PILOT PROJECT REPORT

Realisation of a tridimensional structure to host PV panels/shading device and integration of Skylights in Santa Verdiana (School of Architecture - University of Florence)

REGIONE AUTÒNOMA DE SARDIGNA
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Med-EcoSuRe

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Project funded by the EUROPEAN UNION

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beXLab building environmental eXperience

INTRODUCTION

In the framework of the Med-EcoSuRe project, a pilot renovation action has been implemented in the School of Architecture of the University of Florence, where a Living Lab has been activated to innovate the renovation process of Mediterranean public buildings.

Merging an interdisciplinary group of researchers, the Living Lab (called beXLab - building environmental eXperience) has been primarily intended to support university managers in the implementation of the pilot renovation project by engaging a wide range of stakeholders (local innovative companies, experts) and the strategic end-users (students) Finally, over the course of the project, it will become an interdepartmental laboratory fostering the collaboration between researchers in architecture, energy engineering and information engineering. The central focus of the Living Lab is digitalization to advance more collaborative approaches among decision makers, stakeholders and end-users for the co-design of eco-sustainable renovations of public buildings in the Mediterranean region.

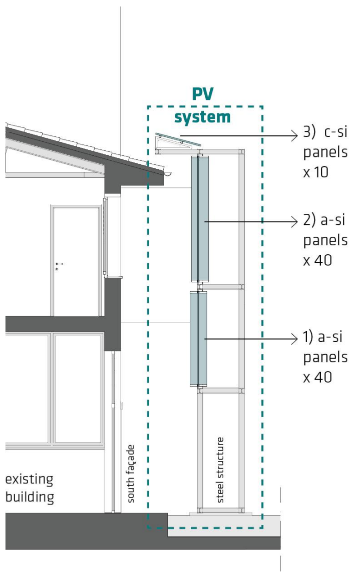
The development of the pilot project in the context of the Living Lab allowed the real-life testing and validation of the innovative approaches, methodologies and technologies emerged in the collaborative renovation process.

For the implementation of the pilot renovation project, as well as for the setting up of the Living Lab, a building block has been selected in the School of Architecture of the University of Florence, hosting typical functions of the university life. The main peculiarity of the pilot-site is the position in the historical complex of Santa Verdiana, located in the UNESCO city center of Florence. Originating in the 14th century as a convent, the complex underwent transformations over the centuries, serving as a female prison before eventually assuming the current educational role in the 1990s, construction period of the selected pilot building.

Energy Production

In line with the objectives of the Med-EcoSuRe project, the pilot project has been intended as a demonstrator for the young generation of students/future professionals to showcase, in the strategic university context, the architectural quality of innovative and sustainable technologies for the energy efficient renovation of public buildings in the Mediterranean region.

Considering the historical and heritage context, the pilot project was the occasion to experiment with an external "not touching" infrastructure as an innovative typology of building integrated photovoltaic systems (BIPV).



Typical of public buildings in Mediterranean cities, the presence of architectural constraints has been considered as an opportunity to explore a new typology of energy efficiency intervention, combining the attention to the heritage building, the production of solar energy and the search for a new aesthetic, along with the reduction of energy consumptions and the improvement of comfort for occupants.

The totally prefabricated and reversible tridimensional steel structure hosting the PV system has been positioned in front of the southern façade of the identified building block, detached about 1.5 m.

The design of the framed steel structure derived from the analysis of the existing facade and of the renaissance cloister where it is located, following its geometry and modularity. The steel structure consists of four vertical and pre-fabricated portals (modules) completed by two half-modules at the ends, divided into horizontal bands that highlight the facade elements following a principle of compositional harmony. The overall dimensions of the steel structure are 19.7 m in width, 7.46 m in height, and 0.80 m in depth.

The module has been designed with a principle of reversibility, featuring a frame composed of prefabricated steel profiles assembled dry, allowing the place to return to its original state after use and having a low impact on the existing environment. The structural components of the frame are HEB 100 steel profiles, with the orientation of the flanges concealing the passage of cables from the photovoltaic panels. The foundation of the structure is achieved through a system of seven prefabricated pedestals in reinforced concrete accommodating two vertical elements, with plan dimensions of 1.20 m x 0.30 m and a limited depth of 0.40 m. The project foresees the absence of infill elements in the modules at ground level, to maintain open access and views from the ground floor classrooms.

The innovative glass-glass PV panels (see INNOVATION OF TECHNOLOGIES) have been organized vertically in the two upper bands of the metallic tridimensional frame (panels in amorphous silicon), and horizontally on the top of the structure (panels in monocrystalline silicon).

The façade PV panels have been arranged in a pattern of vertical blades characterized by varying rotations relative to the vertical axis, in order to ensure proper shading and energy collection at different times of the day.

The middle band houses 40 panels (1.80 m x 0.45 m) with 20% of transparency to provide better shading for the two glass classrooms on the ground floor. The upper band integrates 40 panels (2.40 m x 0.45 m) featuring 10% of transparency to ensure proper lighting level and comfort inside the main classroom on the first floor.

On the upper part of the structure, slightly overlapping the roof projection, the pilot project also comprised the installation of additional 10 panels (1.70 m x 1.00 m), arranged with an inclination on the horizontal plan of about 15° for the optimization of the performance of the overall PV plant system.

