Methodology of energy efficient building refurbishment: Application on two university campus-building case studies in Italy with engineering students

Marta Maria Sesana*, Manuela Grecchi, Graziano Salvalai, Caterina Rasica

Politecnico di Milano-Department of Architecture, Built Environment and Construction Engineering, ABC-Via Ponzio 31, 20133 Milan, Italy

Politecnico di Milano (POLIMI) has launched since 2011 the project "Città Studi Sustainable Campus" to improve the university's sustainability performances within three main principles: building refurbish-ment, sustainable campus development and integration of facilities, research and education. The paper aims to discuss these issues, focusing on the energy efficient refurbishment on two university campuses in Milan, Italy. A Methodology for Energy Efficient Building Refurbishment (MEEBR) has been identified and tested on two case studies with students of the Integrated Design Refurbishment Laboratory of Building Engineering Faculty at POLIMI. In particular, the performance energy analyses were conducted on two university building case: the first at POLIMI campus, and the second located in the Università degli Studi di Milano (UNIMI) campus. These analyses were carried out using numerical simulations, considering the increasing important role which software are playing in refurbishment building design process also in early design phase. This preliminary experience with students on MEEBR application, with also the overview on building refurbishment methodologies, show that case study examples can help to: increase consideration of the integrated research approach and improve sustainability perfor-mance in historical buildings taking into account also the user's participation of a university campus. The comparison of the energy assessment methodology, of the two software used for the analyses (CENED+ and Sefaira), leads to the statement that it is essential from the beginning, selecting a program in function of the particular job and the outputs that you want to reach with the tool.

Keywords:
Sustainable campus
Building refurbishment
Energy efficiency
Case study
Sensitivity analysis

1. Introduction

Universities can nowadays be regarded as 'small cities' due to their large size, population, and the various complex activities taking place in campuses, which have some serious direct and indirect impacts on the environment. Campus sustainability has become an issue of global concern for university policy makers and planners as result of the realization of the impacts the activities and operations of universities have on the environment. There is a common understanding in the literature that a sustainable university campus implies a better balance between economic, social and environmental goals in policy formulation as well as a long-term perspective about the consequences of today's campus activities [36].

Velazquez defined a sustainable university as "a higher educational institution that addresses and promotes the minimization of negative environmental, economic, societal and health effects generated in the use of their resources in order to fulfill its function of teaching, research, outreach and partnership to help society make the transition to sustainable lifestyles" [53].

Some universities have also voluntarily signed some declarations to indicate their commitments to sustainability and the number of those universities is increasing [57]. In 1972 the Stockholm Declaration was the first that made reference to sustainability in higher education and they identified many strategies to achieve environmental sustainability [49]. They follow many others important declarations [48,50–52] which focuses their attention on addressing and incorporating sustainability and environmental literacy in teaching, research, operations and in the buildings themselves of the university campus. The need for environmental sustainability in university campuses has been stressed in many articles [10,13,14,55,9]. The higher educational sector has discovered that its activities and physical structures can have significant impacts on the environment and have started devising ways to organize the activities and to recognize and

Abbreviations: POLIMI, Politecnico di Milano; MEEBR, Methodology for Energy Efficient Building Refurbishment; UNIMI, Università degli Studi di Milano; ISCN, International Sustainable Campus Network; WBETs, Whole Building Energy Tools; EPDB, Energy Performance of Buildings Directive

* Corresponding author.
E-mail address: marta.sesana@polimi.it (M.M. Sesana).

Article history:
Received 1 July 2015
Received in revised form 11 February 2016
Accepted 14 February 2016
Available online 16 February 2016

Published Journal Article available at: http://dx.doi.org/10.1016/j.jobe.2016.02.006

reduce their adverse effects on the environment. These include workshops and laboratory use, buildings and grounds maintenance as well as energy and materials use [25].

1.1. "Città Studi Campus Sostenibile" project

To transform an institution into a sustainable university and contribute to a sustainable world, various efforts have been made by universities around the world. One of the best examples is the International Sustainable Campus Network (ISCN), which provides a platform for leading universities and educational institutions around the world to exchange ideas and information for realizing a sustainable campus. To date, its signatories include the world's top ranked universities, such as Yale and Harvard in the United States, National University of Singapore, University of Gothenburg in Sweden and many other renowned educational institutions [47].

In June 2011 "Politecnico di Milano" (POLIMI) participates at the ISCN in Gothenburg and then joins the network. The establishment and participation evidences the urgency and the strength of POLIMI to establish a sustainable campus, ISCN provides a global forum to support leading colleges, universities, and corporate campuses in the exchange of information, ideas, and best practices for achieving sustainable campus operations and integrating sustainability in research and teaching.

POLIMI has taken a more responsible approach to managing its environmental performances and improvements with a well-organized green agenda and different initiatives. In particular, POLIMI together with "Università degli Studi di Milano" (UNIMI) promoted the "Città Studi Campus Sostenibile" project [12] with the aim to transform the whole campus neighborhood into an urban area which can serve as an urban model in Milan with respect to life quality and environmental sustainability.

During the 4th UNESCO Chair Conference on Higher Education for Sustainable Development in September 2011 at Leuphana University of Lüneburg, the campus roundtable highlighted, in fact, the role of communication, the importance of engaging all university members and the value of acting as an example of sustainability for neighboring communities [35].

The project is open to the participation and support of researchers, students and all campus citizens. The main goals are: to test innovations developed by scientific research; to promote life style transformation and more livable spaces; to become a positive example for the entire city and to cope with the international network of sustainable campuses. In particular, the project focuses on the sustainability performance of buildings stock on campus to minimize environmental impacts and to optimize the integration of the built and natural environments.

This paper provides an overview on the latest energy efficien-cy buildings refurbishment researches, the identification of a methodology for energy efficiency building refurbishment (MEEBR) and its application on two buildings of "Città Studi Campus Sostenibile". The first one is located into the POLIMI Campus and the second one in the UNIMI Campus; the main purpose is to test and verify the methodology on different building heritage in order to validate the approach replicability.

