Article

An Integrated Energy and Environmental Audit Process for Historic Buildings

Elena Mazzola, Tiziano Dalla Mora * , Fabio Peron and Piercarlo Romagnoni

Department of Architecture and Arts, IUAV University of Venice, Dorsoduro 2206, 30123 Venice, Italy; elenoire_me@libero.it (E.M.); fperon@iuav.it (F.P.); pierca@iuav.it (P.R.)
* Correspondence: tdallamora@iuav.it

check for updates

Abstract: The valorization and sustainable management of historic centers is a topic relevant to the cultural identity and heritage of European cities. A rational strategy to preserve the centers must consider both energy and environmental retrofitting, even if this is a complex issue requiring interdisciplinary approaches, dedicated diagnostic procedures, and specific tools. Within this context, this paper proposes an integrated method for energy and environmental analysis specifically devoted to historical building retrofit. Attention is focused on cases in which building management is not interested in renovation or in a deep conservation project, but instead in green management and maintenance overhaul. The basis of the procedure is the Leadership in Energy and Environmental Design for Existing Buildings: Operations and Maintenance (LEED O+M) rating protocol. The global goal was the definition of an intervention strategy indicating the principal direction of action. The first step is identifying critical issues in the operation of the building through energy diagnosis and dynamic thermophysical simulations. The second step is defining a panel of appropriate retrofit measures. The third step is choosing between alternatives to increase the sustainability performance following an environmental assessment scheme. Ca' Rezzonico in Venice (Italy), a 17th-century palace, nowadays the seat of a museum, was used as a case study to apply the proposed methodology.

Keywords: energy audit; green buildings; LEED rating system; operation and management; methodology; workflow; historic buildings

1. Introduction

According to the United Nations previsions [1], in 2050, most people will live in cities or urban centers; therefore, it is increasingly vital to work toward a more sustainable urban environment and to guarantee adequate public services realizing greener cities [2]. In European countries like Italy, this presents a significant challenge due to the historical context and important cultural heritage witnesses.

Historical buildings express the cultural identity of European countries, characterize cities, and provide continuity of the connection from our past to our future [3]. Historic centers have the potential to valorize different cultures and to attract financial capital, real estate investments, and building renovation projects, so it is necessary to think about how to coordinate the continuous intervention and management of historic centers to increase citizen and tourist attendance and improve relevant economic and cultural activities. A main goal of managing these centers is to detect and promote new tools for the sustainable management of historic centers. This management would enhance the attractiveness of city centers and their surroundings, increasing their suitability for both citizens and tourists [4]. National authorities are committed to valorization policies for the buildings of their historical heritage. Energy retrofitting could provide an effective strategy to protect the cultural heritage through operational costs reduction and environmental quality improvement [5].

Unfortunately, the evaluation of environmental and energy performance of historical buildings is complex and requires dedicated tools, sophisticated diagnostic procedures, and an interdisciplinary approach [6–8]. The energy requalification process must not work against the conservation necessities; it has to be an instrument of protection [9,10].

Energy and environmental diagnosis should be integrated for better identifying inefficiencies and wastefulness and to define the most appropriate retrofit measures [11]. In this context, two tools exist: the green energy audit that integrates the methodologies for evaluating energy performance (energy audit) and environmental impacts (green assessment) tools to guide green retrofits [12], and the green assessment protocols [13]. The most common of these analysis tools are multi-criteria, and evaluations are based on comparisons with real or reference performance [14,15]. Developed by the United States Green Building Council (USGBC) in 1998, currently Leadership in Energy and Environmental Design (LEED), represents the most influential and widespread rating system [16]. This certification system has been set for all types of buildings and proposes different protocols according to the typology, from home to hospital, from data center to school. The USGBC database reports that more than 100,000 projects are listed or certified by LEED, making it the most used certification system in the world [17].

The application of sustainability assessment protocols to the energy retrofit of historic buildings faces various difficulties [18,19]. Even if sustainability aspects were originally integrated into historical buildings, some rehabilitation processes ignore some of the sustainability aspects, and specific categories and criteria of rating systems, such as indoor environmental quality, conservation of materials and resources, and sustainability in the site management, have more effective and considerable impacts on sustainable rehabilitation [20]. Rating systems can be applicable to the interventions involved in the thorough renovation of historic buildings but may not address the specific issues related to a sustainable valorization of the historical and cultural aspects of this particular segment of the built environment [21].

GBC Italia developed a protocol dedicated to architectural heritage, GBC HB (historic buildings), which has been applied a few times [22,23]. LEED protocols (new construction, homes, core and shell, neighborhood development) are addressed to new constructions or major renovations; only the Italian GBC HB considers the refurbishment and the certification of the sustainability level of interventions. GBC Italia has developed a guide dedicated to neighborhoods, historic buildings, and the management of existing buildings. These studies have highlighted the compatibility between the safeguard requirement, maintenance, and preservation of historical contexts with current needs and future provision for energy efficiency [24]. An exemplary model is Savona, Italy [25]: the project reached the gold level of USGBC's LEED for Cities, increasing the efficiency of the energy management of the whole urban area by the adoption of LEED certification as a planning tool and the fulfilment of city development interventions, with the purpose of improving the lives of citizens.

USGBC guidance for applying LEED certification does not propose a method or a strategy for the calculation of LEED requirements, but refers to the professional experience of technicians and stakeholders for achieving the certification. The complexity of options and the required documentation complicate the process to achieving a LEED certification, often deterring technicians and surveyors from approaching the rating system process. The goal of this work was to create a methodology for selecting aspects to consider and the credits to calculate according to the project characteristics [16]. This paper presents a new procedure for optimizing the integrated environmental and energy audit dedicated to historical buildings, referring to the general scheme of the energy diagnosis process defined in the UNI CEI EN 16247-1:2012 standard [26] and to the LEED Operation and Management (LEED O+M) rating system that focuses on the management and operative aspects of a building. A specific procedure for the application to historic buildings was implemented starting from previous proposals [27,28]. A univocal and unambiguous workflow that optimizes the effort on assessment process and the resources, reaching higher levels of sustainability and energy efficiency, is presented.

LEED O+M is used to analyze the operative and management aspects usually aimed at existing buildings [18], even if it has been applied in a few cases to historic buildings [29]. LEED O+M can be usefully applied to historical buildings where the management is not interested in a complete renovation or in a complete conservation project. In Italy, the protocol was applied to one historical building, the Ca' Foscari University headquarters in Venice [30], and the Galleria Borghese in Rome is a case study for a future application [31].

Here, following some previews works [32–35], the authors propose integrating LEED O+M with green audits to guarantee a sounder evaluation of the operating strategies to apply during the preliminary analysis of a retrofitting project. A case study of a museum is considered, Ca' Rezzonico in Venice (Italy), that is not interested in renovation or a thorough conservation project (as required for the adoption of standard LEED protocols) but is interested in green management and maintenance. The green audit is used to identify a better framework of the critical issues and the potential for sustainability of the building. The environmental assessment protocol was applied, choosing the issues and credits that most optimize time and costs to result in a high level of sustainability, good performance assessment by the protocol, and to ensure the effectiveness of retrofitting.

