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Sustainability of a historical building renovation design through the application of LEED® rating system

Marialuisa Baggio, Chiara Tinterri, Tiziano Dalla Mora*, Alessandro Righi, Fabio Peron, Piercarlo Romagnoni

Department of Design and Planning in Complex Environments, University IUAV of Venice, Santa Croce, 191, Tolentini Venice 30135, Italy

Abstract

This paper presents a case study of a sustainable certification of a building renovation. The new LEED® rating system, GBC Historic Building™ protocol, proposed by Green Building Council Italy and addressed to Italian historical heritage, was applied to the High School "A. Canova" in Treviso, chosen because it was built before 1945 and it required a restoration work.
The aim of this paper is to present a retrofit design based on strategies according to three objectives: energy saving, preservation of historical architecture, improvement of indoor environmental quality for users.
The application of GBC Historic Building™ protocol has been carried out according to the protocol guidebook. The novelty of this paper is that GBC Historic Building™ has been used as a design tool, not as assessment tool, in order to develop a design strategy. At first a building survey of the building has been performed to define the state of art in terms of structural instability and deterioration of surfaces and architectural elements in order to propose the most important renovation measures; the dynamic simulation was performed to calculate the building envelope thermal losses and the building energy demand for heating. Different energy efficiency measures have been proposed and an optimal solution has been defined according to simulation data and cost analysis evaluation. Three main goals have been achieved: the reduction of building energy consumptions up to 39 %, the conservation of the historical parts of the building and the attainment of good thermal comfort in school classrooms. A Silver LEED level of certification has been gained.

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Keywords: LEED® rating system; historical building renovation; energy saving; school building; sustainability; dynamic simulation; GBC Historic Building™

* Corresponding author.
E-mail address: tdallamora@iuav.it

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1. Introduction

The role of the construction sector in pursuing the reduction of greenhouse gases emissions and to tackle the climate change and global warming is widely known and recognized by the European Council which has set the objective of reducing greenhouse gases emissions by 2050 in respect to 1990 [1]. In fact it has been estimated that construction sector is responsible of almost 36 % of greenhouses gas production: in this case the targets are fixed on an ambitious reduction about 89–91 %.

To achieve these objectives one of the major challenges concerns the refurbishment of existing buildings stock, especially residential sector that in Italy corresponds to 88 % of total buildings [2]. Even if a significant part of the Italian building stock has been realized between the '50s and the '80s (beyond 1,5000,000 buildings), as a result of the urban growth following the Second World War, over 3,900,000 buildings have been built before the 1920s [3]. Moreover, many of these constructions are characterized by historical-artistic values and therefore they are protected as Cultural Heritage, so they are excluded from energy refurbishment obligations according to the present Italian energy legislation [4], in order to safeguard their integrity.

Concerning buildings renovation, the European Directive 2012/27/EU [5] on Energy Efficiency establishes that Member States have to promote a long-term strategy for mobilizing investment in the renovation, emphasizing the exemplary role and increasing the rate of retrofitting public buildings: in fact from January 2014 public Institutions had to renovate a share equal to 3 % of owned or occupied buildings.

Given that public buildings are often host in ancient buildings one of the most important challenge in building energy retrofitting is represented by historical buildings. For historical buildings it is commonly recognized as something that is significant as a source for the discipline of history and can be associated with a particular meaning or value, according to one or more of the following criteria: age; rarity; unique or unusual example; outstanding example; connected to a well-known person; associated with a historic event [6]. However an intervention on historic building has to consider different aspects: historical and energy motivations, but also economical (cost, maintenance) and environmental. The aim of energy retrofit lays into an opportunity for revitalizing and conserving cultural heritage [7]. In this terms Ascione et al. [8] proposed a multi-criteria approach, specifying that the adoption of energy efficiency measures is possible if these interventions allow the preservation of the cultural and historic identity of the building. Some authors investigated and compared different strategies to improve energy efficiency in public buildings: Ma et al. [9] provided an overview of recent research demonstrating that energy performance could be enhanced through envelope insulation and HAVC systems replacement. Public sector meets in school typology the ideal and principal test case because of some reasons: a) schools represent the most widespread typology among the public stock; b) the energy efficiency strategy could be replicated in many similar contests; c) the energy refurbishment has positive effects on internal comfort and on policy example. De Santoli et al. [10] analysed consistency of existing school buildings in terms of energy consumption, proposing the implementation of different measures comparing measured consumptions and theoretical needs.