The first analyses on the buildings were carried out by the students of Integrated Design Refurbishment Laboratory with the support of professors and researchers of this topic. This practical experience highlights the importance of the participatory design planning that is also one of the most important project tasks. The refurbishment design process followed, in the respect of the historical and architectural value of the buildings, was based on synergistic steps in order to do not concentrate the refurbishment only on the energy efficiency of the single case studies, but to convert their sites into a unique sustainable campus; making the "Città Studi" area of Milan an example of campus with low environmental impact.

2. Methodology for Energy Efficiency Building Refurbishment (MEEBR)

During the last decade, many governments and international organizations have put significant effort towards energy efficiency improvement in existing buildings. The International Energy Agency (IEA) has launched a series of Annex projects to promote energy efficiency of existing buildings [17,3–6] and at the same time a significant amount of research has been carried out to develop and investigate different opportunities for the definition of a sustainable refurbishment strategies [22,33,34,58,7,8].

The results have showed that energy use in existing buildings can be reduced significantly through proper retrofitting. Among the critical aspects of a sustainable campus are waste, such as food waste and recycling, energy consumption and transportation. Each aspect potentially contributes to lower total campus carbon emission. Hence, a set of implementation strategies targeted at the specific aspects is essential to support the whole process [47].

At educational level, as remarked by Crofton [15], the engineers must play a key role in global effort towards sustainability and moreover different experiences from a classroom case study have been already conducted [1,11,31,38,56]. Many system sustainable approaches have been investigated in the last decades on university campuses with implications to: social-economic and environmental aspect [23,43]; innovative technologies [24,26,29,45]; participation design process [19,41] tool simulation and ecological indicators [16,18,20,28,37,39,46].

The methodology adopted for the Integrated Design Refurbishment Laboratory exemplification derives from the study and

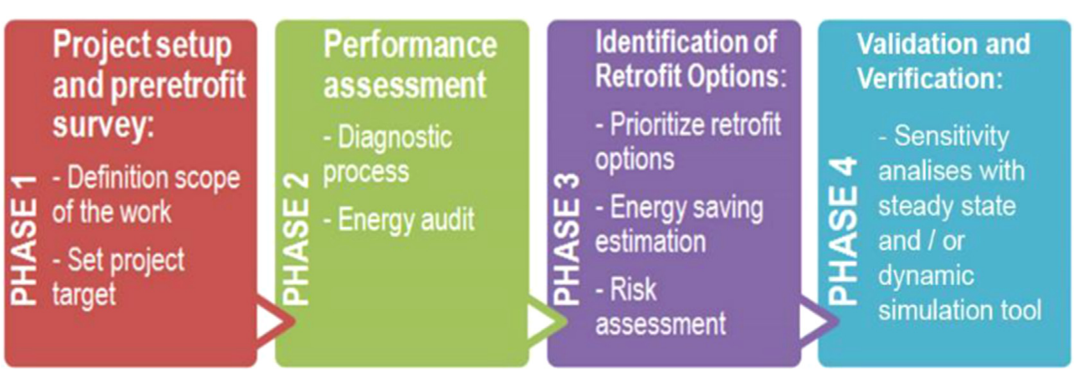


Fig. 1. Key phases of a sustainable building retrofit program.

the application of the researches above indicated and also to the process individuated by Ma et al. [32]. The overall process of the Methodology for Energy Efficiency Building Refurbishment (MEEBR) was structured into four major phases (Fig. 1).

In the first phase the objective is to define the scope of the refurbishment and set the project targets. A pre-retrofit survey at this stage is important to better understand the building operational problems.

The performance assessment of the second phase aims, with the collected data, understanding the building energy use and individuate the inefficient and unacceptable thermal comfort conditions.

In the last two decades, the development of building performance assessment tools has been very active (LEED, BREEAM, CASBEE, HKBEAM, GBTool, NABERS, etc.), although these rating tools provide only a framework on how to evaluate building energy performances and their rating process is conducted via benchmarking the assessed building against prescribed performances indicators. A wide range of research investigated the application of the appropriate models and strategies for diagnostic, but for a particular project, Ma et al. [32] stated that the appropriate performance assessment method and diagnostic tool can be selected by taking into account the client requirements, experience of energy services companies and major retrofit focus.

The identification of the retrofit options is the main goal of the third phase by using energy models, risk assessment method and economic analysis tools. The reliable estimation and energy benefits and the economic feasibility are essential in a sustainable building retrofit decision system in order to prioritize the most suitable options. Also in this phase many simulation tools (TRNSYS, Energy Plus, IDA ICE, ESP-r, VETool, Sefaira etc.) [2] and economic analysis methodologies [27,30,40,44,54] were presented during the lessons to students to provide them an overview on the whole possible assessment techniques which allow the selection of the most cost effective retrofit measures.

The fourth phase is the validation and verification of the retrofit measures chosen through sensitivity analyses with simulation tools in order to quantify with numerical data the effective energy saving reductions.

2.1. Modeling MEEBR

With the expanding interest in energy-efficient building design, Whole Building Energy Tools (WBETs) are increasingly employed in the design process to help professionals determine which design strategies save energy and are cost-effective.

Different simulation programs may have different software architectures, different algorithms to model building and energy systems, and require different user inputs even to describe the same building envelope or HVAC system component.

Detailed building energy simulation programs, although powerful and sophisticated, are seldom used by practising building designers like architects and building engineers. Many building designers and practitioners often find it difficult to carry out the building energy analysis and they are reluctant to use the simulation software because of the lack of confidence in the simulation results and the time and effort needed to learn how to use them. To conduct the analysis properly and effectively, the aims of the study and the intended use and possible limitations of the simulation tool must be fully understood. The level of technical knowledge needed to correctly use the simulation tools are often high so that mis-applications and mis-interpretations are not uncommon in building energy studies. Similarly it happened in the Laboratory of Integrated Design Refurbishment the building physics and energy analyses background of students were different: being part of them students of architectural course and others of building engineering course.

Considering this fact, the modeling methodology, followed in phase 4 of MEEBR application on the case studies, was conducted on two different buildings campuses.

For the case study 1, the architectural students used a steady state software, CENED +[21], for the case study 2, the engineering students used two different software: a steady state CENED +, and a dynamic simulation tool Sefaira [42], and then they compare the results.

The choice derives at the beginning as a necessary conditions from student's background, but then it became an occasion to identify the different level of accuracy and complexity which the methodology could reach and to understand the main differences of a steady state software in comparison with a dynamic one to individuate the best retrofitting options.