2. Materials and Methods

The specific issues connected with the analyses of historic buildings in the framework of sustainable and green retrofit must be considered. For creating a procedure to lead environmental retrofitting, the examination and deconstruction of different approaches available in standards and legislations are necessary. Here is considered the general scheme of the process of energy diagnosis defined in the UNI CEI EN 16247-1:2012 standard [26] and the green energy audit referring to the UNI EN 16883:2017 standard [36]. It is also considered the LEED O+M rating system that focuses on management and operative aspects.

2.1. The Green Energy Audit

The energy diagnosis was introduced by Directive 2006/32/EC [37] and modified by Directive 2012/27/EU [38]: these directives request this procedure for all requalification actions. The interventions on historic building are usually considered voluntary: standard regulations for these cases are lacking [39]. The energy diagnosis general procedure was introduced by the UNI CEI EN 16247-1:2012 standard [15] that defines energy audits as a "systematic inspection and analysis of energy use and energy consumption of a site, building, system or organization with the objective of identifying energy flows and the potential for energy efficiency improvements and reporting them". The green energy audit retains the basic features of an energy audit but is aimed at a more important goal: improving the overall sustainability of the building. The main difference with the general energy audit's process is that during the analysis phase, only sustainability retrofits are evaluated. The audit is strictly related to environmental assessment protocols and the retro-commissioning process, presenting a systematic scheme to investigate the level of maintenance and operation of the systems in existing buildings, proposing operative interventions for improving the overall performance.

2.2. The LEED O+M Rating System

A different approach can be adopted in the management of the retrofit of an historical building based on LEED assessment scheme. Frequently, the complexity generated by cultural preservation and technical innovation and the necessity to find proofs of sustainability action through consistent documentation can discourage surveyors and technicians from pursuing the certification. Here, is considered the LEED O+M for buildings [37], which is normally intended for operative and management aspects for existing buildings undergoing limited retrofitting.

This protocol is subdivided into 20 mandatory prerequisites and 37 credits that indicate the points obtained from the characteristics of the structure and its management. The rating system organizes the prerequisites and credits into categories: Location and Transportation (LT), referring to

the building site and the effect on commuting patterns; Sustainable Sites (SS), referring to environment surrounding the building and highlighting the relationship among services, ecosystems and buildings; Water Efficiency (WE), which considers water holistically, including indoor use, outdoor use, specialized uses, and metering, and recognizes the use of non-potable and alternative sources of water; Energy and Atmosphere (EA) focuses on the energy use reduction, renewable energy sources, and energy-efficient design strategies; Materials and Resources (MR), which considers the constant flow of products purchased and discarded to support building operations; Indoor Environmental Quality (EQ), which considers the satisfaction of occupants, the visual and thermal comfort, and the indoor air quality; Innovation (IN) identifies exemplary and innovative features or practices able to generate environmental benefits; and Regional Priority (RP), which identifies specific priorities according to the location and type of rating system.

The LEED performance credit system allocates points to each credit considering human benefits and the potential environmental impacts, so some categories are weighted according to the score of the associated credits, the relevance of the topic, and the intent described in the credit. As such, LEED O+M states that the categories EQ and EA are weighted higher than the total value of the other categories combined.

The structure of credits and prerequisites is organized in different sections: intent and requirements, behind the intent, step-by-step guidance, further explanation, required documentation and related credit tips, changes from LEED 2009, referenced standards, exemplary performance, and definitions [38]. It is a voluntary assessment tool that provides guideline to enhance the use of natural resources, to encourage restorative and regenerative policies, to maximize the positive and to minimize the negative environmental and human health consequences of the buildings sector, and to produce high quality indoor environments. LEED systems pursue sustainability goals by achieving mandatory prerequisites and choice credits. Four levels of sustainability are reachable according to the achieved points, platinum, gold, silver, and certified [23].

2.3. The Proposed Methodology

The proposed methodology starts from the green energy audit, then adding specifications in terms of:

(1) Collecting data: in historic buildings, it is crucial to dedicate a long period of time to researching historic data as well as planning field surveys to investigate stratigraphy; in new construction, all the project and decisions are registered, but in this case, it is necessary to examine all the building properties.

(2) Energy opportunities: the retrofit and the retro-commissioning are presented in this section because they pursue sustainable objectives; with the aim of producing an energy certification, it is possible to inspect a building's energy systems and their operating procedures.

(3) Analysis: considering the costs and benefits is insufficient for historic buildings because the compatibility of interventions must be considered. As previously mentioned, in this case, all the analyses were applied for the improvement of and not for the adaptation to standards.

A phase of monitoring energy values post-intervention is added at the end of the process. The effects of the energy requalification interventions are introduced to the scheme, where the auditor examines indicators such as energy consumption for heating, cooling, or domestic hot water.

The green energy audit aims to improve the sustainability of the building. For this reason, the selection of intervention measures must be evaluated according to the contribution in terms of energy savings, economic costs, and environmental impacts. This evaluation should be assessed by the adoption of a rating system that certifies a level of sustainability with a global score determined by the adopted design strategy and the achievement of selected credits, so, the proposal is to follow the environmental assessment on the basis of LEED O+M scheme. A workflow is proposed for achieving the certification score using a new classification of prerequisites and credits that consider the points of

credits and the document to be delivered. This method references previous studies [40] that aimed to identify the credits necessary to achieve the minimum score to attain the certification label with the better use of resources in term of time and costs. This step consists of two phases:

(1)　Phase 1 applies a prerequisites classification, assigning a score to the parameters selected within the LEED guide that describe the requirements and documentation for the achieving the prerequisites [41,42];

(2)　Phase 2 considers the credits and is split into two different steps:

　　(a)　Sub-phase 2A involves the selection of credits
　　(b)　Sub-phase 2B applies a credits classification according to the same approach in phase 1.

