the actors and supported by the exploitation of the DT, the co-creation in the LL context consented to reach an ambitious renovation project, in terms of innovative process and achieved results.

Addressing the LL's renovation strategy, in line with the strategically set targets, and as predicted by the DT, the pilot project achieved important results in terms of energy efficiency, environmental impact, improved comfort and wellbeing, highly considering architectural quality. This last point was of particular interest, given the quality of the historical heritage context of the pilot project, where the need to improve the social acceptance of renovation measures, in particular the integration of renewable sources, is more challenging.

The main intervention of the pilot project resulted in the definition of an experimental tridimensional steel structure positioned in the south side of the pilot building and hosting innovative photovoltaic panels (semitransparent and amorphous). Standing as an active solar shading device, the iconic new façade highly influences the indoor environmental conditions, augmenting energy efficiency while reducing the energy expenses and the environmental impact, thanks to the production of clean energy. The persistence of the pilot in the School of Architecture acts as a tangible result showing day by day to the future generation of professionals and citizens the potential of renovations, such as the creative and the aesthetic quality of renewable technologies integrated in architectural solutions.

Beyond the pilot action, the most important result achieved by the project is that all the actors involved experienced in the LL a different way of renovating buildings, community-driven and bottom-up, acknowledging in a real-case application the role of collaboration in achieving innovative and satisfying results. Moreover, all the actors entered in contact with the DT. This consented to spread awareness, and to educate, towards the most advanced digital technologies and opportunities, but also to researchers to retrieve information about the limits and challenges of the digital transition. In particular, limitations emerged in the possibility to fully develop a DT for the management of the university building stock: even if DT technologies are almost ready to be implemented, more efforts are required to advance the digital knowledge and skills of technicians in the public sector. The experience-led learning process activated by the LL, both for building/energy managers and for students, such as the produced educational outcomes (e.g. Toolkit) represents a step in this direction.

Conclusions and future works

Augmenting the LL methodology with the DT represents an innovative transformative path to boost the renovation of public buildings, addressing the green and digital challenges through a renewed collaborative and participative spirit. Beyond the analytic and predictive possibilities enabling an advanced decision making, DT represents a valid support tool for more collaborative and engaging practice, whose experimentation in LLs is an opportunity for mutual learning and awareness raising. Beyond energy efficiency and short-term results, an innovative renovation of public buildings combining LL and DT can be an occasion to reinforce the role of actors from the bottom, laying the foundation of a cultural shift truly supporting the urgent green turn and its persistence in the long term.

The local LL experience in Florence, with the pilot as manifest, demonstrated the quality deriving from more collaborative and innovative processes. However, the LL adventure is just at the beginning, with a lot of future works in the pipeline. Looking wider, the replication of the LL experience in other university contexts[5] and other typologies of public buildings (i.e. schools), is on agenda. At local scale, the didactic potential of the monitoring system, of the DT and of the pilot project should be improved, by advancing the sharing of the project data and results. This requires more effort in communication, and the simplification of quantitative data in an user-friendly way. The collaboration with the service design experts is working in this direction, with the short-term idea to the realise divulgation totems for the fruition and navigation of the DT data and, in a long-term perspective, to develop a dedicated app for the exploitation of the DT both for the university building/energy managers (expert users), with the possibility manage building portfolio, and for building's end-users (not expert users), oriented to stimulate more proactive behaviours toward a more sustainable use of buildings, strategic in the education of young architects/citizens.

The created LL/DT, physical and digital infrastructure, is at disposal for further research, looking at new collaboration and development opportunities with other disciplines and stakeholders.

Notes

[1] Available at: https://www.enicbcmed.eu/projects/med-ecosure (30/11/2024)

[2] Available at: https://enoll.org/living-labs/#living-labs (30/11/2024)

[3] The draft version of the Toolkit is available online at: https://medbexlive.org/. The final version is the subject of an ongoing dedicated publication.

[4] Available at: https://www.snap4city.org/dashboardSmartCity/view/Baloon.php?iddasboard=MzQyNA== (30/11/2024)

[5] The creation of a network of LLs is one of the objectives of the cross-border Living Lab activated in the context of the Med-EcoSuRe project, called Med-beXLive. Available at: https://medbexlive.org/ (30/11/2024)

References

Compagnucci, L., Spigarelli, F., Coelho, J. and Duarte, C. (2021), "Living Labs and user engagement for innovation and sustainability", *Journal of Cleaner Production,* Vol. 289, pp. 125721. Available at https://doi.org/10.1016/j.jclepro.2020.125721.