2.2. Comparison between software analyses evaluation

Following are the main differences between the two predefined software used for the heating and cooling loads calculation. This allows understanding the general potentials and limitations of each software used.

In CENED+, it is only possible to insert the U-value of the whole envelope regardless of the layers composing it, and only one input for the ventilation rate all year long. The internal gains cannot be set when evaluating the energy demand in the buildings, since they are attributed standard values. Sefaira on the other hand enables to identify the thermo-physical properties of each layer composing the building envelope. The ventilation rate can be defined with different values for each hour, and the internal gains depend on users' activity and occupancy schedule, PC type and usage, as well as the lighting consumption and schedule. The results in the steady condition are in monthly balances, while in dynamic simulations the results are on an hourly or fraction of hourly basis. The heat flux, in the steady-state condition follows a single direction; while in the dynamic simulations the direction of heat flow depends on the variation of temperature between inside and outside the space, and within the building envelope.

The simulations did not take into consideration the effects of thermal bridges. Different urban environments or different orientations for the building were not simulated either. The ventilation rates used for calculations assimilate mechanical ventilation, while in reality adaptive window opening and ventilation seems more realistic, especially in hot climates. Finally, the inputs used in Sefaira vary in complexity and number of parameters compared to those used in CENED+.

3. Overview on Città Studi area and the two buildings case

The sustainable campus project concerns the Città Studi area which is composed by two of the major university of the Milan city: Politecnico di Milano (POLIMI) and Università degli Studi di Milano (UNIMI). Today, the POLIMI Leonardo Campus occupies a surface of 186,613 m^2 equal to 34 buildings and 17,484 students are enrolled in the different programs offered by the university (data referred to the 2010/2011 academic year). In addition, 1748 staff members (professors and administrative and technicians collaborators) work every day on the campus. The area occupied by the UNIMI Campus, has a surface of 209,067 m^2 equal to 49 buildings. The number of the students enrolled in the different programs offered by the university are 17,052 (data referred to the 2010/2011 academic year), and the staff members that work here every day are 1955.

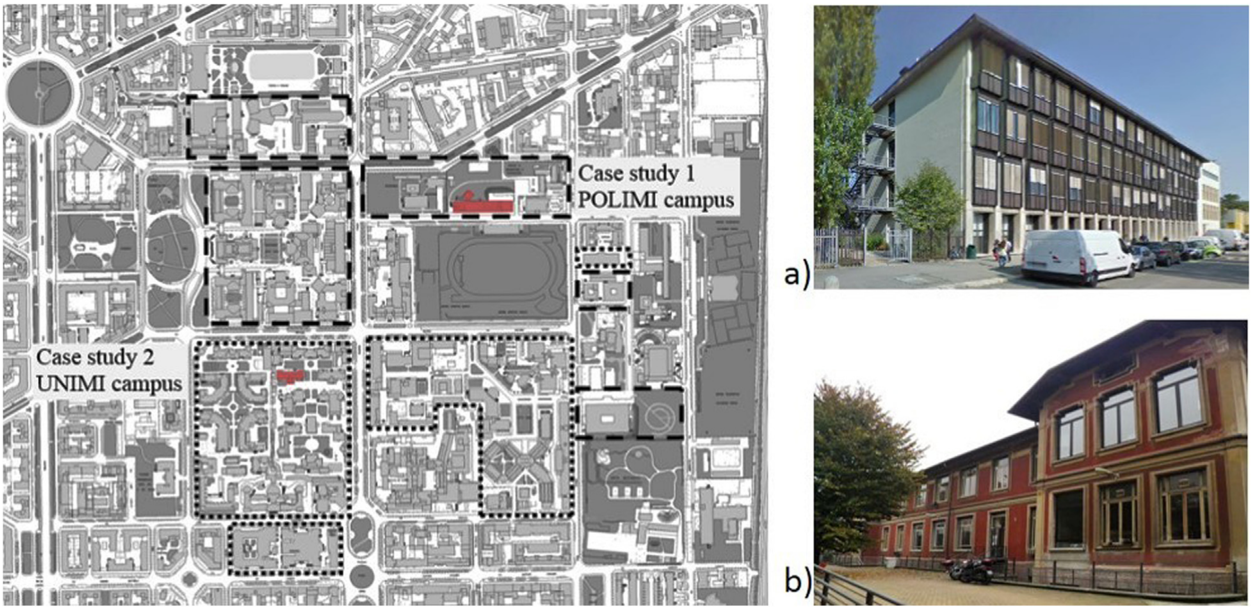


Fig. 2. Identification of the building case studies in the POLIMI (———) and UNIMI (...) Campus Milan map and view of the façade of both case study.

The campus is here intended as the place where knowledge and practice can meet. The initiative is based on a strong bottom-up approach in which everyone can collaborate and propose ideas. The prerequisite for the success of the initiative is the creation of a strong awareness on the topic of sustainability within the community.

Given the historical and architectural value of the campus existing buildings, the refurbishment is the solution to improve the environmental performances and to provide considerable potential for energy conservation and further sustainable benefits. Case studies are a proven validation of the MEEBR methodology and the possibility to replicate the approach to other buildings (Fig. 2).

The case studies analyzed in the "Integrated Design Refurbishment Laboratory" are the buildings identified. In both buildings there are offices, classrooms and some laboratories.

In the following paragraphs a brief state of art of the case studies is provided in order to better identify the most suitable strategies of retrofitting to adopt in each case, while the applica-tion of MEEBR is presented in the Section 4 and the respective results are discussed in the Section 5.

3.1. Case study 1 at POLIMI campus

The building (Fig. 2a) has a regular rectangular plan, oriented along the North–South direction and it is constituted by two parts, one built in 1965 and the other, more recent, built in 1991. The building no. 20 is structured into one basement and four floors above ground, in which there are meeting rooms, offices and workshops for teaching and research and a large classroom in the header. The entire area of the building is 1350 m^2 for around 150 daily users (considering students, professors and temporary visitors or services). It has three main entrances: two on the South face and the third in the North one; while in West façade there is the emergency exit with external metallic stairs. The oldest part of the building has a load-bearing structure made of reinforced fin-ished concrete and the envelope is built with a coating of pre-fabricated panel with a very low thickness of insulations. The re-cent part of the building has a load-bearing structure made of reinforced concrete with plaster coating that at ground floor be-comes "a bugnato". The result is a great modularity of the facade, typical of the prefabrication system.