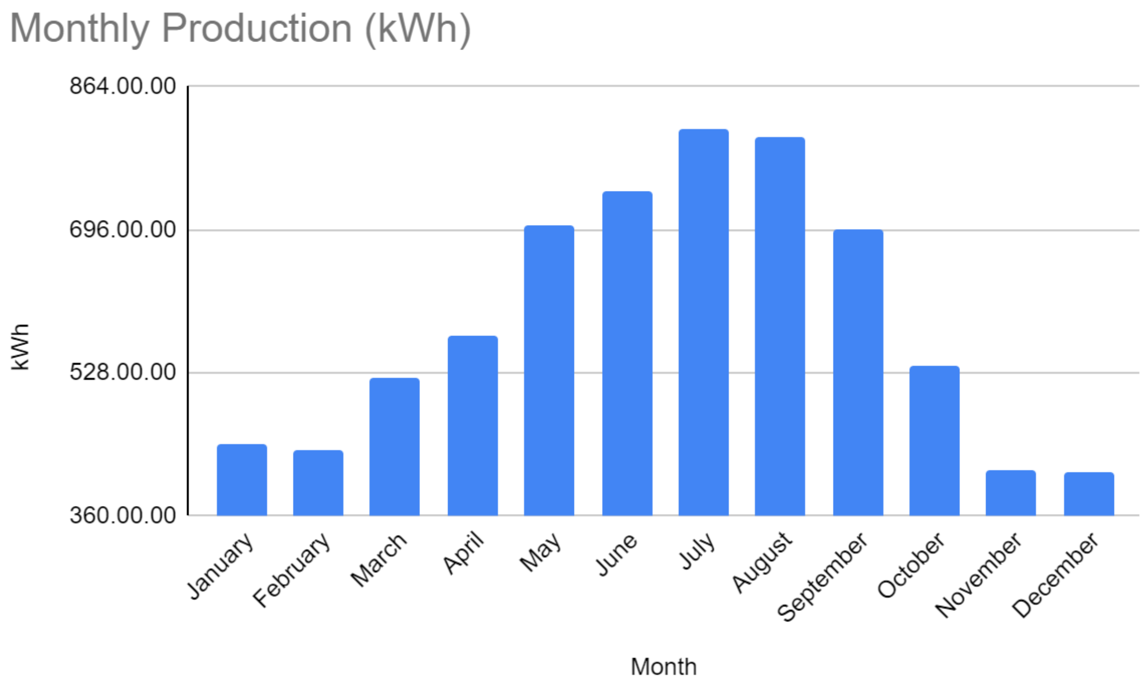
With a total of 90 modules covering an area of 92.6 m^2, the photovoltaic system is organized in three photovoltaic generators, the two groups of vertical panels in the façade (40+40) and the horizontal group on the top (10), connected with three inverters to the low-voltage three-phase grid.

PV PANELS AND GROUPS DATA

Group	Cell Type	Panel Dimension	Thickness	Transparency	Nominal peak power (panel)	Number of installed panels	Nominal peak power (group)

1	a-si (amorphous silicon)	1800x450 mm	8+3.2+8 mm	10%	32 Wp	40	1.3 kWp
2	a-si (amorphous silicon)	2400x450 mm	8+3.2+8 mm	20%	37 Wp	40	1.5 kWp
3	c-si (crystalline silicon)	1000x700 mm	4+4 mm	-	295 Wp	10	3 kWp

Month	**Daily Production (kWh)**	**Monthly Production (kWh)**
January	14.14	438.345
February	15.609	437.058
March	16.685	517.247
April	19.026	570.77
May	22.31	691.618
June	24.515	735.436
July	25.924	803.655
August	24.822	796.488
September	23.2	696.004
October	17.232	534.192
November	13.798	413.95
December	12.957	401.679



The total peak power reached by the PV system is of about **6 kWp**, resulting in an annual production of **7000 kWh**.

The installed PV system consents to reduce the emission of pollutants in the atmosphere, equivalent to a thermoelectric production:

- carbon dioxide (CO_2): 3.66 t
- sulfur dioxide (SO_2): 4.91 kg
- nitrogen oxides (NO_x): 6.18 kg

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Energy Saving

With a total surface of 412 m^2, the two floors building block selected for the renovation pilot action is characterised by a symmetrical but opposite north-south exposition. The envelope is composed by opaque vertical walls in tuff finished with plaster; transparent elements are made by a single glass layer at the ground floor, where they are prominent in fixed archways, and by double glasses in the windows of the first floor; the roof is made by prefabricated sandwich panels covered by a mantle of traditional clay tiles.

The functioning of the building is guaranteed by the presence of a heat pump powering heating and cooling with a standard ventilation system; it is not foreseen hot domestic water; and the artificial lighting is provided by old neon lamps.

Following the innovative renovation process (see PROCESS INNOVATION), all the actors involved in the Living Lab have been engaged in the definition of a robust knowledge framework of the pilot building to renovate (phase 1), starting from the collection of existing documents; moreover, an energy audit has been performed, revealing the main criticalities and the needed retrofit actions.

On the basis of the data and information collected, a BIM asset model of the pilot building has been created, supporting a deeper analysis of criticalities (phase 2 of the renovation process) with simulations of the energy and environmental performance with different applications (dynamic calculations). Simulations showed the low energy performances of the pilot-building with major consumptions referable to air conditioning and artificial light, in line with the energy audit.

Focusing on the thermal behaviour of the building, simulations consented to calculate the impact of the passive thermal contributions of the envelope on energy consumptions for heating and cooling, showing that the most impacting negative contribution regards solar radiation on the south façade.

Given the destination use, a big attention has been given to the quality of the visual environment, with simulations run on the distribution and intensity of solar radiation inside the spaces (daylight factor and illuminance). The analysis revealed the uneven distribution of natural light, with the over exposure to solar radiation from south in particular in the ground floor due to the dimension of the arched windows, and under lit conditions in the central part of the first floor.