Daniotti, B., Masera, G., Bolognesi, C.M., Lupica Spagnolo, S., Pavan, A., Iannaccone, G., Signorini, M., Ciuffreda, S., Mirarchi, C., Lucky, M. and Cucuzza, M. (2022), "The Development of a BIM-Based

Interoperable Toolkit for Efficient Renovation in Buildings: From BIM to Digital Twin", *Buildings*, Vol. 12(2), pp. 231. Available at: https://doi.org/10.3390/buildings12020231.
Fingleton, J. and Jammet, M. (2021), *Capturing the benefits of building renovation*. Available at: https://worldgbc.org/wp-content/uploads/2022/03/BUILD-UPON-Framework-indicators-methodology_doublepage.pdf (Accessed on 15/11/2024).
Hossain, M., Leminen, S. and Westerlund, M. (2019), "A systematic review of living lab literature. Journal of Cleaner Production", *Journal of Cleaner Production,* Vol. 213, pp. 976-988. Available at https://doi.org/10.1016/j.jclepro.2018.12.257.
Liao, H., Ren, R. and Li, L. (2023), "Existing Building Renovation: A Review of Barriers to Economic and Environmental Benefits", *International Journal of Environmental Research and Public Health*, Vol. 20(5), pp. 4058. Available at: https://doi.org/10.3390/ijerph20054058.
Malmberg, K. and Vaittinen, I., Evans, P., Schuurman, D., Ståhlbröst, A. and Vervoort, K. (2017), *Living Lab Methodology Handbook*. DOI: 10.5281/zenodo.1146321.
Marksel, M., Pavletič, N., and Letnik, T. (2024), "Enhancing Knowledge on Energy Refurbishment of Buildings and Green Procurement through Living Labs", *Buildings*, Vol. 14(9), pp. 3009. Available at: https://doi.org/10.3390/buildings14093009.
Selje, T., Schmid, L. A. and Heinz, B. (2024), "Community-Based Adaptation to Climate Change: Core Issues and Implications for Practical Implementations", *Climate*, Vol. 12(10), pp. 155. Available at: https://doi.org/10.3390/cli12100155.
Trombadore, A., Calcagno, G., Montoni, L. and Pierucci, G. (2024), "Advancing the design process experience of heritage buildings' renovation: a Toolkit for an ethical best path", in Battisti, A. and Baiani S. (Ed.), *ETHICS: Endorse Technologies for Heritage Innovation. Cross-disciplinary Strategies*, Springer nature, Swiss, pp. 115-130. ISBN: 978-3-031-50121-0.
van Geenhuizen, M. (2016), "Living Labs as boundary-spanners between Triple Helix actors in Journal of Contemporary Eastern Asia", *Journal of Contemporary Eastern Asia,* Vol. 15(1), pp. 78-97. Available at: https://doi.org/10.17477/jcea.2016.15.1.078.