3.2. Case study 2 at UNIMI campus

The building (Fig. 2b) was designed in 1913 by two architects Augusto Brusconi and Gaetano Moretti. Officially the first stone was laid in November 1915; however work immediately slowed due to the First World War and were not finished until 1927.

This building is composed by a basement and two floors above ground, in which there are offices, laboratories and classrooms. It has a regular plan oriented along the West-East direction. The load-bearing is made of structural walls composed with two bricks walls and in the main wall with two bricks and a half walls. The ceiling and the floors have different structure, the second floor has an arched ceiling made with bricks, and instead the other floors are made of hollow brick block. The facades are practically devoid of ornament, where the use of "humble" materials are typical of the local architecture and it represents the desire to keep public architecture free of luxury.

The building area amount in 1162 m^2 for around 90 daily users (considering students, professors and temporary visitors or services).

4. Application of the MEEBR to the case studies

The students, applying the MEEBR for their project during the Refurbishment Lab, tested the four phases focusing on their respective goals derived from the analysis of the current state of the buildings and the energy potentials estimated for each building.

From the MEEBR application, two different refurbishment approaches derives being fundamental the declination of the project target of the first phase.

Bought case studies focuses yours refurbishment project on the energy efficiency improvement, investigating a series of interventions to reach a very low energy consumption.

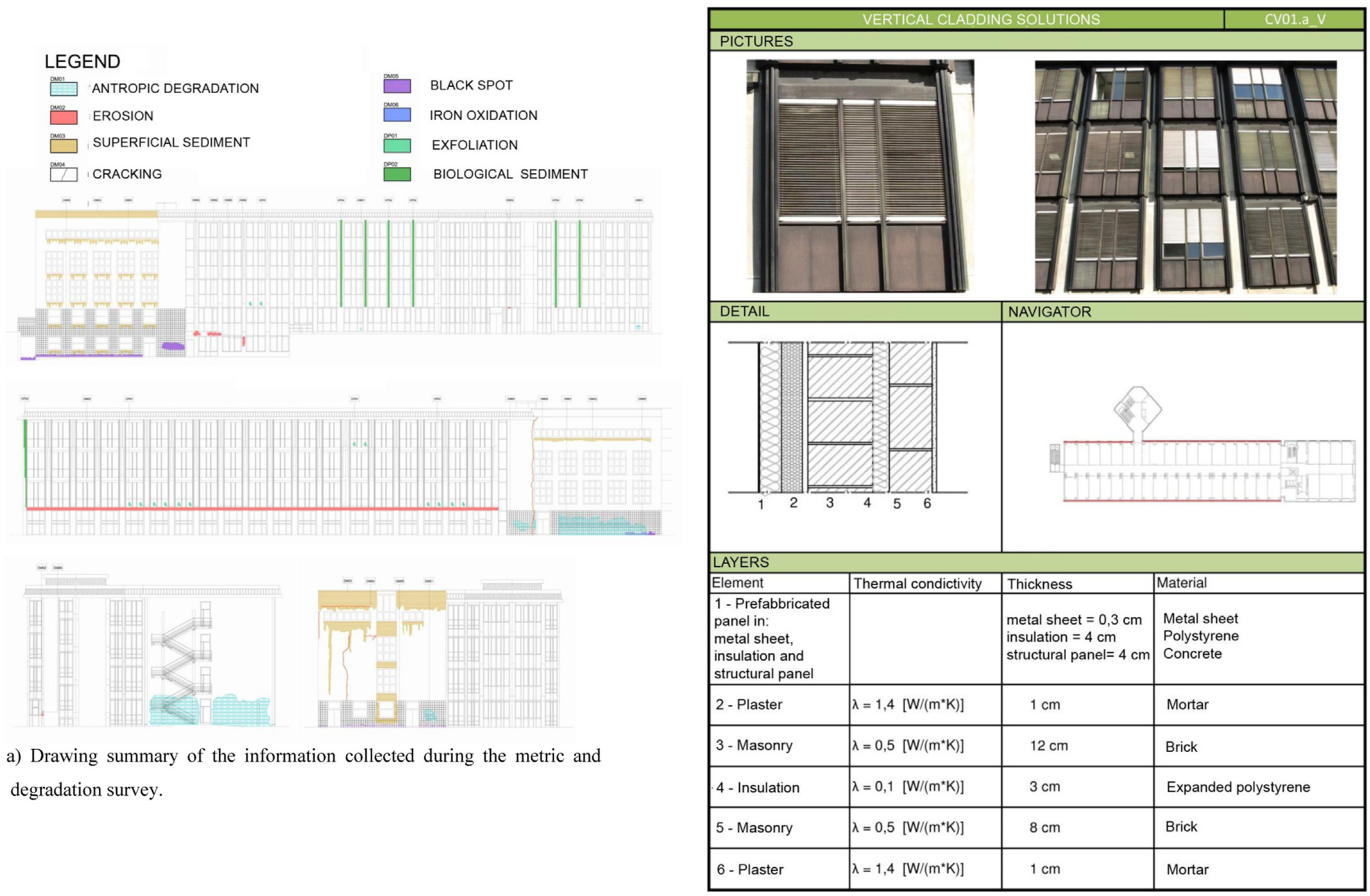
The MEEBR application within the four phases is summarized in Table 1 for each case study.

5. Main results and discussion

The main results for both case studies are presented below, which is intended as a summary of the whole process followed by

Table 1
Key phases application to the case studies of the MEEBR.