In this framework the Italian Green Building Council [11] proposed a new rating system for integrative design for a sustainable process in buildings restoration: the GBC Historic Building Protocol. Boarin et al. [12] presented the scope and the structure and the contents of GBC Historic Building, underlining the importance to consider the historical values and the performance of heritage in a restoration strategy.

In recent years research showed high interest in energy efficiency and thermal comfort in historic buildings: Martínez-Molina et al. [13] summarized different methods and techniques used for achieving performance refurbishments, organizing a selection of case studies by building type (residential, religious, academic and palace, museums, libraries and theaters, urban areas, and others); in particular the overview underlines that historic buildings dedicated to educational use are widely spread in Italy but also this building type represents difficulty on energy refurbishment and lower number of investigation due to the restricted flexibility of use and design and the not possible accessibility to the structures.

This study aims to propose GBC Historic Building^{TM} as operative tool for a sustainable retrofit design on historical and educational buildings, showing how an integrated design could improve energy performances and indoor thermal comfort, also preserving cultural heritage: the framework allows to consider different kind of interventions depending on the objectives. A multi-criteria strategy is presented, identifying the best solution in terms of economical and energy impacts that reduces of 39 % of the actual school energy consumption.

2. Method

2.1. GBC Historic Building^{TM} rating system

GBC Historic Building^{TM}, developed by GBC Italy and published in 2014, is a rating system for the assessment and voluntary certification of the sustainability level in restoration and rehabilitation of historical buildings. The aim of this protocol is to achieve high energy performances while maintaining and transmitting the historical and testimonial values of cultural heritage. The protocol refers to historical building, meaning constructions recognized as "material witness having the force of civilization" [14]. According to this definition, analyzed buildings had to be marked by a pre-industrial character in the construction process, that conventionally in Europe is before 1945, when the building sector knew a deeply change in terms of materials, techniques and technologies. In particular existent technical components should be an amount of 50 %, proved by the compilation of a specific form, called "historical building identity card" [15], that collects all qualitative and quantitative information about the building, based on the division of technological system proposed by the Italian Standard UNI 8290: 1981 [16].

The structure of GBC Historic Building^{TM} is based on LEED® (Leadership in Energy and Environmental Design), a set of rating system for design, construction, operation and maintenance of green buildings, and it has been adapted to the specificity of the historical heritage developing an Italian version of LEED® rating system for New Construction and Major Renovation, named LEED® Italy. The system is based on a list of requirements: pre-requirements are mandatory to succeed the certification, credits are voluntary and are awarded with points. All requirements are grouped in different topics: Sustainable Sites (SS), Water Efficiency (GA), Energy & Atmosphere (EA), Materials and Resources (MR), Indoor Environmental Quality (QI), Innovation in Design (IP), Regional Priority (PR).

Table 1. GBC Historic Building^{TM} categories, points and weighting.

Category	Pre-requirements	Credits	Points	Weighting
Historic Value (VS)	1	10	20	18 %
Sustainable Sites (SS)	1	9	13	12 %
Water Efficiency (GA)	1	3	8	7 %
Energy & Atmosphere (EA)	3	5	29	26 %
Materials and Resources (MR)	3	5	14	13 %
Indoor Environmental Quality (QI)	2	13	16	15 %
Innovation in Design (IP)	/	6	6	5 %
Regional Priority (PR)	/	4	4	4 %
Total	11	55	110	100 %

In GBC Historic Building^{TM} a new topic, i.e., Historic Value (VS), has been added. This new category aims at a high level of sustainability of the process by the valorization of the positive qualities of pre-industrial asset, through the identification of precise methods of investigation and specific operational principles. In Table 1 categories have been listed and the weight of each category among a final score of 110 points is reported. The total amount of achieved credits qualifies the building among four level of certification, Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), Platinum (80 points and above) until a 110 points maximum. In this way GBC Historic Building^{TM} represents the first rating system specifically targeted to the historic buildings and also it aims to quantify the energy efficiency and environmental quality of the intervention with the preservation of all the equipment of a building.