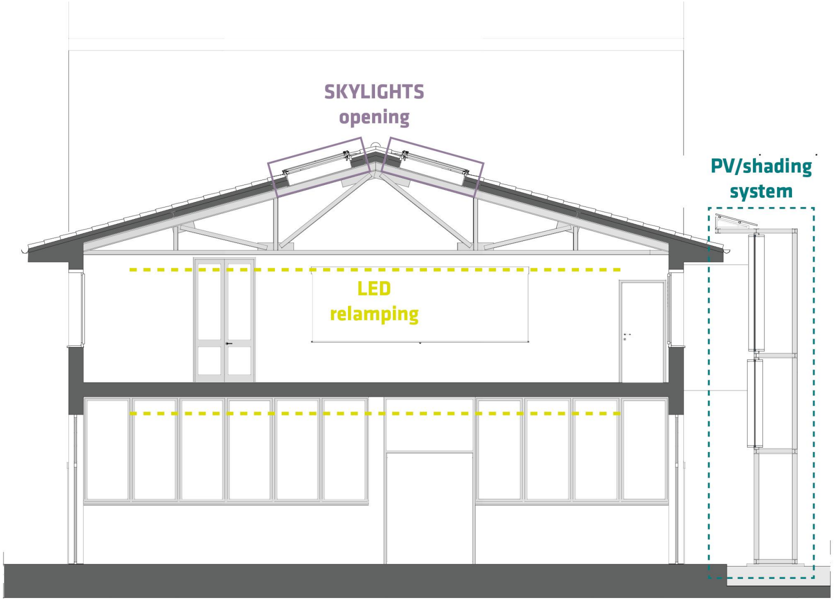
Working digitally, a wide range of retrofit technologies and scenarios have been integrated in the BIM model to simulate the energy and environmental performance (phase 3 - planning and design); it was possible to observe the contribution of the single/mix of technologies to the achievement of energy savings and improvement of indoor environmental quality conditions. For example, the need to protect the south front from the impacting solar radiation has been evaluated with different shading devices, consenting to define the best configuration.

For this purpose, a co-design workshop has been launched in the School of Architecture, and inserted in the calendar of the New European Bauhaus activities of the Department of Architecture, with students called to propose innovative solutions for the building renovation, highly contributing to the definition of the final solution. At the same time, different local and international companies have been contacted to obtain data and information on the innovative technologies to integrate.

Considering the peculiar heritage context and the results of the analysis of criticalities, the pilot renovation project has been defined in the three main interventions (Fig. x):

1. creation of an external 3d structure hosting innovative PV panels as shading devices;
2. opening of skylights;

3. re-lamping.



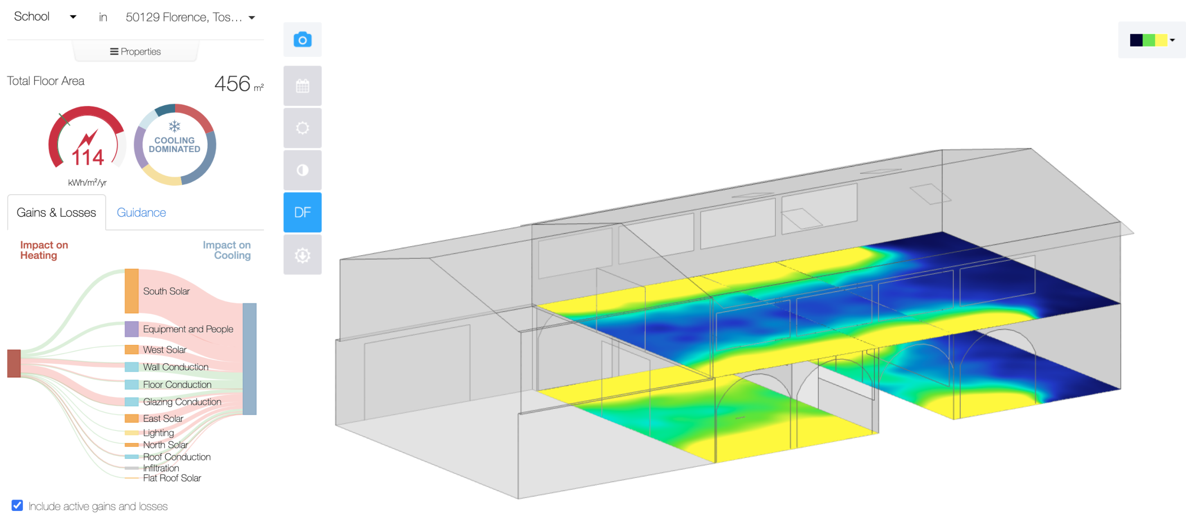
Beyond the production of solar energy, the external 3d structure has been intended as a shading device for the overexposed south façade of the building that, due to the prevalence of transparent surfaces, highly contributes to the energy consumptions for cooling and, at the same time, causes visual problems of overlit in both the building floors.