Case study	Phase 1	Phase 2	Phase 3	Phase 4
1	SCOPE = envelope + system plant refurbishment ENERGY PROJECT TARGET = A label class of Lombardia Region	DIAGNOSTIC PROCESS: degradation analysis ENERGY AUDIT: building physic and performances assessment	RETROFIT OPTIONS: Definition of 12 refurbishment interventions	VALIDATION and VERIFICATION: investigation with sensitivity analyses using CENED+
2	SCOPE = envelope + system plant refurbishment PROJECT TARGET = A label class of Lombardia Region	DIAGNOSTIC PROCESS: degradation analysis ENERGY AUDIT: building physic and performances assessment	RETROFIT OPTIONS: Definition of 27 refurbishment interventions	VALIDATION and VERIFICATION: investigation with sensitivity analyses using Sefaira



a) Drawing summary of the information collected during the metric and degradation survey.

b) Example of codification and mapping reports of the construction technologies

Fig. 3. (a) Drawing summary of the information collected during the metric and degradation survey. (b) Example of codification and mapping reports of the construction technologies.

students during the Laboratory.

The refurbishment process followed for the case study 1 and 2 had as main scope the refurbishment of the whole building (envelope + system plant) in order to reach the project target of class A label of Lombardia Region (Phase 1). The performance assessment (Phase 2) was conducted with different types of survey for the diagnostic process. While for the energy audit a performance assessment of the energy consumptions, for the case study 1 were conducted with the software CENED+ [21], open source tool provided by Lombardia Region, and for the case study 2 were conducted with the software Sefaira a dynamic simulation tool for energy and thermal performance assessment.

The whole diagnostic process concerned:

a) analysis of context, critical survey of all the factors that concern the area (roads, accessibility, transformations, significant buildings by importance or function, and physical and climatic characteristics, etc.) supported by a photographic survey;
b) historical reconstruction to investigate which transformations occurred in the course of building life (extensions or demolitions, significant variations of use, etc.);
c) metric and architectural typologies survey. This survey was supported by a literature search, about characteristic details developed in the area and in the period. The information collected were cataloged and indexed in order to understand for example repeated elements, use of special materials, shapes, types and construction details;
d) survey of construction technologies;

Table 2
Retrofit strategies summary identified from diagnosis process.

	Requirement	Performance required	Current state	Retrofit strategies
a	Thermal transmittance	U_V=0,27 W/m^{2}K U_H=0,24 W/m^{2}K U_W=1.8 W/m^{2}K	Uvalues does not meet the limit of regulation on performance requirements	Windows and frames substitution and insulation improvement of the external cladding
b	Ventilation	Health Indoor Air	No mechanical ventilation system. Presence of natural ventilation system control by casual window opening from users, not enough to ensure a healthy indoor air exchange.	Introduction of mechanical ventilation system with heat recovery
c	System plant performance	$\eta \geq 0,85$	The overall performance of the heating system is equal to 0.5.	It is necessary to increase the overall efficiency of the heating system varying the efficiency of the subsystems: emission control, distribution and generation.
d	Acoustic comfort	Thermal insulation for facade ≥ 42 dB Level of impact noise ≥ 55 dB	The performance requirements are already quite satisfied.	The change of windows and the envelope insulation could improve more the acoustic comfort of the building.
e	Building air tightness	Target set – Best Practice Outcome for school equal to 3.0 m^3/hr/m^2@ 50 Pa) (*)	The windows and their connection to the closure opaque present problems of tightness.	The change of windows and an adequate connection to the façade could reach the target set.
f	Water tightness	Target set Class 9 A Roof – no infiltration According to UNI EN 1027 – UNI EN 12,208	No problem for the window+frame. Some cases of infiltrations in the roof.	The change of windows and an adequate connection to the façade could reach the target set. For the roof, necessary a waterproofing intervention.
g	Structural Strength	Test ULS and SLS Seismic	Seismic monitoring non-compliant	Seismic analysis required to assess consolidation works
h	Fire prevention	Compliance with the fire protection requirements from legislation	Compliance with the fire protection requirements	Periodic maintenance

(*) According to ATTMA Technical Specification Standard 1 Measuring Air Permeability of Building Envelope, ATTMA TSL2 and CIBSE Technical Memorandum 23:2000.

e) survey of degradation. This survey was conducted referred to each technical elements. The information collected were shown with two instruments: survey forms of anomalies (intended as an unexpected visible event or detectable by instruments), which indicate the individual degradation occurred; and mappings that reports, with graphic codes, extent and location of each anomaly and the superposition of all degradations detected.

Phase 3 follows subsequently with the identification of possible retrofit options with performance improvement strategies.

In the end, phase 4 verify and validate the retrofitting strategies chosen in order to estimate with numerical data the effective energy saving reduction with a comparison of energy consumption before and after the retrofitting on building model. For the validation phase two different kind of tool were used: a steady state software, CENED+, for the case 1 and a dynamic simulation tool, Sefaira, for the case 2.

5.1. Case study 1: analyses and results

Once defined in phase 1 the scope of the refurbishment approach and the project target (Table 1), an energy audit was realized on POLIMI campus in order to identify which strategies could be more suitable to reach the objective of the A label class according to the energy regulation mandatory in Lombardia Region in parallel with a whole diagnostic process. The detailed descrip-tion of the phase 2, being not the main purpose of the paper, is omitted, but a summary of the information and drawing reports used for the diagnostic process is presented in Fig. 3a and b.

The main indicator considered for the comparison before and after the application of refurbishment strategies was the primary energy for heating (EPH). During the performance assessment, the EPH value estimated, before the simulated refurbishment intervention, was equal to 311,43 kWh/m^{2}y corresponding at G energy label. Crossing all these information (metric, construction technology, materials, degradation and energy performances) students were able to make a reliable diagnosis.

The retrofitting options identified for the case study 1 at POLIMI campus during the phase 3 are summarized in Table 2. From a critical review of Table 2 contents in order to reach the best energy retrofitting process, students individuated 12 strategies to investigate using the steady state CENED+ tool. The verification of the effectiveness of these strategies simulated on the respective building model are summarized in Table 3 with the indication of the % of energy saving and the energy label reached, which represent the MEEBR final phase.

The results (Figs. 4 and 5) of the sensitivity analyses showed that the refurbishment strategies necessary to reach the A label cannot regarding only the envelope, but they must be coupled with the enhancement of the heating and ventilation system generation.

5.2. Case study 2: analyses and results

After the definition of refurbishment objective and energy target, a complete diagnostic process were conducted also for the case study 2 with the same survey of the case study 1, while the energy audit were conducted with the Sefaira PlugIn of SketchUp. The results of the energy and building physics assessment showed the need to improve the energy efficiency of the whole envelope (opaque+transparent) due to the high losses through the envelope (Table 4). This consideration became the central idea which guided the identification of the possible retrofitting strategies in phase 3. The solutions were structured into two main families: building and system plant and then subdivided

Table 3
Main results of the 12 simulated scenarios conducted with CENED+.