2.2. Case study

The case study is an ancient school building, the "A. Canova" High School, whose characteristics are shown in Table 2. In Italy [17] a great number of schools, more than 60 %, have been built before 1974 and more than 30 % lays in a bad state of conservation showing low energy performances, thus requiring urgent redevelopment. The case study is both a historical and public building. It is placed in the historical center of Treviso, in the North–East of Italy

[18]. The building was built in 1922 and was rebuilt following the bombing of 1945. In the last thirty years significant interventions were not carried out, just any maintenance for replacing of heating system, compliance with safety regulations and reorganization on space distribution.

The building presents a neo-classical style and each element in the façade and in the internal space recalls to Vitruvian criterions: a monumental façade with Ionic semi-columns and pediment, presence of friezes and decorations in imitation ashlar, a broad entrance, high ceilings and windows with large surface area and lighting.

In general the structure presents a tripartite conformation: atrium and connections are in the main building that is advanced on the street front, while classrooms are located along the two symmetrical and backward wings. It consists of three floors above ground with the administration and didactic spaces, a basement including storage and thermal power plant, and an attic used as a scientific laboratory. Currently the building has a traditional low efficient heating system (no cooling system) with two gas-fired boilers with a total useful heating power of 464 kW each, radiators as emission systems.

Table 2. “A.Canova” High School characteristics.

“A.Canova” High School characteristics	
Site	Treviso (TV)
Altitude	15 m a.s.l.
Heating degree days	2378 HDD
Climate zone	E
Total Building Area	5346.55 m^2
Net Conditioned Building Area	3650.18 m^2
Gross Floor Area	3193.77 m^2
Dispersion Surface	4545.63 m^2
Total Volume	13107.23 m^3
Compactness ratio (S/V)	0.34 m^2/m^3
Window to Wall Ratio (WWR)	13.85

The choice of this example is motivated by the lack of improvements in the recent past, by the need for interventions of architectural restoration and by the possibility to comply with all the requirements for access to certification process, in terms of age and presence of historical components.

Since 2007, the province of Treviso has promoted an energy audit campaign and monitoring of energy consumptions and environmental comfort in high schools, aimed at finding parameters for the possible retrofit. For this reason it has been possible to collect all the information necessary for applying the protocol.

3. Work frame

While LEED certification is usually applied to assess a finished project, this work aims at using GBC Historic Building™ as a design tool, not an assessment tool, in order to develop a design strategy. Work frame consists in three parts: the analysis of the building, the study of structure and requirements in the GBC Historic Building™ Guidebook and the proposal of a design strategy.

The first step identifies the potentiality and criticality of the school in terms of restoration needs and energy consumptions. A metric survey and archival research of architectural design and documents allowed to understand the historic development of the structure, the composition and the materials of the building; collected data allowed to fill the required preliminary document the “Historical building Identity Card” that recognizes a 86 % value of “historical substance and witness” in the case study, especially given by the conservation of the whole original structures, masonries and the majority of opaque envelope.

In Italian literature, concerning the high school buildings, Enea-Fire Commission published a Guidebook [19] in which the energy performance of schools buildings have been analyzed. According to this guidebook these buildings can be classified on a three-level scale, depending on the value of a Normalized Energy Index for heating, IENr, which is the energy consumption for heating normalized considering the heated volume, the degree days of the location, the heating period and the compactness ratio of the building. The IENr of "A. Canova" High School is equal to an average value of 9 Wht m^{-3} HDD^{-1}, that corresponds to a good level of quality for heating performance according to the ranking for high schools. Nevertheless the energy consumptions of "A.Canova" High School are too high and an intervention strategy shall be scheduled.

