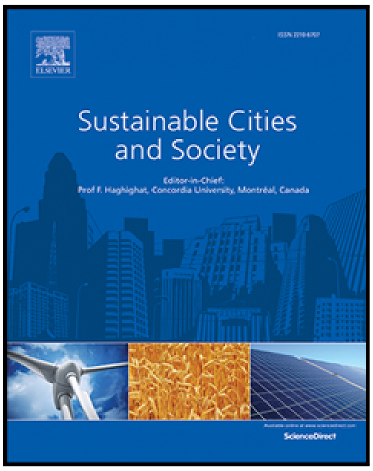

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Highlights

- RRT to evaluate LEED and dynamic simulation results applied by different operators;
- Evaluating the influence of different energy simulation software on LEED results;
- Assessing if subjectivity of operators affects the final LEED rating score.

A Round Robin Test on the dynamic simulation and the LEED protocol evaluation of a green building

Francesco Asdrubali[1*], Claudia Guattari[1], Marta Roncone[1], Giorgio Baldinelli [2], Eid Gul[3], Cristina Piselli[4], Anna Laura Pisello[4], Andrea Presciutti[5], Francesco Bianchi[6], Laura Pompei[7], Benedetta Mattoni[7], Fabio Bisegna[7], Dionysia Kolokotsa[8], Elisavet Tsekeri[8], Margarita-Niki Assimakopoulos[9], Chrysanthi Efthymiou[9], Nikolaos Barmparesos[9], Agnieszka Lechowska[10], Jacek Schnotale[10], Francesco Aletta[11], Umberto Berardi[12]

[1]Department of Engineering, Roma TRE University, Via Vito Volterra 62, Rome, 00146, Italy

[2]Department of Engineering, CIRIAF, Perugia University, Via G Duranti, Perugia, 06125, Italy

[3]Biomass Research Center, CIRIAF, Perugia University, Via G. Duranti, Perugia, 06125, Italy

[4]Department of Engineering, University of Perugia, Via G. Duranti 67, Perugia, 06125, Italy

[5]Universitas Mercatorum, Piazza Mattei 10, Rome, 00186, Italy

[6]Department of Physics and Geology, CIRIAF, Perugia University, Via G. Duranti, Perugia, 06125, Italy

[7]Department of Astronautical, Electric and Energy Engineering, Sapienza University of Rome, Piazzale Aldo Moro 5, Rome, 00185, Italy

[8]Chemical and Environmental Engineering School, Technical University of Crete Kounoupidiana, GR 73100 Chania, Crete, Greece

[9]Physics Department, National & Kapodistrian University of Athens, Physics Building 5, University Campus, 157 84 Athens, Greece

[10] Krakow University of Technology, Faculty of Environmental and Power Enginnering, 24 Warszawska Str. 31-155 Krakow, Poland

[11] Institute for Environmental Desing and Engineering, University College London, 14 Upper Woburn Place, London WC1H 0NN, United Kingdom

[12] Department of Architectural Science, Ryerson University, 350 Victoria St., Toronto, M5B 2K3, ON,Canada

*Corresponding author e-mail: francesco.asdrubali@uniroma3.it

Abstract. Green building concept plays a fundamental role in reducing the use of resources and the impacts on human health and environment, during the whole building life cycle. Therefore, a method to measure the building sustainability rate is crucial for comparing various alternatives in terms of use of different materials, energy resources, production processes to reduce energy consumption and environmental impacts.

Many protocols have been proposed to perform buildings' sustainability evaluation; however, different operators applying these certification tools might need to make hypotheses, even different from each other, to complete the whole procedure.

Hence, this work aims to evaluate whether and how the hypotheses formulated by each operator can influence the final certification level. To this end, a Round Robin Test among international partners was performed using different versions of LEED sustainability protocol to the same building with the same boundary conditions, comparing and analyzing the results provided by the participants. The final aim was to identify which issues have more influence on the final performance rate, giving to the users a deeper knowledge of the aspects included in these procedures. The results showed the potential of these building environmental certification systems, capable of offering a transversal level of environmental sustainability.

Keywords: green building rating systems, LEED, Round Robin Test, dynamic simulation, energy efficiency, sustainable construction.

1. Introduction

The green building concept plays a crucial role when the scope is the decrease in the use of resources, such as water and materials, as well as the reduction of effects on human health, human wellbeing, and environment during the whole building lifecycle. To provide a rating for building energy performance, several countries worldwide already developed their own energy certification procedures. In this framework in the last 20 years, different green buildings rating tools have been developed to analyze and rate the building design, construction, operational, and management phases regarding energy consumption and environmental impacts (Husain et al., 2020; Mattoni et al., 2018).

The first evidence of the need of paying more attention to the sustainability aspects of buildings appeared in the 1970s. The energy crises highlighted how difficult it was to pursue high levels of development to rely only on non-renewable energy resources. Starting from this awareness, the most widely accepted definition of sustainable development states that it is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This definition traces back to 1987 when it was proposed by the Brundtland Commission, the United Nation's World Commission on Environment and Development (Commission on Environment and Development, 1987).