	Refurbishment strategies (RS) n.	Refurbishment description	Performance objective	% energy saving for EPH	Energy label
a	1	Change of windows	U_w=0.5	25	E
a	2	Envelope insulation addition	$U_{en}<0.27$	36	D
c	3	Condensing boiler integration	η_i=0.93	24	E
b	4	Heat recovery ventilation	η_r=0.7	38	D
a	5	Strategies n. (1+2)	U_w=0.5, $U_{en}<0.27$	61	C
a+c	6	Strategies n. (1+2+3)	U_w=0.5, $U_{en}<0.27$, η_i=0.93	71	C
a+b	7	Strategies n. (1+2+4)	U_w=0.5, $U_{en}<0.27$, η_r=0.7	90	B
a+b+c	8	Strategies n. (1+2+3+4)	U_w=0.5, $U_{en}<0.27$, η_i=0.93, η_r=0.7	92	A
a	9	New ventilated facade	U_w=0.5, $U_{en}<0.27$	52	D
c+a	10	Strategies n. (3+9)	η_i=0.93	64	C
b+a	11	Strategies n. (4+9)	η_r=0.7, U_w=0.5, $U_{en}<0.27$	91	A
c+b+a	12	Strategies n. (3+4+9)	η_i=0.93, η_r=0.7, U_w=0.5, $U_{en}<0.27$	93	A

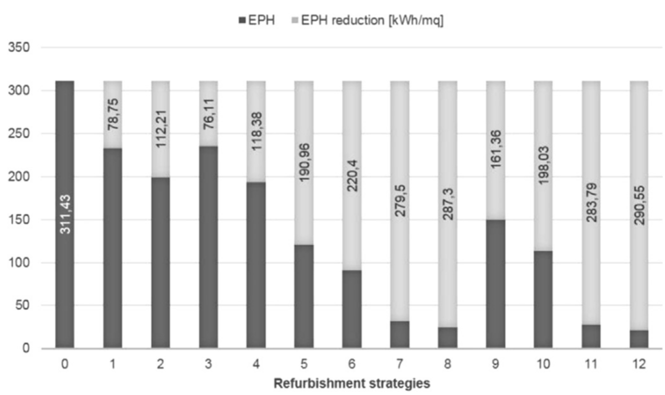


Fig. 4. Comparison of the EPH value before the retrofitting (scenario 0) with the whole sensitivity analyses (scenarios 1 – 12).

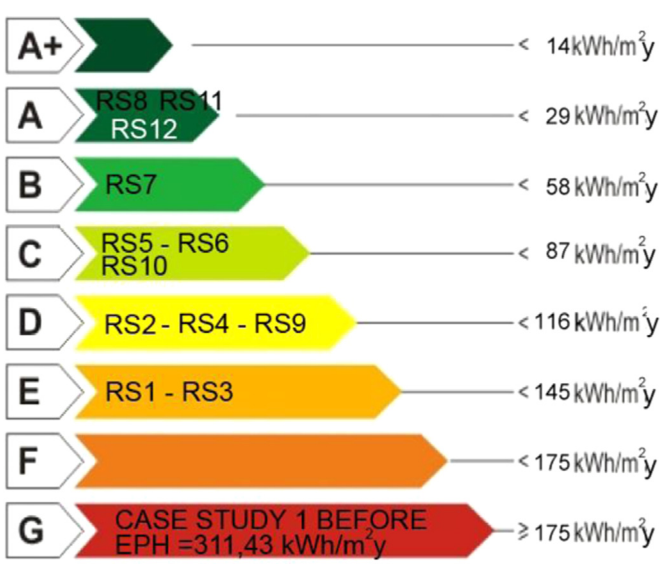


Fig. 5. Identification of the energy class reached with the adoption of the retrofitting strategies (RS) simulated with CENED+.

respectively into subcategories (external wall, window, SGHC and roof for the first and HVAC for the second). The evaluation phase 4 were conducted with two different software: a steady state CENED +, and a dynamic simulation tool Sefaira in order to have a clear and complete overview on the possibility to reduce energy consumptions with different retrofitting strategies. In particular, the student identified a series of combinations of these retrofitting strategies into specific scenarios (Table 5) and considering four main parameters as output: the % of thermal comfort, the annual energy consumption [kWh/m^2], the annual CO_2 production [kgCO_2] and the utility cost [Euro/m^2]. Fig. 6 represents the basic Sefaira 3D model used for the simulation on the case study 2 with the identification on entity palette for each technical element (wall, window, roof, etc.). Sefaira allows to run a first set of simulation results directly in SketcUp thanks to the respective plug-in, which provide immediate feedback of the design options selected.

The comparison of results of the analyses with the two software is summarized in Table 6 highlighting the Energy consumptions for Heating Season (EPH) and the energy label reached according to the Italian regulation on energy consumptions.

Observing the Fig. 7-graphic on the energy used in the whole scenarios-from strategy C1 to C11 there is a constant decrease of energy used which correspond to the increased insulation addition strategies. A marked reduction is registered from C12 to C15, for which the strategies foresee the windows replacement. The greater decrease of energy occurs with the roof replacement (C22). Contrasting the peak of consumption in C24 corresponds to the insertion of the UTA system.

5.3. *Approach limitations*

The MEEBR approach was defined, as stated in the previous paragraph, from a review on existing methodologies and declined into four steps in order to have a systematic process to follow during the building refurbishment design and to identify and verify strategies in terms of energy efficiency with computer simulations.

Energy and thermal simulation is a valuable tool in the refurbishment of buildings: it can identify the most effective upgrades and provide energy-saving information, but at the same time presents limitations. Simulating an existing building is in fact a difficult task, as older buildings are often poorly documented and the condition and efficiency of the plant may be unknown. Metering is usually scarce and a breakdown of significant energy users can be impossible to attain. Attempting to accurately model such a building can be an expensive and often futile exercise. However, the fully refurbished building can be modeled to predict the final expected energy performance and to identify the most effective areas here improvements can be made.