Concerning the conservation level, the building lays in a quite good condition: external walls present some deteriorations, especially on the main façade, due to the exposition to atmospheric agents (biological colonization and color washing), and some damage and cracks into the plaster on pavilion vaults and along the intrados of window frames.

In the second step, a detailed study of the GBC Historic Building Protocol has been carried out to plan which credits were the best to be pursued, which requirements they would need and which interventions should require. The third step identifies the aim of intervention on "A. Canova" High School, consisting on the enhancement of the quality of the building towards a higher energy performance level preserving historical heritage and structure. The main goals of the intervention are summarized in: energy saving, preservation of historical building and guarantee of environmental comfort of the users. These goals are linked to the three categories of the rating system: Energy and Atmosphere, Historic Value and Indoor Environmental Quality.

3.1. Intervention strategy

The choice of intervention strategy involves an overall assessment of the objectives in relation to boundaries conditions, normative and the building itself. In case of new construction many strategies are possible, but in existing buildings, mostly historical, the intervention is bound to geometry, morphology and historic value.

Table 3. Characteristics of selected parameters for identifying the best package of intervention.

Element	Code	Insulation material	Thickness, m	Thermal conductivity, W $m^{-1}K^{-1}$	Cost, € m^{-2}
Roof	A1	Aerogel	0.07	0.014	60.00
	A2	Mineral wool	0.16	0.036	10.00
	A3	VIP	0.03	0.006	138.00
	A4	Reflective	0.03	0.031	55.00
Facade	C1	Aerogel	0.05	0.014	60.00
	C2	Mineral wool	0.06	0.019	10.00
	C3	VIP	0.02	0.006	138.00
	C4	Reflective	0.02	0.031	55.00
		Replacement	U-value frame, W $m^{-2}K^{-1}$	U-value glass, W $m^{-2}K^{-1}$	Cost, € m^{-2}
Windows	B1	Low-E	1.5	1.408	280.00
		Replacement		Efficiency, %	Cost, €
Heating system	D1	Condensing boiler		95	11000.00

For this reason this research proposes a unique strategy based on a restoration plan of the building with a multi-criteria approach: an arrangement of different parameters drives to an optimal intervention in order to improve the existent, to have a balanced result for each goal, to obtain an established certification level. According to this strategy, initially the same importance has been given to each goals, but afterwards the energy audit revealed that the importance of energy retrofitting is the driver to operative conservation of historic value and subsequent indoor quality. In order to compare different measures of intervention a simulation model has been developed and analysed using Design Builder graphic interface and *Energy-Plus* simulation engine. By means of actual consumption data, the energy consumptions and envelope losses of the retrofit solutions have been determined.

Then the potentiality and criticality of the school could be identified by survey data and audit outcomes, so a restoration plan was developed with the aim of matching different measures of intervention in order to reach the best solution in terms of energy saving, historic preservation and comfort. Four parameters have been tested for an intervention on envelope and system: insulation of the roof and the external walls, replacement of windows, replacement of heating system and change of use; a dynamic simulation performed calculation for each package of interventions, that is given by a combination of the selected parameters and relative range of value (Table 3).

Finally by means of a cost-optimal analysis the best kind of retrofit measures has been found. In this phase, the application on rating system could begin according to the aims and main topics of research: relevant credits have been selected and then requirements and parameters have been calculated getting the relative score.