All the sections described for each prerequisite and credit are considered, for example, intent, requirements, relations, score, and options, according to the structure fixed by the LEED rating system (Figure 1).
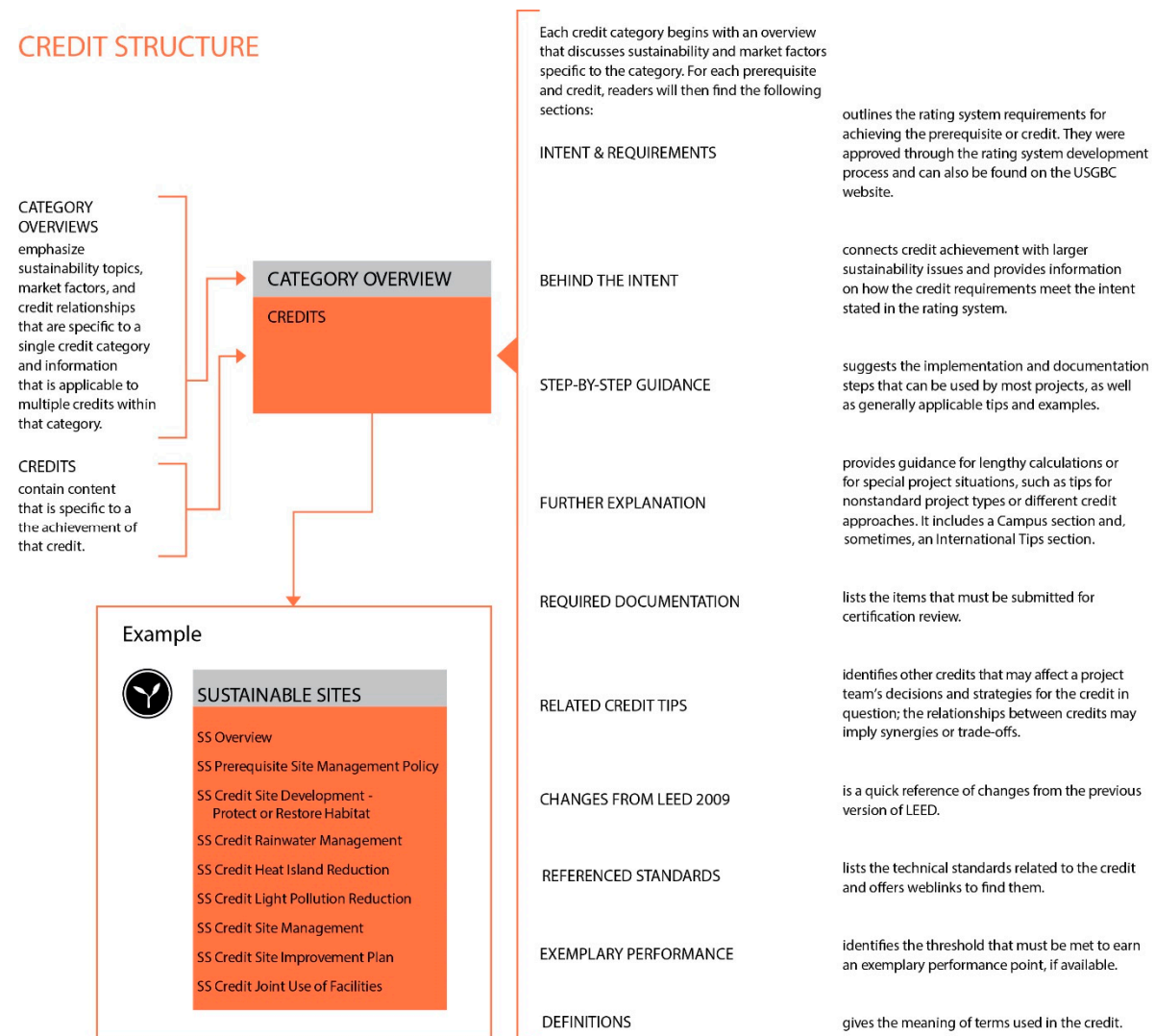

Figure 1. Structure of prerequisites and credits according to the LEED rating system definition [16].

Subsequently, a scoring system, described in Table 1, was developed considering the following parameters: the number of required documents, (listed in the required documentation section),

the connected prerequisites (listed in the related credit tips section), and the effort level to fulfil the forms requested by USGBC (as described in the intent and requirement section).

Table 1. Scoring system for prerequisites according to options: parameters are the requirements in each prerequisite and the score is the score system. In detail: 1 point is assigned for each document required for the achievement of the intent; 1 point is assigned for each prerequisite listed in the section of related credits tips; different points are assigned related to the procedure of the performance period; different points are assigned in relation to the different levels of commitment difficulty in completing and collecting data.

Parameter	Score
Documents requested	1 point = 1 document
Related prerequisites	1 point = 1 prerequisite listed according to related credit tips section
Performance period	0 point = not present 2 points = five-yearly audit or maintenance after certification 3 points = collection of data before the certification
Type of form	1 point = easy to fill in 2 points = calculation required 3 points = form is more complex

As an example, the possible score for the prerequisite p2 of the Minimum Energy Performance (EA category, Table 2) is presented with two options requiring a total amount of four or eight documents to be completed according to the chosen option; there are two related prerequisites: EA p1 Energy Efficiency Best Management Practices and EA p3 Building-Level Energy Metering. The performance period requires 12 continuous months of metered energy data collected before the end of the performance period; the form includes the data collected to fulfil the Energy Star Rating or similar energy audit. Therefore, a partial score could be achieved for each prerequisite option by the application of the method, as explained in Table 1, and the total score of the prerequisite is determined by the average values of the options.

Table 2. Example of a score calculation for prerequisite EA p2 Minimum Energy Performance: the number of options proposed by the prerequisite requirement; the amount of documentation, listed in the documentation required section; the number and types of prerequisites; period and description of performance period; forms requested from USGBC; partial score for each option; and normalization of total score through calculation of average partial scores.

Name	Options	Documentation	Prerequisites	Performance Period	Form	Partial Score	Total Score
EA p2 Minimum Energy Performance	1.1	4	2	3	2	12	14.4
	1.2	4	2	3	2	12	
	2.1.1	6	2	3	3	15	
	2.1.2	8	2	3	3	17	
	2.1.3	7	2	3	3	16	

As shown for prerequisite EA p2, the procedure concludes with the assignment of a final score for each prerequisite, obtained by the normalization of the partial score and the number of options contained in the prerequisite description.

The result is a classification of prerequisites for LEED O+M v.4 (Figure 2), organized from higher to lower scores, also listing the relationships. It represents a workflow for applying the certification process as it lists the prerequisites in order of importance. In case of a correlation (for example EA p3, EA p1, and EQ p1 with EA p2) the prerequisites with a lower score (EA p1 and EQ p1) lose the score because the relationship allows pursuing the same documentation and data for the item with

the higher score (EA p2), receiving the same higher score and the same relevance in the classification and workflow.

			PREREQUISITE	SCORE
EA p2			Minimum Energy Performance	14.4
	EA p1		Energy Efficiency Best Management Practicies	~~9~~
		EQ p1	Minimum Indoor Air Quality Performance	~~9~~
	EA p3		Building-Level Energy Metering	~~10~~
MR p1			Ongoing Purchasing and Waste Policy	9.25
EQ p3			Green Cleaning Policy	7
	MR p2		Facility Maintenance and Renovation Policy	~~2~~
EA p4			Fundamental Refrigerant Management	6.6
WE p1			Indoor Water Use Reduction	6.5
	WE p2		Building-Level Water Metering	~~6~~
EQ p2			Environmental Tobacco Smoke Control	6
SS p1			Site Management Policy	3

Figure 2. Work classification of prerequisites for LEED O+M; scores of prerequisites related to other prerequisites are struck through. LEED's goals drive the weighting of points toward certification. Each credit is allocated points based on the relative importance of its contribution toward the goals. The results present a weighted average: credits that most directly address the most important goals are assigned the highest weight [42].

The classification proposed in Figure 2 reveals the most important areas for attaining the certification according to the LEED O+M perspective. The main area of concern for the management of energy performance, the EA category, is the most important topic, followed by signed policies such as requested in the EQ and MR category.

After pursuing mandatory prerequisites, credits allow receiving a score to determine the level of certification: USGBC assigns different points to each option of each credit. Since the complexity of the requirements and the large number of credits and documents, this study tries to simplify the selection process with the aim of receiving higher LEED certification by evaluating the minimum number of documentations for each credit and its relevance to the system. A calculation was developed for assessing the weighing of each credit and for credit selection considering the following parameters: score, relationship, and frequency. Relationship considers the number of credits listed in the related credit tips section of the same credit; frequency counts the quotes for the considered credit in the related credit tips section of other credits.