The MEEBR proposed a way to simplify this process, following step by step all the phases from the information collection on the current state of the existing building, through the identification of strategies, to the final modeling among a series of refurbishment scenarios.

Table 4
Summary and identification of retrofitting strategies for case study 2.

Building Envelope External Wall	Window	SGHC	Roof	System Plant HVAC
I0 No thermal insulation	W0 Wood frame and single glazing	S0 Clear single glazing	R0 Wood structure: uninsulated	E0 Typical gas heating (radiator)
I1 Insulation 3 cm	W1 Aluminum frame and standard double glazing	S1 Clear double glazing	R1 Wood structure: insulated, no ventilation	E1 Typical gas heating (radiator) + ventilation system
I2 Insulation 4 cm	W2 Performance aluminum frame and standard double glazing	S2 Reflective coated glazing	R2 Wood structure: well insulated, ventilated	E2 Efficient centralized ventilation system
I3 Insulation 5 cm	W3 Performance aluminum frame and performance double glazing	S3 Internal blinds	R3 Wood structure: extremely well insulated, ventilated	E3 Efficient lighting system (LED)
I4 Insulation 6 cm	W4 Performance aluminum frame and standard triple glazing		R4 Special structure: Isotec xl and Autan Terreal	E4 Solar PV
I5 Insulation 7 cm				
I6 Insulation 8 cm				
I7 Insulation 9 cm				
I8 Insulation 10 cm				
I9 Insulation 12 cm				
I10 Insulation 14 cm				
I11 Insulation 16 cm				
Current state (CS)	= I0+W0+W1+S0+R0+E0	Project solution (PDR)		= I8+W3+S1+R2+E2+E3

Table 5
Simulated scenarios for the phase 4 of case study 2 with Sefaira.

Strategies combination	Thermal comfort		Energy consumption	CO_2 production	Utility cost
	% < 20	**% > 26**	**kWh/m²**	**kgCO₂**	**Euro/m²**
SDF = I0 + W0 + S0 + R0 + E0	7	29	160	65,486	15
C1 = I1 + W0 + S0 + R0 + E0	7	30	146	60,958	14
C2 = I2 + W0 + S0 + R0 + E0	7	30	144	60,380	14
C3 = I3 + W0 + S0 + R0 + E0	7	30	143	59,940	14
C4 = I4 + W0 + S0 + R0 + E0	7	30	142	59,642	14
C5 = I5 + W0 + S0 + R0 + E0	7	30	141	59,416	14
C6 = I6 + W0 + S0 + R0 + E0	7	30	140	59,189	13
C7 = I7 + W0 + S0 + R0 + E0	7	30	139	58,960	13
C8 = I8 + W0 + S0 + R0 + E0	7	30	139	58,806	13
C9 = I9 + W0 + S0 + R0 + E0	7	31	138	58,574	13
C10 = I10 + W0 + S0 + R0 + E0	8	31	137	58,340	13
C11 = I11 + W0 + S0 + R0 + E0	7	31	137	58,183	13
C12 = I0 + W1 + S0 + R0 + E0	8	30	155	63,886	15
C13 = I0 + W2 + S0 + R0 + E0	7	31	151	62,490	14
C14 = I0 + W3 + S0 + R0 + E0	7	32	147	61,269	14
C15 = I0 + W4 + S0 + R0 + E0	7	32	144	60,298	14
C16 = I0 + W0 + S1 + R0 + E0	7	26	167	67,502	16
C17 = I0 + W0 + S2 + R0 + E0	8	23	174	69,758	16
C18 = I0 + W0 + S3 + R0 + E0	8	19	180	71,739	17
C19 = I0 + W0 + S0 + R1 + E0	7	32	91	43,784	10
C20 = I0 + W0 + S0 + R2 + E0	7	33	81	40,633	9
C21 = I0 + W0 + S0 + R3 + E0	7	34	77	39,423	9
C22 = I0 + W0 + S0 + R4 + E0	7	34	75	38,687	8
C23 = I0 + W0 + S0 + R0 + E1	0	0	183	83,955	19
C24 = I0 + W0 + S0 + R0 + E2	0	0	274	242,504	46
C25 = I0 + W0 + S0 + R0 + E3	7	27	155	56,443	13
C26 = I0 + W0 + S0 + R0 + E4	7	29	153	56,476	14
PDR = I8 + W3 + S1 + R3 + E2 + E3	6	27	68	59,628	12

The accuracy and reliability of the analysis depends on the quality and consistency of data inputs from a range of data sources. Care should be taken to integrate the timing and base assumptions used for each of these distinct analyses, since all the information is needed in order to make the decision. Any analysis gaps will skew the results.

A computer simulation, by its very nature, must make many assumptions about the building, its systems, its controls and the people who operate it. Models are usually based on an idealized set of operating conditions; rather than attempting to model the hysteresis in a control system, a blanket safety factor is applied to the energy consumption of the entire mechanical plant.

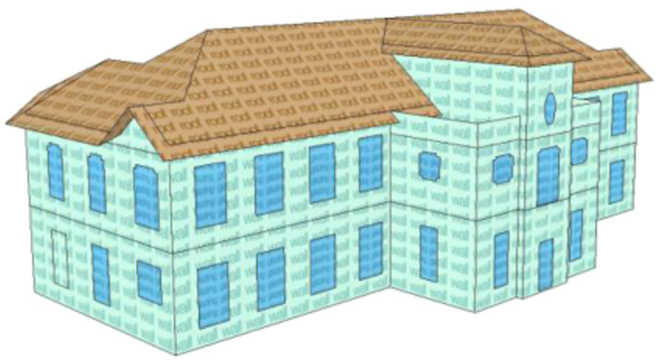


Fig. 6. Building model of case study 2 built in SketchUp.

Table 6
Comparison between steady state software (Cened+) and dynamic simulation tools (Sefaira) of the Energy in use for heating season [kWh/m^{2}y].