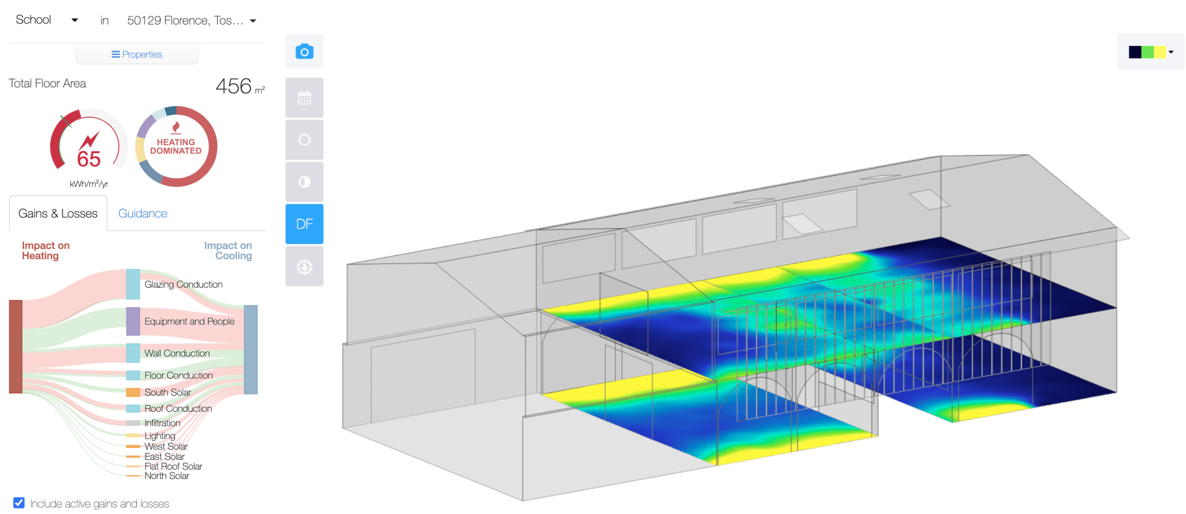
The second intervention related to the opening of skylights has the objective to solve the underlit conditions in the first floor (while overlit is present closed to the windows facing south), where the huge aula magna suffers overall dark visual conditions in the central part determining the continuous recourse to artificial lighting.

Finally the substitution of existing neon lamps with more efficient LED-lamps further contributes to energy savings, considering that a LED lamp can save 65% of energy in comparison to a neon one.

The contribution of these three interventions in terms of energy savings has been evaluated through simulation tools, consenting to appreciate energy savings and the improvement of indoor comfort, mainly in visual quality. The most important energy saving can be attributed to the shading PV structure, highly reducing the cooling load in the summer period thanks to the passive shading.

Simulations consented to quantify the decreasing of energy consumption in the pilot building from 114 kWh/m^2 year before the renovation action to 65 kWh/m^2 year with the three interventions. Moreover, considering the energy production of the PV panels (7000 kWh/year), the energy needs of the pilot building are reduced by 44%.





Moreover, the space of the Living Lab located on the ground floor has been equipped with an innovative re-lamping: thanks to a collaboration with a local company, an innovative LED-system has been equipped, totally customizable remotely with a dedicated app. The redundant system has already been exploited for the creation of *ad hoc* lighting scenarios, useful to set experiments with artificial lighting.

Innovation of technologies

Elaborated in the context of the Living Lab, the pilot project comprised a wide set of innovative technologies, such as the monitoring system, the LED lighting system and the PV system. The latter can be considered as the most impactful innovative technology, also thanks to the great visibility provided in the pilot project.

For the production of clean energy, the pilot renovation project adopted glass-glass photovoltaic panels. Even if experimented since the 80's, in the last years there is a growing attention to this solar technology for the recognised aesthetic value and high integrability, with a large application in BIPV - Building Integrated PhotoVoltaics - solutions , also ideal for the installation in the historical heritage context of the pilot project.

As an evolution of traditional PV panels, their peculiar characteristic is the presence on each side of the module of a glass sheet instead of the traditional opaque polymer backsheet.

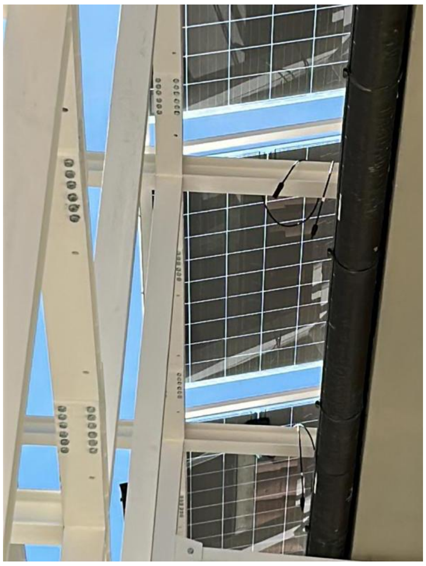
The glass-glass structure provides for a wide range of advantages in comparison with traditional opaque solutions:

- **durability:** the presence in both the faces of glass sheets significantly boosts the robustness of the panels, reducing deformation and the probability of microcracks, making them resistant to humidity and moisture, such as to adverse weather conditions such as extreme rains, hails, snowfalls and extreme temperatures. Thus limits the damage and the wear and tear, increases the protection of the PV cells (high resistance of glass to chemical reactions) and the durability over time, with a lifetime of 30 years consenting a long-term return on investment.
- **flexibility:** can be adapted to different typological solutions where glasses are usually adopted, such as on building facades, windows, curtain walls, canopies or shading systems;
- **visual quality**: allow the passage of sunlight, but according to the types of glass can filter UV harmful solar radiation;
- **aesthetics:** considering the possibilities of glass customization, panels can be realised with different shape, colour, thickness, size, degree of transparency, allowing a wide freedom in the design phase;

In general, glass-glass PV panels have a higher initial cost if compared to traditional panels; yet, the potential for increased energy production,the longer lifespan and the most advanced characteristics (flexibility, integrability and aesthetics) can offset the higher upfront expense, making them a worthwhile investment in time.

Glass-glass panels can integrate different photovoltaic cells. Two of these technologies have been adopted in the pilot project:

1) monocrystalline silicon cells are composed of silicon, a semiconductor material that captures irradiation from the sun and converts it into electricity. They are made from single crystals silicon (vs polycrystalline), consenting to a high efficiency in the energy production, which can reach up to 22% (16% in the pilot). Single cells composing the panel are visible and their order into a grid is the typical appearance.