Phase 2A involves selection process. First, credits are listed and ranked in relation to the number of documents/reports to be completed according to the options. Then, the methodology proposes a new parameter called the "summary credit", as defined in Equation (1), which considers the maximum points achievable (score), the number of correlated prerequisites and credits (relationship), and the quote in other prerequisites/credits (frequency):

$$\text{Summary credit} = \text{point} + \text{frequency} + \text{relationship} \tag{1}$$

The method identifies a choice of credits with the best value as defined using Equation (2). Considering the required documentation (y) and the calculated summary credit (x), the result is a list of best credits (Figure 3) for LEED O+M v.4:

$$y \leq 3/10\,x \tag{2}$$
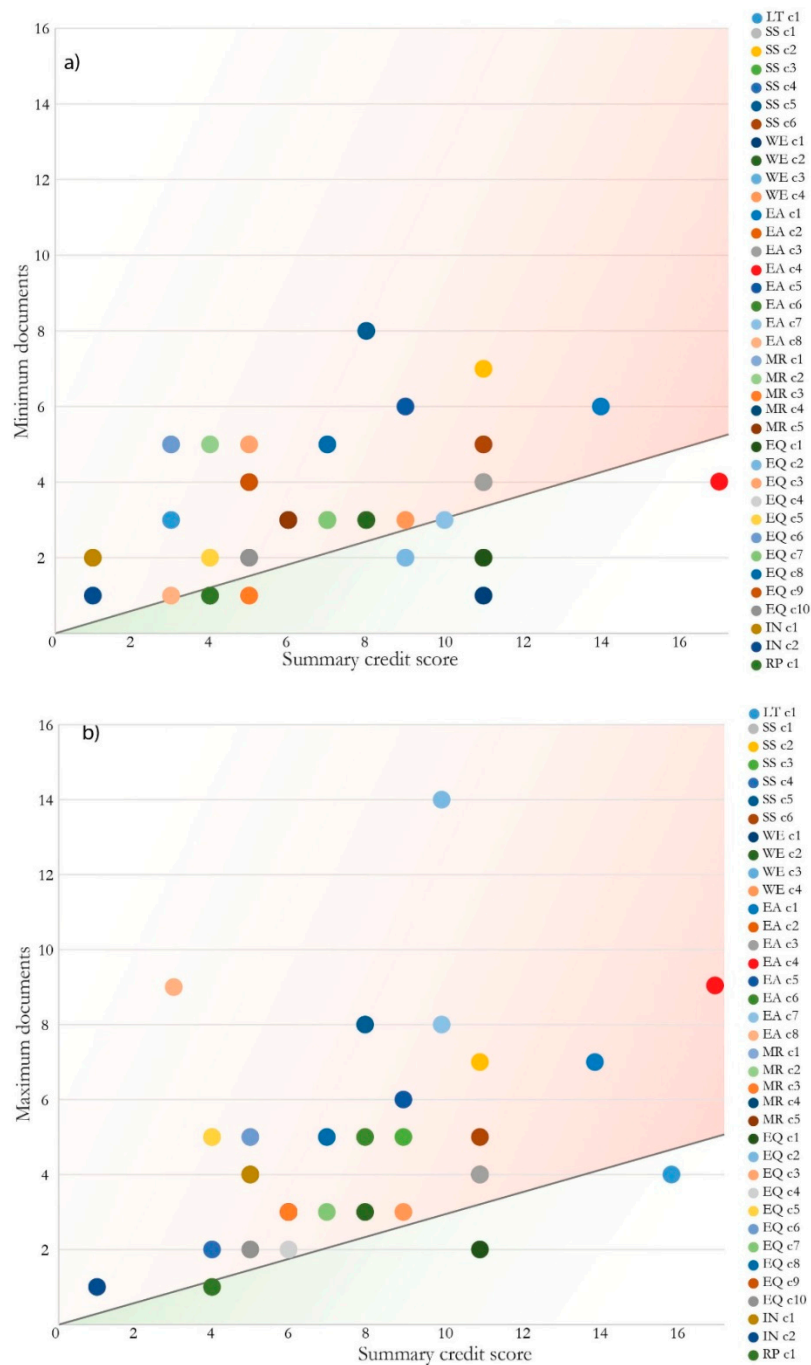
Figure 3. Selection of 10 important credits: on x axis, number of summary credit, on y axis, number of documents, in particular minimum documents in (**a**) minimum documents and (**b**) maximum documents; the chosen credits lay below the line, according to function $y \leq 3/10x$.

Credits are organized in phase 2B, developing a score system that considers the internal options (Table 3) in the requirement for the credit structure: one point is assigned for each requested document, for each connection with prerequisites and credits; different points are assigned based on the performance period and on the level of complexity and difficulty in completing the forms requested from USGBC.

Table 3. Scoring system for credits according to internal options: parameters are the requirements for each credit and score is the scoring system. The system is the same for prerequisites, but more points are assigned in relation to the number of prerequisites and credits listed in the tips section.

Parameter	Score
Documents requested	1 point = 1 document
Relation with prerequisites	1 point = 1 relation with prerequisite
Credits inside	1 point = 1 internal credit
Performance period	0 point = not present 2 points = five-yearly audit or maintenance after the certification 3 points = collection of data before the certification
Type of form	1 point = easy to fill in 2 points = calculation required 3 points = form is more complex

While the previous analysis was only dedicated to the prerequisites, this process was also developed for classifying the credits. The classification of credits has been implemented with the correlation between both credits and prerequisites (Figure 4).

	CREDIT	SCORE
EQ c2	Enhanced Indoor Air Quality Strategies	17.5
EA c4	Optimize Energy Performance	~~13~~
EQ c1	Indoor Air Quality Management Program	9
EA c7	Renewable Energy and Carbon Offsets	9
LT c1	Alternative Transportation	8
EQ c4	Interior Lighting	7
MR c3	Purchasing – Facility Maintenance and Renovation	6.5
WE c1	Outdoor Water Use Reduction	6
SS c1	Site Development – Protect or Restore Habitat	5
SS c4	Light Pollution Reduction	4

Figure 4. Work classification of credits for LEED O+M; scores of credits related to other credits are crossed out.

The credits classification shows how the management of energy use is relevant, as with the prerequisite classification. Particular relevance is assigned to the human health topic presented in the EQ and LT categories, as listed in the management of air quality, the interior lighting, and the incentive to use alternative transportation.

The methodology identifies a list of 10 credits. The application and calculation of the requirements of these credits could achieve a total score of 53 points according to the scorecard, achieving the Silver level of certification [41] for LEED O+M systems, achievable when a project earns 50–59 points.

3. The Application on a Case Study

3.1. Ca' Rezzonico Museum

A case study was considered for the application of the method: Ca' Rezzonico (Figure 5), Museum of 18th Century Venice, in Venice, Italy. Many Italian museums are hosted in historical buildings: 28 museums are pre-12th century, 483 were built between the 12th and 16th centuries, and 544 between the 17th and 19th centuries [43].