3.2. Credits selection

As previously said, this work proposes to apply a rating system as a tool for intervention design: giving the goals identification it is possible to determine the energy refurbishment strategies and, as consequence, the list of achievable credits, after the evaluation of mandatory pre-requirements. LEED® structure proposes Design credits and Construction credits, according the pertinence and the assessment during the whole refurbishment process. This research, being theoretical and without a subsequent executive phase, considers only the verification and the achievement of Design credits and the simulation of Construction credits, after the evaluation of data and design documentation. The selection of interested credits was possible by the holistic approach of LEED® methodology: each credit has been related to others in the same item but different area of interest or in the same LEED® category. In this way the co-relation allows to achieve credits regarding and sharing the same topic and also making an operative link between general aims and specific requirements. For example, an energy survey on an historical envelope (VS c1.1), including thermal transmittance calculation and IR thermography analysis, certainly affects the technical and conservative measures during the process of intervention, improving the envelope energy performance (EA c1), but it is connected also to the quality of indoor comfort (QI c6.1 and c6.2). The GBC Historic Building Protocol proposes a default setting with some possible correlations for each credit; this setting has been designed according to the three aims and has identified a selection of relevant credits (Fig. 1): due to this interconnection it is possible to achieve more credits and to use the same data for filling the required documents.

4. Results and discussion

The main result consists in a successful strategy of intervention in an historical educational building, able to manage an integrated and homogeneous design with energy and conservation measures. In terms of score, the proposed intervention achieves 27 verified points and 29 simulated points, giving a total 56 points that leads a silver level certification (Fig. 1). A brief presentation of the topics selected in the main thematic areas is presented: Historic Value, Energy & Atmosphere and Indoor Environmental Quality.

In Historic Value the preliminary diagnosis by the historical research has been rewarded: the analysis of materials and degradation level have been carried out and proposed interventions concerning cleanings and consolidation in the exterior masonry. Other issues concern the conservative reversibility, consistent with operating and structural destination and the management of the site from the point of view of sustainability; the total score is 9 points.

In Energy and Atmosphere, according to strategy and dynamic energy simulation, a multi-criteria approach allows to find the optimal package of measures in terms of energy performances and costs, reducing consumption by 39 %. Other issues concern the basic commissioning of energy systems, the minimum energy performance, basic management of refrigerants and the introduction of energy addressed by green power; the total score is 23 points.

In Indoor Environmental Quality, monitoring and management of systems is provided with the possibility of single regulation of lighting and temperature, resulting in greater comfort for users. Other issues relate to the minimum requirements for air quality, environmental control from tobacco smoke, evaluation of the minimum air flow rate, and thermal comfort design; the total score is 5 points.

Given the possibility of related credits, also in remaining thematic areas, Site Sustainability, Water Management, Materials and Resources, an additional total of 19 points can be achieved.

It is important to put in evidence some notes about the adopted strategy: the total score is given by the almost exclusive study of Design credits, which allow to reach a score of 40 points, corresponding to the minimum level to get LEED® certification. In this way this research shows the validity of the proposed strategy: the correlation of credits according to the objectives allows a good level of certification and sustainability of the intervention already in the planning stage and it will be developed and improved in future operational and construction phases. In fact these results could be the start for a new work based on topics and credits that belong to Construction category, connected to the executive and monitoring phases of the renovation design.