2) amorphous silicon PV cells are made by a layer of not ordered silicon with a thin-film structure, which is deposited onto another material (float glass in the pilot). As tiny and uniform sheets, their appearance highly depends on the substrate, with the flexibility to be integrated in curved surfaces. Even if with good performance in diffuse-light conditions, their efficiency ranges from 5 to 10%.

Administrative process

The implementation of the pilot renovation project required a complex administrative process, mainly linked to the location of the pilot building in the historical context. The responsibility of the administrative process was in charge of the Technical Office of the

University of Florence, but it has been supported by the group of researchers of the Living Lab, according to their competences.

As the first step, the preliminary project elaborated in the context of the Living Lab has been presented by the university technical office to the Superintendency of Archaeology, Fine Arts and Landscape for the metropolitan city of Florence and the provinces of Pistoia and Prato.

During the authorization period, two parallel activities have been performed: from a side, a market research to obtain quotations related to the construction works and to the purchase of the innovative PV panels characterizing the pilot; from the other side, different professionals have been consulted for the definition of the architectural, structural and electric plant project.

In order to optimize the procedures and in compliance with the national normative framework, the public tender was organized as an integrated procurement, merging the executive design, the supply and construction works.

A parallel public tender of supply was organized for the purchase of the innovative PV panels. A different path was followed for the re-lamping, referring to a convention with a local company for the testing of the innovative Led system.

Process Innovation

The pilot renovation project has been developed in the context of the Living Lab experimenting innovative processes for the renovation of Mediterranean public buildings based on the exploitation of Digital Twins.

Fixing the principle that working together in participatory processes can produce more sustainable and innovative solutions, the adoption of Living Lab methodologies consented to the interdisciplinary group of researchers (promoters) to support university building/energy managers (customers) in the implementation of the pilot renovation project by engaging a wide range of stakeholders (public organisation, innovative companies) and involving the strategic group of end-users (students).

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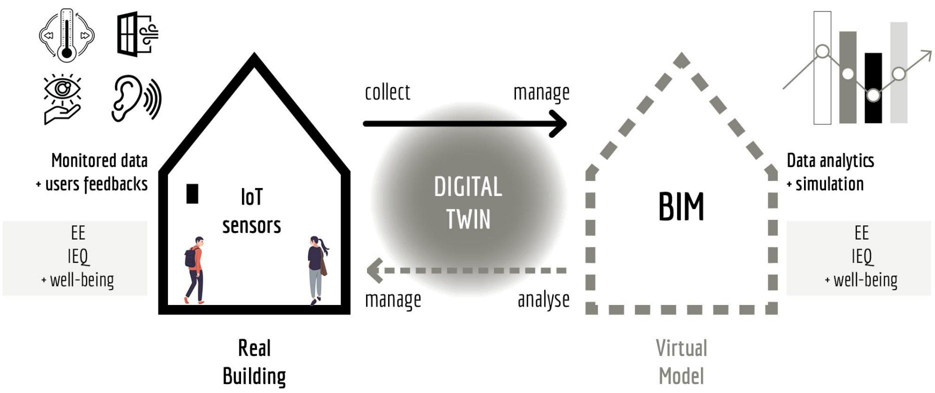
To accelerate the implementation of public buildings renovation in the Mediterranean region, university-based Living Labs can act as real-life laboratories where the university community, as a little society, can co-experiment, test and share innovative renovation processes, strategies and technologies.

The Living Lab is working on the innovation of renovation processes by experimenting with Digital Twins, considered as the best-path to support more collaborative and reliable renovation processes by integrating the challenges and opportunities of the digital and the green transitions.



Process innovation through Digital Twins derives from the possibility to bidirectionally connect the physical building with a digital model (from BIM to the integration of even more data) to enhance predictive and proactive systems. The digital/physical connection has been created through the installation of a protocolled monitoring system and the retrieval of subjective feedback from end-users, whose data are going to be integrated in the Digital Twin (see COMFORT MEASUREMENT).

The LL is exploring the potentialities of DT with the scope to better understand and influence the building energy and environmental performances both before and after the renovation action, in order to optimise quality and efficiency through the experimentation of innovative solutions (technological and processual).

The possibility to capture and elaborate a wide range of real-time data and to visualise them in different ways opens towards multiple scopes: to simulate the construction of ambitious scenarios, to stimulate advanced participatory process, to support the facility management, to enhance the capability to plan and implement sustainable renovations, to analyse and evaluate technologies, performances and costs, but also to educate towards more responsible energy behaviours.

The synchronisation of the real building/virtual model allowed an augmented environmental experience, such as new levels of user involvement. The Digital Twin worked as a predictive systems, central and active repository to calibrate the configuration of improvement scenarios in the design/operational phase on well-being objectives, expanding the awareness of the process actors for a new centrality of the decision as an ethical value.

The innovative renovation process experimented in the context of the Living Lab, and tested for the implementation of the pilot renovation project, encompassed five main phases, anticipated by a zero phase regarding the activation of the Living Lab.

- phase 0: Living Lab setting up
- phase 1: knowledge framework
- phase 2: analysis of criticalities
- phase 3: planning and design
- phase 4: intervention
- phase 5: post-management

For each phase, the Living Lab explored novel forms of collaboration among academics, decision-makers, stakeholders and end-users, such as the best tools and methodologies, focusing on the opportunities deriving from the exploitation of Digital Twins.