Images

Fig. 01

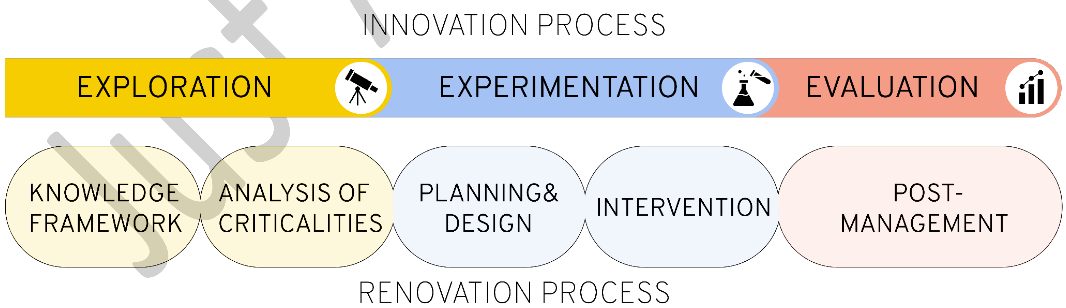

Fig. 02

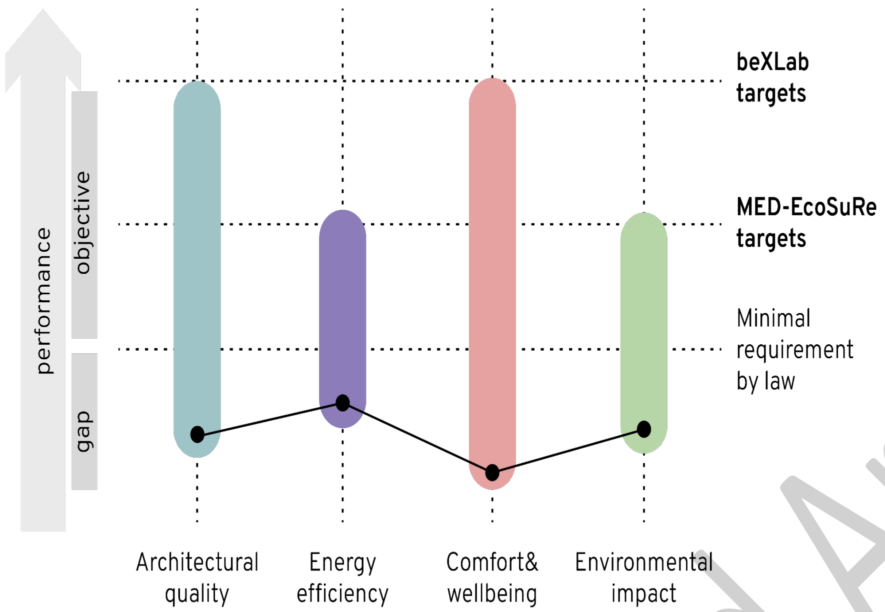
performance
objective
gap
beXLab targets
MED-EcoSuRe targets
Minimal requirement by law
Architectural quality
Energy efficiency
Comfort& wellbeing
Environmental impact

Fig. 03

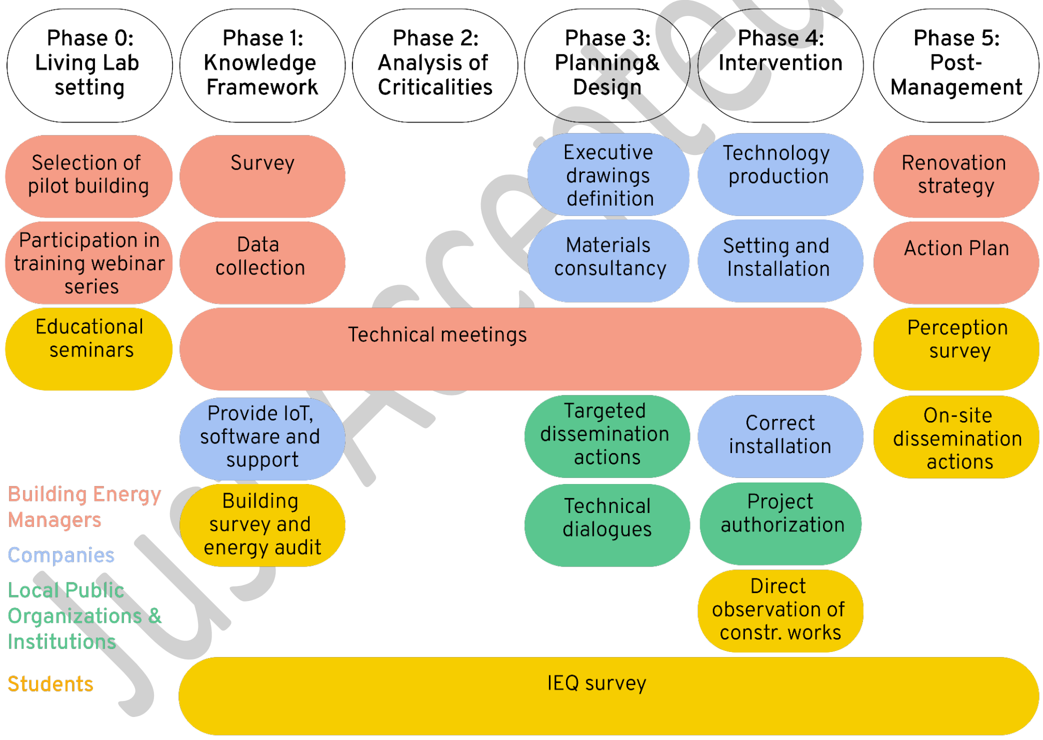
Phase 0: Living Lab setting
Phase 1: Knowledge Framework
Phase 2: Analysis of Criticalities
Phase 3: Planning& Design
Phase 4: Intervention
Phase 5: Post-Management
Selection of pilot building
Survey
Executive drawings definition
Technology production
Renovation strategy
Participation in training webinar series
Data collection
Materials consultancy
Setting and Installation
Action Plan
Educational seminars
Technical meetings
Perception survey
Provide IoT, software and support
Targeted dissemination actions
Correct installation
On-site dissemination actions
Building Energy Managers
Companies
Local Public Organizations & Institutions
Students
Building survey and energy audit
Technical dialogues
Project authorization
Direct observation of constr. works
IEQ survey

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Fig. 04

Captions

Fig. 01 – Three phases of the LL methodology adapted to the five stages of the renovation process
Fig. 02 – LL renovation mission and targets
Fig. 03 – Actors and LL involvement activities fostered by the DT
Fig. 04 – PIlot project renovation results (photo credit: ETA Florence)