Figure 5. Ca' Rezzonico: (**a**) main front on the Grand Canal (Fondazione Musei Civici di Venezia s.d.); (**b**) ballroom on the first floor.

This palace was built during the Baroque age and was converted into a museum in 1936 after refurbishment interventions. The quality of architecture and exhibited works make Ca' Rezzonico an interesting and unique witness of the Venetian 19th century. It has four floors that host several museum rooms, a library shop, and a coffee bar, for a total surface are of 6400 m^2. Seven different types of external walls and five different types of windows exist in the building. The energy consumption is about 142 kWh/m^{2}a, including about 81 kWh/m^{2}a for electricity, determined by averaging the bills of three consecutive years from 2014 to 2016 (Table 4).

Table 4. Energy consumption of Ca' Rezzonico for 2014–2016. The data represent the average use for the three years and are reported for each month; the large consumption is due to electricity; heating and domestic hot water are provided by natural gas. Note that heating is not required from May to September; the values are listed using kWh/ m^{2}a.

2014–2016 Energy Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Electricity use (kWh/m^{2}a)	5.79	5.34	5.85	5.62	6.26	8.41	9.99	9.42	7.23	6.06	5.27	5.54	80.77
Natural Gas use (kWh/m^{2}a)	13.93	11.41	9.00	2.36	0.38	0.41	0.57	0.59	0.54	2.69	7.20	12.28	61.35

The museum is managed and promoted by the Fondazione Musei Civici di Venezia foundation, which chose Ca' Rezzonico as a pilot case to test LEED requirements for achieving the certification for all museum systems.

3.2. First Step: Green Audit

According to the previous above of the integrated energy and environmental audits of historic buildings, in this case study, different surveys were developed, including a thermography analysis, data were collected about the schedule and system plan, and a dynamic energy model was created to evaluate the building energy performance. Using this method, some energy efficiency measures were identified.

The entire building envelope does not have thermal characteristics similar to the energy behavior required by actual normative; the historical protection status and heritage value do not allow energy efficient interventions such as thermal insulation of external/internal walls or window substitution, so the best energy improvements cannot be adopted.

The energy performance of the building envelope is low, especially in some zones (such as the attic) or in some local points (for example, near the external systems placement or where, in previous years, a replacement and refurbishment has been completed with the use of different materials causing thermal bridges), so interventions should completed to maintain the integrity of the building structure.

The thermal energy lost through the windows is high, thermal loss and need improvement, especially into the curved partition. The intervention involves redoing the sealing between the frame and glass to maintain the historical elements and reduce the thermal bridge problem.

An electrical system intervention should be considered as the most important measure due to the high consumption and costs; the energy and economic savings should be achieved without altering the historical elements of the buildings that are listed and protected by the Historical Superintendent.

Intervention on the reduction of domestic hot water (DHW) should not be considered relevant due to its low use and cost.

Another useful tool in the audit step is dynamic simulations. A numerical model of Ca' Rezzonico was set up by Design Builder®(powered by EnergyPlus®) to validate simulated values with real consumption. As shown in Table 5, the deviation was 1% on average for natural gas and electricity use.

Table 5. Comparison of energy consumption between real data from bills and output simulation by the Design Builder model.

Energy Type	Real data (kWh/m^{2}a)	Simulation (kWh/m^{2}a)	Deviation (%)
Electricity use	80.77	81.7	1%
Natural gas use	55.16	52.4	5%

3.3. Second Step

3.3.1. Part A: Application to Prerequisites

Phase 2A is the completion of prerequisites that are mandatory to be admitted to the LEED certification process. According to the classification of prerequisites (Figure 2), prerequisite EA p2, concerning operating energy performance, was developed first. For Ca' Rezzonico, the prerequisite was achieved in comparison with similar buildings and the recently completed energy performance assessment. A 25% improvement in the energy consumption was verified (with reference to the previous 12 months) in comparison with the usage data of the three contiguous years (with reference to the last five), using a normalized index for occupancy, building use, and climate.

The work program indicates the need for an investigation into the real connections between other prerequisites through the analysis of required data and documentation. The documents needed for prerequisite p2 in the EA category can be used for other prerequisites (Table 6). The meter calibration report requires data collection from permanently installed meters, according to prerequisite p3 in the EA category; the early assessment for energy performance required by prerequisite EA p1 could be integrated into the utility bill summary. Prerequisite EQ p1, regarding minimum indoor air quality, requires the same occupation schedules as in the energy audit. The table presents an example of the relationships between credits. The documents that manage the same kind of information are highlighted in the same color, showing that they could be treated together as proposed in the methodology.

Table 6. Example of relationship between the first four prerequisites according to the work program in Figure 2. The required documentation is listed for each prerequisite and the colors indicate the similar documents because they manage the same kind of information.

Prerequisite	Required Documentation
EA p2	Meter calibration report
	Energy Star portfolio
	Utility bill summary pages of performance period for each fuel source
	Weather-normalized source EUI
	Calculation supporting additional normalization

Table 6. *Cont.*

Prerequisite	Required Documentation
EA p1	Preliminary energy use analysis Energy audit Current facility requirements and operations and maintenance plan
EA p3	Confirmation of permanently installed meters Letter of commitment Confirmation of data sharing source
EQ p1	Measured outdoor airflow rates Information about ventilation Ventilation maintenance program Table with occupied rooms, spaces, or zones

3.3.2. Part B: Application to Credits

A selection of 10 credits was applied according to the methodology to produce a draft of energy and environmental certification by achieving the minimum score necessary and minimizing the internal documents to achieve the highest possible score. This score and the consequent level of certification are integrated with the evaluation of other issues and credits by the design team.

In Ca' Rezzonico, the evaluation strategy was conducted considering the requests of the museum administration, who had expressed the desire to evaluate some specific aspect such as the energy efficiency and management, the internal lighting quality, and the ventilation system. These requests were consistent with what is expressed in the documentation necessary for the selection of the 10 credits, as previously described in Figure 4.

The information in Table 7 focuses on the application of 10 credits in the case study. The administration of the museum will have to apply some specific requirements (highlighted in red) to obtain validation and achieve certification. According to the case study characteristics, a preview showed the museum could earn 47 points toward LEED O+M certification. In detail Table 7 shows the credits and what their characteristics and documentation are [42].

EQ c2, Enhanced Indoor Air Quality Strategies: the intent is to ensure better indoor air quality for users' productivity, well-being, and comfort. The requests include permanent installations (such as slotted systems and grilles). Currently Ca' Rezzonico does not have such systems.

EA c4, Optimize Energy Performance: the intent is to increase the energy performance beyond the prerequisite standard for reducing economic and environmental problems in relation to the unnecessary use of energy. The requirements include a demonstration of continuous energy efficiency improvement during the performance period in comparison to a baseline, and Ca' Rezzonico has an energy use 43% lower with respect to similar buildings in terms of typology, use, and characteristics.

EQ c1, Indoor Air Quality Management Program: the intent is to maintain users' well-being by modifying and preventing indoor air quality problems. The requirement includes conducting an I-BEAM audit on a regular basis and revising the IAQ management program.