To support the replicability of the innovative renovation process, the “Toolkit for innovative and eco-sustainable renovation processes” (link to MedbeXLive page) has been created as an easy-friendly step-by-step guide to drive more sustainable, innovative and inclusive renovation processes for Mediterranean public buildings. For each phase of the renovation process, the Toolkit identifies:

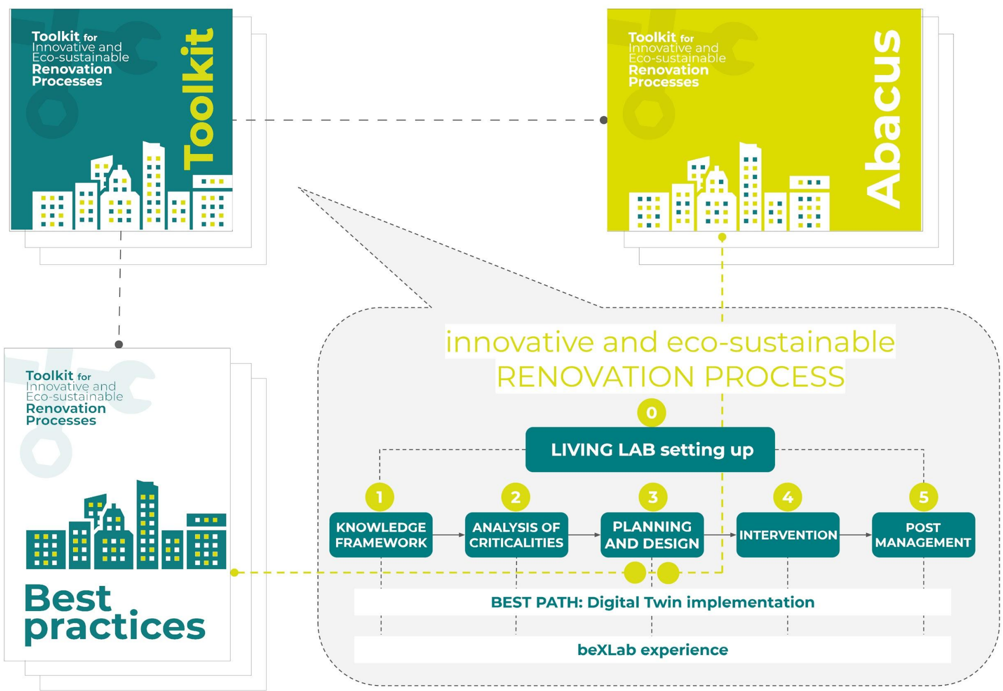
- activities to be undertaken
- people to engage
- methodologies and tools for implementation

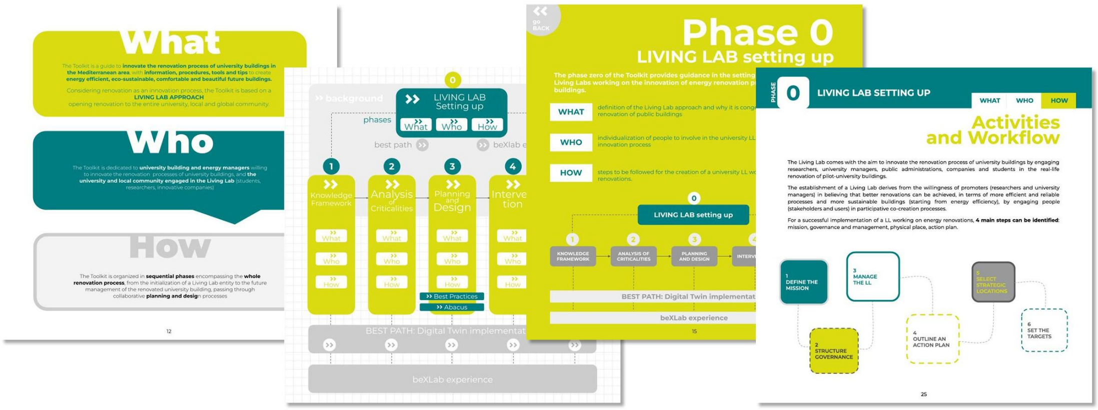
Moreover, two sessions run parallels to the progression of the renovation phases:

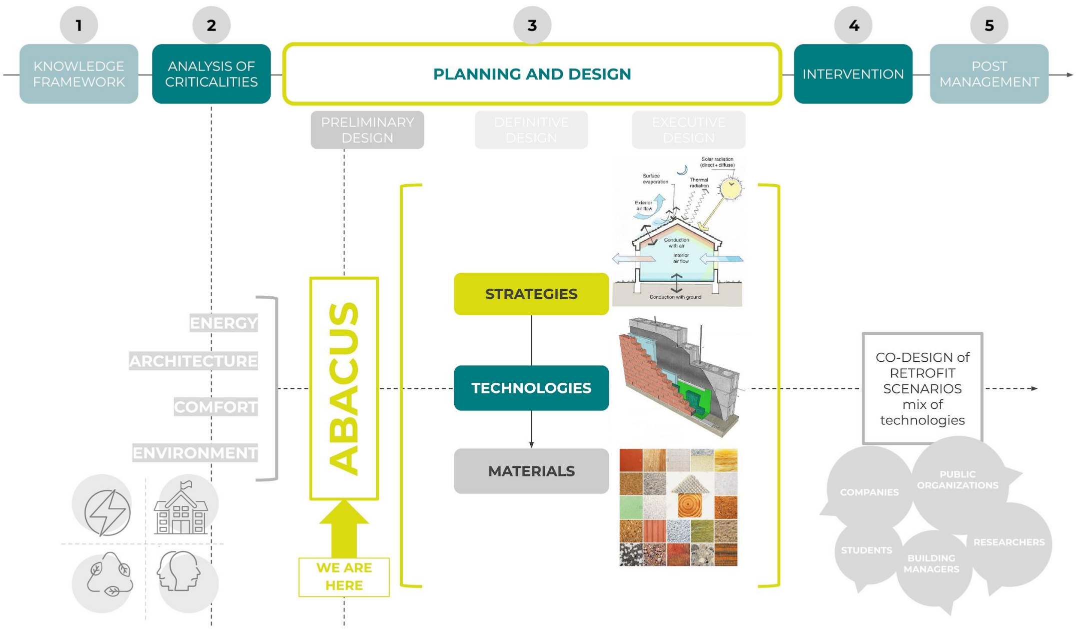
- the Digital Twin Best Path - on the digital possibilities to innovate the renovation process;
- the beXLab Experience - on the Toolkit application in the real-case pilot renovation action in the School of Architecture of the University of Florence.