Strategies combination	EPH with CENED+	Label	EPH with Sefaira	Label	% variation
SDF=I0+W0+S0+R0+E0	110	D	118	E	6.94
C1=I1+W0+S0+R0+E0	98	D	102	D	3.93
C2=I2+W0+S0+R0+E0	95	D	99	D	4.00
C3=I3+W0+S0+R0+E0	94	D	98	D	3.90
C4=I4+W0+S0+R0+E0	93	D	97	D	3.57
C5=I5+W0+S0+R0+E0	92	D	96	D	3.51
C6=I6+W0+S0+R0+E0	91	D	95	D	3.43
C7=I7+W0+S0+R0+E0	90	D	94	D	3.35
C8=I8+W0+S0+R0+E0	90	D	93	D	3.56
C9=I9+W0+S0+R0+E0	89	D	92	D	3.47
C10=I10+W0+S0+R0+E0	88	D	91	D	3.37
C11=I11+W0+S0+R0+E0	89	D	91	D	2.87
C12=I0+W1+S0+R0+E0	107	D	112	D	4.77
C13=I0+W2+S0+R0+E0	103	D	107	D	4.17
C14=I0+W3+S0+R0+E0	99	D	103	D	4.06
C15=I0+W4+S0+R0+E0	95	D	99	D	4.05
C16=I0+W0+S1+R0+E0	119	E	126	E	5.28
C17=I0+W0+S2+R0+E0	126	E	134	E	5.86
C18=I0+W0+S3+R0+E0	132	E	141	E	6.29
C19=I0+W0+S0+R1+E0	53	B	53	B	0.23
C20=I0+W0+S0+R2+E0	45	B	44	B	0.86
C21=I0+W0+S0+R3+E0	42	B	41	B	1.91
C22=I0+W0+S0+R4+E0	40	B	39	B	2.37
C23=I0+W0+S0+R0+E1	128	E	135	E	5.00
C24=I0+W0+S0+R0+E2	109	D	93	D	14.22
C25=I0+W0+S0+R0+E3	129	E	142	E	8.81
C26=I0+W0+S0+R0+E4	108	D	114	C	5.15

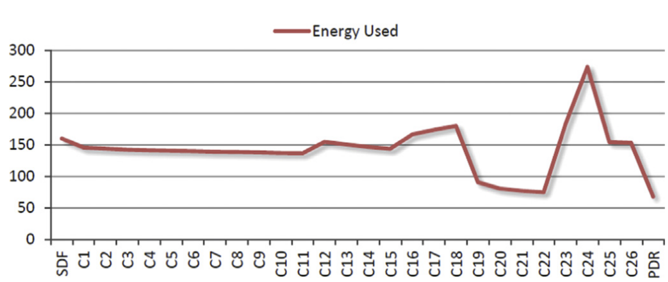


Fig. 7. Diagram of Energy used in kWh/m^{2}y for all the scenarios of Table 5.

In our specific case, the following assumptions were considered for both software: CENED+ and Sefaira. The simulation settings were kept the same or as close as possible in order to compare the different tools and the results with the actual building energy performance. The inputs used in Sefaira vary in complexity and number of parameters compared to those used in CENED+.

Moreover, the findings illustrate that, although it is possible to use CENED+ as a design tool at the early stages in order to predict annual energy consumption and to investigate design improvements, there are limitations in its application. Firstly the absence in CENED+ of a graphical representation of the building and an inability to interrogate results for individual rooms. The ability of a dynamic methodology (Sefaira) and a steady state methodology (CENED+) to capture the effects of design changes was established by a parametric sensitivity analysis. Both programs illustrated a capability to investigate the key parameters, but application and interrogation of results were facilitated with greater ease in Sefaira. Both programs generated an improvement in annual energy performance and rewarded the same design changes as the greatest improvement although the percentage of acceptable errors between the two methods is around 4.40% (Table 6).

6. Conclusions

The paper presented an overview on retrofitting approaches, in particular for the university communities, highlighting the importance to promote green building initiative on campuses and it proposed the outline for the MEEBR methodology to identify the most suitable strategies for energy efficiency refurbishment and verify them with Building Energy Performance Simulation tools (BEPS).

The major fundings of the presented work-supported by the practical experience of the "Città Studi Sustainable Campus" project and the students' application of the MEEBR to the two case studies-are following described.

(1) The refurbishment is the most effectiveness solution in case of building stock with a historical and architectural values.
(2) Each building is unique. There is no solution one fits-all. This is even more true when it comes to cultural heritage where the priority remains protecting the building and its value. Nonetheless the MEEBR approach outlines generic steps, recommendations and factors that can contribute to the success of an energy efficient retrofit regardless of the specific features of the building and to the potential replicability of the methodology.
(3) Computer simulation of existing buildings can assist the refurbishment to achieve desired energy performance. It can be useful in assessing the merit of various pieces of equipment and can identify the most effective upgrades. However, adequate information regarding the building, its services and its operation is vital in achieving a robust and useful model.
(4) It is crucial from the beginning of the refurbishment design process, selecting a software for the energy assessment in function of the particular job and the outputs that you want to reach with the tool.

The concluding remarks and recommendations for future investigations in this area are as follow.

1. Whole-of-building retrofit with comprehensive energy simulation, economic analysis and risk assessment is an effective approach to identifying the best refurbishment solution.
2. The MEEBR presented in this paper is a systematic methodology that must be adapted case by case considering the refurbishment target, the economic feasibility and buildability since the beginning of the refurbishment design process.
3. This preliminary experience with students on MEEBR application shows that case study examples like these can help increase consideration of the integrated research approach to improve sustainability performance in historical buildings taking into account

also the user's participation of a university campus.
4. The case studies results were carried out using numerical simulations, considering the increasing important role which, building energy simulations is playing in refurbishment building design, also at early phase, above all to achieve the energy efficiency target goal as requested by recent EPBD recast.
5. The building energy simulation software available in the market ranges from the simple and approximate to the detailed and sophisticated. In the presented paper the evaluation of the retrofitting strategies were conducted with both type of software: a steady state, CENED+ and a dynamic one, Sefaira. The comparison of their methodology analyses, in particular on the case study 2, leads to the statement that it is essential from the beginning selecting a program in function of the particular job and the outputs that you want to reach with the tool and that the percentage of acceptable errors between the two methods is around 4,40%.
6. The current methodology could be integrated in the future into a software tool that can be linked in real-time readings from meters based in order to have a more realistic energy audit of phase 1 and project setup and a validation of the respective sensitivity analyses with monitoring data (phase 4).

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