EA c7, Renewable Energy Carbon Offsets: the intent is to reduce greenhouse gas (GHG) emissions through the use of local and grid-source renewable energy technologies and carbon mitigation projects. The requirements include a demonstration that renewable energy systems determine the total energy use or the engagement of contracts to purchase carbon offsets, green power, or Renewable Energy Certificates (RECs) as the annual renewal of the energy supply contract for Ca' Rezzonico.

LT c1, Alternative Transportation: the intent is to reduce pollution and land development effects from automobile use for transportation. Alternative transportation strategies that contribute to this reduction include human-powered transport (e.g., walking or biking), public transit, telecommuting, informal transit options, compressed workweeks, carpooling, and green vehicles. For Ca' Rezzonico, the credit is achievable as for all buildings on the Venice isle.

Table 7. Analysis of the 10 selected credits in Figure 4 in application to the case study. The requests of Ca' Rezzonico management are highlighted in red color, the already requests are in black. The score obtainable is listed, compared with the maximum achievable with the LEED O+M rating system.

Credit	Requirements	Max. Score Achievable	Points for Ca' Rezzonico
EQ c2 Enhanced Indoor Air Quality Strategies	Install permanent entryway systems; each ventilation system that supplies outdoor air to occupied spaces must have particle filters or air cleaning devices.	2	2
EA c4 Optimize Energy Performance	Demonstrate energy efficiency performance that is at least 26% better than the median energy performance for typical buildings of similar type.	20	18
EQ c1 Indoor Air Quality Management Program	Develop and implement an indoor air quality management program.	2	2
EA c7 Renewable Energy Carbon Offsets	Demonstrate that the total energy use is met directly with renewable energy systems.	5	4
LT c1 Alternative Transportation	Demonstrate that regular building occupants and visitors use alternative transportation.	15	15
EQ c4 Interior Lighting	Implement individual lighting controls; analyze internal lighting quality level and obtain an improvement.	2	1
MR c3 Purchasing: Facility Maintenance and Renovation	Purchase maintenance and renovation materials that are environmentally sustainable.	2	1
WE c1 Outdoor Water Use Reduction	Calculate the landscape water requirement and install an irrigation meter.	2	2
SS c1 Site Development – Protect or Restore Habitat	Provide financial support to a nationally or locally recognized land trust or conservation organization.	2	1
SS c4 Light Pollution Reduction	Measure the night illumination levels, which must not be more than 20% above the level measured with the lights off.	1	1
Total		53	47

EQ c4, Interior Lighting: the intent is to improve occupants' well-being, comfort, and productivity through the provision of high-quality lighting. The requirements include an analysis of the quality of light control system. Currently, for the case study, only some changes to lighting consumption were possible because the requirements for by this credit are constrained by the Superintendent.

MR c3, Purchasing—Facility Maintenance and Renovation: the intent is to reduce the environmental harm due to the materials used in building renovations. The requirement includes purchasing at least 50%, by cost, of the total maintenance and renovation materials that meet at least one of the criteria of being recyclable, reusable, bio-based, cradle-to-cradle certification, and low emissions of volatile organic compounds. In this case, Ca' Rezzonico is a building listed by the Superintendent, so the requirements for renovation and credit will have to be analyzed more in-depth in accordance with the various stakeholders, even if no particular difficulties have yet been detected.

WE c1, Outdoor Water Use Reduction: the intent is to reduce outdoor water consumption. The requirement is reducing the project's landscape water requirement (LWR) by at least 50% from the calculated baseline for the site's peak water use month. Reductions must first be achieved through plant species selection and irrigation system efficiency as calculated in the Environmental Protection Agency (EPA) Water, Sense Water Budget Tool. The museum administration is active in monitoring and validating the consumption reduction.

SS c1, Site Development—Protect or Restore Habitat: the intent is to maintain existing natural areas and restore damaged areas for habitat provision and biodiversity promotion. The requirement is the coverage by vegetation (adapted or in place native) of a minimum area during the performance period. Another option, effectively chosen for the case study, is the provision of financial support equivalent to at least USD $4 per square meter for the total site area (including the building footprint), to a nationally- or locally-recognized land trust or conservation organization within the same EPA Level III ecoregion or the project's state.

SS c4, Light Pollution Reduction: the intent is to minimize the light escaping from the site and building, by reducing sky-glow, improving night sky access, enhancing the night-time visibility, and reducing the impact from lighting on nocturnal environments. The requirement includes the use of an external shading device or reducing the measured illuminance level of external lights by 20% compared with lights off. In the case study, this second option is achievable due the installation of external light pointed only on the main external surface of the building.

3.4. Overall Results

As described in Table 7, the certification process in the case study could achieve 47 points toward LEED O+M certification, corresponding to a Certified level (40–49 points). This is a good result because the application of the methodology guarantees the certification only by the calculation of 10 credits, but above all, confirms a good level of sustainability focusing on the management of energy use and the improvement of indoor quality. The same procedure could be applied and verified for other LEED rating systems given the identical structure, but also to other certification systems based on criteria, indicators, ratings, and the certification process.

With the adoption of a LEED protocol, a single intervention measure could result in the achievement of different credits. For example, the intervention for the same inefficiencies, analyzed by energy diagnosis, could be evaluated by environmental impact; the improvement involves the selection and calculation of credits that concern n these items and inefficiencies (Table 8). A higher the score evaluated based on available credits, the higher the assessment of the environmental improvement achieved.

Table 8. Description of the analyzed inefficiencies. Each intervention is defined using a qualitative assessment according to the energy improvement, sustained costs, economic benefits, and preservation of the historical asset (+ positive value, - negative value).

Type of Inefficiency	Type of Analysis	Energy Improvement	Costs	Heritage Conservation
Electric energy use	Consumption data, benchmark comparison	+++	++	+++
Opaque envelope (local element)	Thermographic analysis	++	+++	+++
Transparent envelope (local windows)	Thermographic analysis	++	+	+++
Whole envelope	Minimum requirements by normative	+++	+	- - -
DHW use	Consumption data, benchmark comparison	+	++	+

In the description each credit, the rating system considers a list of related credits that are similar or comparable in terms of items or calculation approach. Table 8 shows how to address the inefficiencies and the calculation of the requirements for a list of credits. For example, in the Ca' Rezzonico analysis, a Base level of certification should be achieved by the application of recommended credits, but the calculation of related credits, as proposed in Table 9, could increase the level.

Table 9. Environmental assessment of the interventions examined using energy diagnosis. The recommended measures are selected according to the credits in LEED O+M, specifying the nomenclature of the reference credit and the related credits. The last column reports a qualitative environmental assessment.

Type of Inefficiency	Recommended Intervention by LEED	LEED Credit	Related Achievable Credits	Environmental Improvement
Electric energy use	Indoor light management and metering; management plan for inner air quality	EQ c4	EQ c3 Thermal Comfort. EA c2 Existing Building Commissioning—Analysis; EA c3 Existing Building Commissioning—Implementation; MR c2 Purchasing—Lamps	+++
		EQ c1	EQ c9 Integrated Pest Management	
Opaque envelope (local analysis)	Energy use improvement	EA c4	EA c2 Existing Building Commissioning—Analysis	+
Transparent envelope (single windows)	Energy use improvement	EA c4	EA c2 Existing Building Commissioning—Analysis	+
Whole envelope	Energy use improvement	EA c4	EA c2 Existing Building Commissioning—Analysis	++
DHW use	Management and metering for water use on green areas	WE c1	WE c3 Cooling Tower Water Use; WE c4 Credit Water Metering	+

4. Discussion and Conclusions

Historic buildings require special consideration because they represent a large proportion of Italian buildings. The desire to achieve energy saving, global costs management, and environmental impact goals is growing, aiming to reduce CO_2 emissions and other greenhouse gases, and to improve in internal quality air and comfort. In fact, the objective of this research was to investigate the energy and environmental assessment systems and the tools that allow their implementation.