The central renovation phase of "planning and design" has been enriched with two additional resources focusing on architectural aspects:

- a best-practices catalogue of recently renovated and newly constructed high educational buildings selected for adopting energy efficiency solutions
- an Abacus of retrofit solutions, guiding the selection of the most appropriate renovation strategies, technologies and materials for the Mediterranean socio-climatic and cultural context.







Comfort measurement

For the activation of the Digital Twin, a monitoring system has been installed in the space of the Living Lab, hosted in the pilot building to renovate, with the objective to collect data on indoor environmental quality and related perceived comfort.

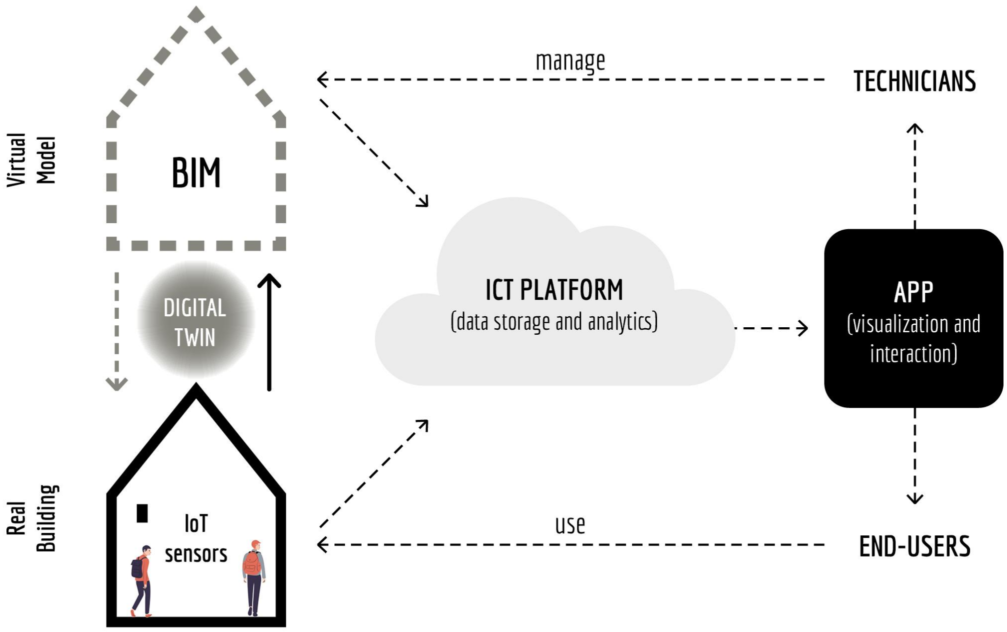
The monitoring system consists of more than 40 sensors that detect quantitative environmental data on the distribution of internal temperatures and relative humidity, thermal flows through the envelope elements, lighting levels, air quality, but also local external parameters thanks to the installation of a weather station.

The monitored data are subject to postprocessing for the quantification of the comfort aspects based on IEQ models (Indoor Environmental Quality), in terms of predicted mean vote and percentage of satisfied subjects (UNI EN ISO 7730:2006).

These results are validated by collecting feedback on the actual experience of the occupants through an online questionnaire on the perception of comfort within the Living Lab, related to thermal, lighting, acoustic and air quality aspects (EN ISO 10551:2019).

The possibility of acknowledging the real and dynamic environmental conditions of the building, influenced by the users, allows to validate the digital model. The connection of the BIM model with the data continuously collected by the sensors and user feedback was possible thanks to the collaboration with IT experts for the fist data visualisation and aggregation.