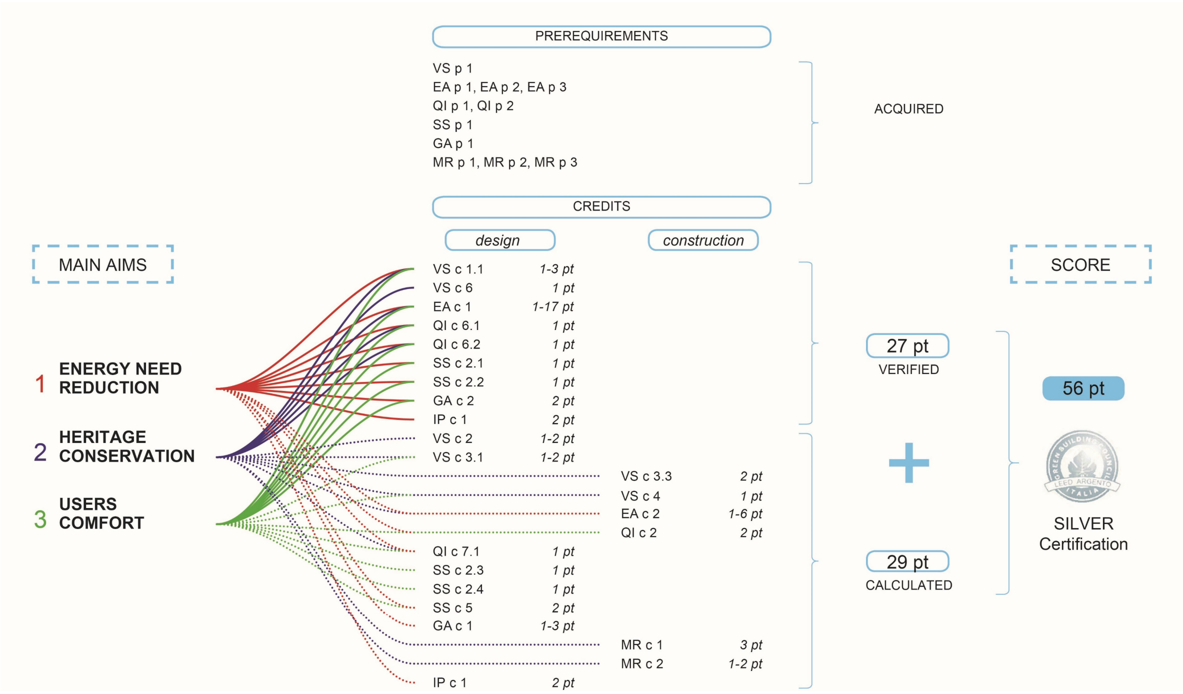

Fig. 1. Relationship between project aims, credits and final score obtained. Lines identify which credits have been selected to achieve the aims; Solid lines connect to credits for which it has been possible to perform calculation, to verify the results and to fill the required documentation by the protocol; dashed lines represents instead credits for which the result has not yet verified because of a lack of data for filling the required documentation or because it will be verified during the building phase.

The best package of energy efficiency measures is obtained by a roof insulation with reflective material into coverage, a replacement of windows and heating boiler. Annual primary energy demand is reduced of 39 %, from 197,000 kWh to 121,000 kWh. The total cost of this intervention is around 16,0000 €, that corresponds to a 15 years of simple payback time in case of use of national incentives [20]; the amount is also comparable to the annual average costs of management in school buildings in Veneto region (€ 14.634 annual) [17]. This combination of measures is identified previously by the strategy: in fact the building is listed and there were no possibilities to insert insulation in the external layer of envelope, neither to modify the WWR ratio or to change the dimensions of windows, neither to install photovoltaic system over the roof.

Results of research are confirmed in the studies carried out in other school buildings: Ascione et al. [8] investigates on an administrative and didactic building built on 1927 in the historical center of Benevento: it consists in listed building, with a net conditioned area of 1311 m^2 and a compactness ratio (S/V) equal to 0.4 m^2/m^3, that is quite similar to “A. Canova” High School. In Ascione et al. [8] refurbishment measures are simulated with a multi-criteria approach, resulting in a 21 % reduction of heating request and corresponding in a final annual energy consumption of 31.54 kWh/m^2 in respect with the 33.15 kWh/m^2. Results are obtained by considering the different climate conditions and by the different value of heating degree days.

Sustainability issues and energy saving in historical buildings could be developed and awarded by a well-planned project of renovation that fix main objective in an integrative work frame; actually the case study presents need of restoration in envelope and critically in energy consumption, that could be solved in a holistic point of view by use of GBC Historic Building™ and evaluation of requirements for design phase. Obviously, this proposal need a new evaluation of the more relevant aim in case of equal score: to maintain a higher level of conservation rather than to prefer comfort or energy savings. This choice, however, will occur only in the construction phase, by carefully analyzing the needs of users, a hypothetical client and the buildings state of conservation.

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