The research proposes different approaches to obtain an energy and environmental audit for historic buildings:

(1) A new formulation for the operative workflow of the energy audit that considers energy evaluations and the characteristics in the analysis of an historic building. The research underlines the importance of non-destructive investigations and post-intervention monitoring, and the selection of a rating system able to select the most appropriate intervention measures.

(2) An environmental analysis developed through the assessment of the operational and management aspects through the application of the LEED O+M rating system with the addition of a new strategy to organize and optimize the use and the calculation of the requirements.

(3) A validation with a case study of Ca' Rezzonico museum. The building was analyzed according to the normative by the completion of an operative check list, using data from the archive of the Superintendent and through the development of non-destructive investigations. The energy audit according to normative and an environmental assessment was developed according to the LEED O+M.

This paper highlights some other findings. The energy diagnosis requires benchmarks that refer only to the museums [12], and the research lacks quantitative analysis of the interventions from economic and financial viewpoints. The investigation into supply costs, time of return of investments, and comparisons with the Superintendent references need to be further analyzed.

The proposed method was tested on to LEED rating system and was developed according to the characteristics of the LEED O+M credit system. Even if LEED rating systems have a standard

structure, each protocol includes different requirements, connections, scores, and weighing. Future developments should focus on validating the proposed method and finding a robust system for the credits selection that is applicable for different LEED protocols.

Notably, the application of the methodology indicated a Silver level LEED O+M certification cold be attained through the calculation of a list of 10 credits for a maximum total score of 53 points, which could be implemented with other credits in relation to the characteristics of the projects.

As previously described, the proposed methodology is an upgrade of the GBC Historic Building system proposal [44] and the research is revising and deepening the application to other protocols with the aim of defining Equation (3) and improving the method to increase its applicability:

$$\text{ratio} = \frac{\text{summary credit}}{\text{required documents}} \tag{3}$$

This study was conducted as part of a research program that includes different phases; therefore, some weaknesses and uncertainties still need to be studied. For example, for Ca' Rezzonico, the certification process and the credits completion are still ongoing, so the methodology is being verified with the progression of the credits achievement. The paper presents a calculation method that has only been analyzed in some historical buildings and therefore, in future developments, we intend to validate the method on other cases, including both museum and other types of buildings.

A weakness of the study is the lack of applicability to all LEED protocols, precisely because the structure of the credits and categories in O+M is substantially different from most rating systems. The research intends to develop the application for other protocols to create a method for preliminary evaluation of certification achievement in terms of documentation, score, and difficulties. After verifying the prerequisites and the selected credits using the generic formula in Equation (3), in the case of non-achievement of a satisfactory score or obstacles, a change of rating system could be considered during in a first phase of a check.

References

1. United Nations, Department of Economic and Social Affairs, Population Division (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations. 2019. Available online: https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf (accessed on 16 March 2019).
2. Saleem, H.A. Green Cities: Urban Growth and the Environment. *J. Am. Plan. Assoc.* **2008**, *74*, 143. [CrossRef]
3. Ragni, M.; Maurano, A.; Scoppola, F.; Soragni, U.; Baraldi, M.; D'Amico, S.; Mercalli, M.; Banchini, R.; Bellisario, M.G.; Rubino, C.; et al. *Linee di Indirizzo per il Miglioramento Dell'efficienza Energetica nel Patrimonio Culturale*; Architettura Centri e Nuclei Storici ed Urbani, Ministero dei Beni Culturali: Roma, Italy, 2013; pp. 1–200. Available online: http://soprintendenza.pdve.beniculturali.it/wp-content/uploads/2018/04/Linee_indirizzo_miglioramento_efficienza_energetica_nel_patrimonio_culturale.pdf (accessed on 16 March 2019).
4. Martinez-Molina, A.; Tort-Austina, I.; Cho, S.; Vivancos, J. Energy efficiency and thermal comfort in historic buildings: A review. *Renew. Sustain. Energy Rev.* **2016**, *61*, 70–85. [CrossRef]
5. Vieites, E.; Vassileva, I.; Arias, J.E. European initiatives towards improving the energy efficiency in existing and historic buildings. *Energy Procedia* **2015**, *75*, 1679–1685. [CrossRef]
6. Roberti, F.; Oberegger, U.F.; Gasparella, A. Calibrating historic building energy models to hourly indoor air and surface temperatures: Methodology and case study. *Energy Build.* **2015**, *108*, 236–243. [CrossRef]
7. Lucchi, E.; Pracchi, V. *Efficienza Energetica e Patrimonio Costruito: La Sfida del Miglioramento Delle Prestazioni Nell'edilizia Storica*; Ed. Maggioli: Milano, Italy, 2013.

8.   Ma, Z.; Cooper, P.; Daly, D.; Ledo, L. Existing building retrofits: Methodology and state-of-the-art. *Energy Build.* **2012**, *55*, 889–902. [CrossRef]

9.   De Santoli, L.; Mancini, F.; Rossetti, S. Studio di interventi di riqualificazione energetica e impiantistica per la Galleria Borghese a Roma. *AiCARR J.* **2016**, *36*, 32–40.

10.   Ascione, F.; Bianco, N.; de Masi, R.F.; de Rossi, F.; Vanoli, G.P. Energy retrofit of an educational building in the ancient center of Benevento. Feasibility study of energy savings and respect of the historical value. *Energy Build.* **2015**, *95*, 172–183. [CrossRef]

11.   Mustafaraj, G.; Marini, D.; Costa, A.; Keane, M. Model calibration for building energy efficiency simulation. *Appl. Energy* **2014**, *130*, 72–85. [CrossRef]

12.   Dall'O', G.; Speccher, A.; Bruni, E. The Green Energy Audit, a new procedure for the sustainable auditing of existing buildings integrated with the LEED Protocols. *Sustain. Cities Soc.* **2012**, *3*, 54–65. [CrossRef]

13.   Jagarajan, R.; Asmoni, M.N.A.M.; Mohammed, A.H.; Jaafar, M.N.; Mei, J.L.Y.; Baba, M. Green retrofitting—A review of current status, implementations and challenges. *Renew. Sustain. Energy Rev.* **2017**, *67*, 1360–1368. [CrossRef]

14.   Berardi, U. Comparison of sustainability rating systems for buildings and evaluation of trends. In Proceedings of the SB11 Helsinki: World Sustainable Building Conference, Helsinki, Finland, 18–21 October 2011; pp. 1696–1702.

15.   EI Yamany, S.; Afifi, M.; Hassan, A. Applicability and Implementation of U.S. Green Building Council Rating System (LEED) in Egypt. *Procedia Environ. Sci.* **2016**, *34*, 594–604. [CrossRef]

16.   U.S. Green Building Council, LEED Rating System. 2009. Available online: http://www.usgbc.org/leed/leed_main.asp. (accessed on 26 March 2019).