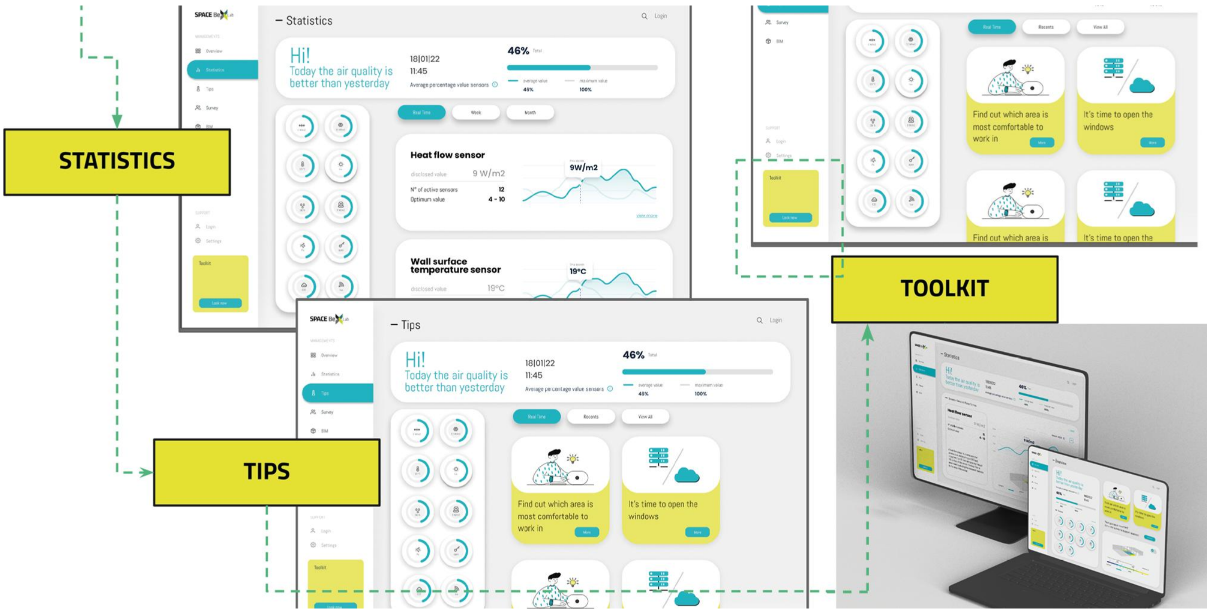
The experience of the Living Lab has been enriched with the collaboration with User Experience designers, exploiting the Digital Twin in the cloud for the definition of an App that, by extracting data from the Digital Twin, can increase user awareness in taking action in the indoor space to improve environmental/energy comfort (IMAGE).



The app design is based on the principles of multi-user reading, usable and understandable communication (infodata), and on storytelling that promotes empowerment and learning from the data collected.

The engagement process aims at increasing a learning framework based on experience that will allow the different users/actors involved to develop new knowledge on energy efficiency and sustainability issues, but also to actively participate in the process of collecting quantitative and qualitative data and to deal with real energy and sustainability problems.

User participation is built around engagement design strategies, which involve the user in generating creative solutions based on the environmental parameters of thermo-hygrometric comfort, lighting, air quality and energy performance.



Lesson learned

The pilot renovation initiative in Florence showed that it is possible to achieve significant energy savings and a relevant production of renewable energy also in historical contexts.

The success of the pilot project has been possible through the implementation of a robust methodology, relying on the collaboration within the Living Lab., The synergies created with local stakeholders and the involvement of decision makers since the beginning, and across the whole renovation process, consented to create consensus and raise awareness not only on the environmental benefits deriving from the retrofit, but also on the architectural possibilities to create high quality and aesthetically appropriated solutions. Thanks to the load of innovation and creativity that emerged in the Living Lab, the pilot project challenged conventional beliefs on the achievement of energy savings, such as the need to intervene directly on the envelope.

The rich and multidimensional knowledge framework on the existing building and the dynamic analysis of criticalities, allowed a wide exploration of different scenarios of retrofit solutions (with the integration of different mix-of-technologies) in the planning and design phase (also enriched by the contribution of students involved in the Living Lab), leading to the identification of the detached “solar active façade”. In particular, the collaborative network established by the Living Lab consented to transform the existing architectural constraints, linked to the heritage built context, into greater opportunities for innovation.

The innovative solar technologies adopted (glass-glass crystalline and amorphous PV panels), also exploited as shading devices, have been integrated into an innovative construction process characterised by modularity, prefabrication, dry construction, and full reversibility (pre-requisite of the intervention in the historical context). This optimised not only the sustainability and feasibility of the intervention but, contextually, to speed up the time for the realisation timeline (intervention phase), consisting in just 20 days.

On the other hand, the administrative process to comply with the authorization procedures and with the activation of the public tender required unexpected long-times, slowing down and delaying the start of the construction works.

Confirming the vision of the Med-EcoSuRe project, the most important lesson learned from the pilot project is that the location in the university context is a excellent occasion to *catalyse* attention, stimulating awareness and engagement, but also debate, about the increasing need to couple with public buildings renovations, also in historical areas.

In direct contact with the new infrastructure, students and the academic community, but also people walking in the historical city-centre, can not only observe innovative technologies but also be informed on the benefits they bring in terms of sustainability, in terms of clean energy production, enhanced energy efficiency, improved comfort and reduced environmental impact.

Recommendations

In the light of the pilot project experience, and of the lessons learned, four main recommendations can be provided to approach and delivery innovative and eco sustainable pilot-renovation actions:

1) ***Engage people - share and align the target:*** innovative practices require the alignment of needs, aspirations, wills and capacities of all the interested parties (decision makers, stakeholders and users). Involving/engaging them since the beginning of the project in a Living Lab context, sharing the aim and the targets, is the best path for a successfully result;

2) ***Renovate well - Renovate together***: high quality renovations require a solid methodology to acknowledge, analyse and design the best architectural and technological solution fitting the specific needs of cultural heritage buildings, but also able to taking into account, and valorise, the multidisciplinary contribution of all the people engage in the Living Lab in co-design processes;

3) ***Focus on sustainability - Not only energy efficiency***: the primary goal of innovative renovations is to foster the level of ecology quality and sustainability in buildings. Co-design practices, supported by evidence-based data, are intended to find suitable solutions (low tech/high tech/NBS) to improve the energy efficiency of the existing building and to reduce its environmental impact (e.g. with the integration of renewable energies, integration of recycled material, passive solutions, nature based solutions etc.);

4) ***Raise awareness - facilitate the real experience***: for their demonstrative nature, pilot-projects stimulate not only the dialogue about energy renovations but a real experience of technological solutions, mostly if supported by an ad hoc communication and data visualisation system showing the sustainability performance of the new infrastructure (Digital Twin - Immersive experience - tactile and visual experience, etc.)