17.   Gurgun, A.P.; Polat, G.; Damci, A.; Bayhan, H.G. Performance of LEED energy credit requirements in European countries. In Proceedings of the Creative Construction Conference, Budapest, Hungary, 25–28 June 2016; pp. 25–28.

18.   Sun, X.; Gou, Z.; Lu, Y.; Tao, Y. Strengths and Weaknesses of Existing Building Green Retrofits: Case Study of a LEED EBOM Gold Project. *Energies* **2019**, *11*, 1936. [CrossRef]

19.   Stephens, J.F.; Siddiqi, K. LEED Rating Systems for Historical Restorations. In Proceedings of the 49th ASC Annual International Conference, San Luis Obispo, CA, USA, 10–13 April 2013; pp. 1–6.

20.   Sadrykia, S.; Medghalchi, L.; Mahdavinejad, M. Sustainability assessment, rating systems and historical buildings Case study: Rehabilitated construction in a university site. In Proceedings of the 4th International Building Control Conference (IBCC 2016), Kuala Lumpur, Malaysia, 7–8 March 2016; pp. 1–9.

21.   Boarin, P.; Guglielmino, D.; Pisello, A.L.; Cotana, F. Sustainability assessment of historic buildings: Lesson learnt from an Italian case study through LEED®rating system. *Energy Procedia* **2014**, *61*, 1029–1032. [CrossRef]

22.   Lucchi, E.; Boarin, P.; Zuppiroli, M. GBC Historic Building®: A new certification tool for orienting and assessing environmental sustainability and energy efficiency of historic buildings. In Proceedings of the EECHB on Energy Efficiency and Comfort in Historic Buildings, Brussels, Belgium, 19–21 October 2016; pp. 1–8.

23.   Troi, A.; Lucchi, E. Cultural Heritage Preservation. In Proceedings of the 3rd European Workshop on Cultural Heritage Preservation; Felix Verlag: Bozen/Bolzano, Italy, 2013; pp. 16–18.

24.   Dall'O, G.; Galante, A.; Sanna, N.; Miller, K. On the Integration of Leadership in Energy and Environmental Design (LEED)®ND Protocol with the energy planning and management tools in Italy: Strengths and weaknesses. *Energies* **2013**, *6*, 5990–6015. [CrossRef]

25.   Bisello, A.; Vettorato, D.; Stephens, R.; Elisei, P. *Smart and Sustainable Planning for Cities and Regions*; Springer: Berlin/Heidelberg, Germany, 2016; pp. 389–401.

26.   Ente Nazionale Italiano di Unificazione. *Diagnosi Energetiche—Parte 1: Requisiti Generali*; Norma CEI UNI EN 16247-1:2012; Ente Nazionale Italiano di Unificazione: Milano, Italy, 2012.

27.   Roberti, F.; Exner, D.; Oberegger, U.F.; Gasparella, A. Diagnosi energetica e simulazione di un edificio storico. In Proceedings of the 49th AICARR Conference, Venice, Italy, 26–28 February 2014.

28.   Ascione, F.; de Rossi, F.; Vanoli, G.P. Energy retrofit of historical buildings: Theoretical and experimental investigations for the modelling of reliable performance scenarios. *Energy Build.* **2011**, *43*, 1925–1936. [CrossRef]

29. Sudo, C. The 11 Oldest LEED Certified Buildings in the U.S., LEED Ed., 2017, 25. Available online: https://www.bisnow.com/national/news/construction-development/its-all-about-the-shell-the-10-oldest-leed-certified-buildings-in-america-72560 (accessed on 16 March 2019).

30. Fedrizzi, R. The oldest LEED-Certified Building in the World, LEED Ed., 2013, 25. Available online: https://www.usgbc.org/articles/oldest-leed-certified-building-world (accessed on 26 March 2019).

31. De Santoli, L.; Perini, G.P.; Rossetti, S. Come affrontare e gestire un progetto di riqualificazione energetica di un bene culturale con l'obiettivo di certificarne la sostenibilità? Il caso della Galleria Borghese a Roma, Quine Ed. *AiCARR J.* **2017**, *43*, 34–39.

32. Mazzola, E.; Mora, T.D.; Peron, F.; Romagnoni, P. Proposal of a methodology for achieving a LEED O+M certification in historic buildings. *Energy Procedia* **2017**, *140*, 277–287. [CrossRef]

33. Mora, T.D.; Cappelletti, F.; Peron, F.; Romagnoni, P.; Bauman, F. Retrofit of an historical building toward NZEB. *Energy Procedia* **2015**, *78*, 1359–1364. [CrossRef]

34. Mora, T.D.; Righi, A.; Peron, F.; Romagnoni, P. Historical buildings retrofit: The city hall of the city of Motta di Livenza (TV). *Energy Procedia* **2017**, *133*, 392–400.

35. Cappelletti, F.; Mora, T.D.; Peron, F.; Romagnoni, P.; Ruggeri, P. Building renovation: Which kind of guidelines could be proposed for policy makers and professional owners? *Energy Procedia* **2015**, *78*, 2366–2371. [CrossRef]

36. Ente Nazionale Italiano di Unificazione. *Conservazione dei Beni Culturali—Linee Guida per Migliorare la Prestazione Energetica Degli Edifici Storici*; UNI EN 16883; Ente Nazionale Italiano di Unificazione: Milano, Italy, 2017.

37. Commission, European, Directive 2006/32/EC on Energy End-use Efficiency and Energy Services. 2006. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0064:0085:EN:PDF (accessed on 16 March 2019).

38. European Parliament, Directive 2012/27/UE of The European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF (accessed on 16 March 2019).

39. Dall'O', G. *Green Energy Audit—Manuale Operativo per la Diagnosi Energetica e Ambientale Degli Edifici*; Ed. Ambiente: Milano, Italy, 2011.

40. Baggio, M.; Tinterri, C.; Dalla Mora, T.; Righi, A.; Peron, F.; Romagnoni, P. Sustainability of a Historical Building Renovation Design through the Application of LEED®Rating System. *Energy Procedia* **2017**, *113*, 382–389. [CrossRef]

41. U.S. Green Building Council, LEED v4 for Building Operations and Maintenance. 2014. Available online: https://www.usgbc.org/resources/leed-v4-building-operations-and-maintenance (accessed on 16 March 2019).

42. U.S. Green Building Council, LEED v4, Reference Guide for Building Operations and Maintenance. 2016. Available online: https://www.usgbc.org/resources/leed-reference-guide-building-operations-and-maintenance (accessed on 16 March 2019).

43. De Santoli, L.; Bellia, L.; Corgnati, S.P.; d'Ambrosio Alfano, F.R.; Filippi, M.; Mazzarella, L.; Romagnoni, P.; Sciurpi, F. *Efficienza Energetica Degli Edifici Storici*; Ed Delfino: Milano, Italy, 2014.

44. Green Building Council Italia. *Sistema di Verifica GBC Historic Building®—Parte 1*; Green Building Council Italia: Rovereto, Italy, 2014.