Thus, the sustainability concept incorporates several fields and can be applied to widely different scales. When it is necessary to make a choice among various materials, energy resources, and production processes, it is essential to provide a measure of sustainability in order to compare competing alternatives (Bisegna et al., 2016; Klemeš, 2015; Nematchoua et al., 2021).

In developed countries, buildings are responsible for a very significant share of the total energy consumption (approximately 40%) and CO_2 emissions (e.g., 30%) (Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (Recast), 2010; Yang et al., 2014). Due to this, over the past years, several Green Building Rating tools have been developed by different countries to evaluate the degree of sustainability of buildings construction and operational phases and, eventually, the disposal one, with the final aim of controlling and reducing their environmental impacts. Historically, the first type of labeling applied to buildings regarded energy efficiency. In Europe, following the request by the Energy Performance of Buildings Directive (EPBD), issued by the European Commission, each member country has to make mandatory the need of an Energy Performance Certificate (EPC) for existing and new buildings. Energy efficiency in a building is usually one the most important aspects (Agdas et al., 2015; Bisegna et al., 2016; Dall’O et al., 2012) in the overall analysis that leads to a Green Building labeling. Moreover, it is worthy to notice that the energy efficiency aspects and the sustainability ones may be conflicting (Hanley et al., 2009). While energy efficiency labeling is nowadays mandatory, sustainability one is still, in most cases, made voluntarily. The most widespread tool internationally is the Leadership in Energy and Environmental Design (LEED), better known through its acronym LEED (U.S. Green Building Council., n.d.). The United State Green Building Council (USGBC) issued the first version of this green buildings rating system in 1998. It is a voluntary system for the design, construction and management of sustainable buildings and high-performance territorial areas and which was developed more and more internationally. LEED can be used on any type of building and promotes an integrated design system that concerns the entire building. This is a flexible and articulated system that provides differentiated formulations for new constructions, existing buildings, small homes, for urban areas while maintaining a coherent basic approach between the various areas.

The adjective "Sustainable" is increasingly employed to describe some aspects of the construction sector (Mattoni et al., 2018). Even if each of the existing rating systems comes from different nations, they are characterized by a common purpose: guaranteeing the application of environmental impact decrease strategies in the design and construction of buildings or neighborhoods (Dawodu et al., 2017; Grazieschi et al., 2020). They consist of a multidisciplinary

evaluation procedure able to rate the building performance taking into account different sustainability aspects. LEED protocol includes also some scores that evaluate the project from an economic or process point of view such as: Owner Project Requirement (OPR), Basis of Design (BOD), Integrative Design Process (IDP), as well as the evaluation of the investment for Greener Cost (Additional Green Cost), even though their weight is not particularly significant. Other evaluation protocols, such as LCC (Life Cycle Cost) for example, allow to evaluate these aspects, but they raise the complexity level of the analyses and they go beyond the scope of the present work.
Considering the rating tools from other countries, they can differ in the Standard to which refer when applying the procedure, in the way of analyzing some specific themes, and in the weights given to each evaluating criterion. The most important characteristic of these rating systems is the strong attention paid to the energy efficiency aspects, which is the thematic area that has a greater effect on global evaluation and the consequence of the environmental impact on the entire building lifecycle. In particular, a building can only be considered sustainable if the decrease of its environmental impact has been achieved without reducing the end-user's quality of life.

2. State of art

In the last years, several studies were carried with the aim to analyze and compare the methodological approaches that characterize different green buildings rating tools (Bahaudin et al., 2014; Liu et al., 2005; Suzer, 2015).
More in detail, many researchers focused on the analysis and comparison of specific categories of the studied rating systems to assess the different weights given to the subcategory in each tool (Dolezal & Spitzbart-Glasl, 2015; Wei et al., 2015; P. Wu et al., 2017; Z. Wu et al., 2016).
Today, paying attention to a worldwide sustainability concept and identifying which issues have more influence on the final performance rate are very crucial aspects in the environmental sustainability research field.
Round Robin Testing (henceforth RRT) is a well-known technique able to evaluate the effectiveness and the reproducibility of methodological procedures or laboratory tests. This method can be applied to different research fields with different specific goals. The Round Robin Test can be employed to compare different procedures or to investigate actual case studies, and it could be applied to the design phase, the labeling, or audit. Starting from this assumption, in (Tronchin & Fabbri, 2010) a RRT among several energy performance building evaluation methodologies and software scheduled in the Italian law was performed. The outcomes of the Round Robin Test are linked to the relationship between thoroughness of data input and energy evaluation accuracy. The RRT approach was used to evaluate the thermal conductivity of innovative insulating materials by sharing a measurement procedure among the partners at the aim of limiting the possible physical sources of differences in the results (Baldinelli et al., 2019).
In (Le Baron et al., 2019) the RRT procedure was employed for different new optical apparatuses and methods to measure the emittance of various solar absorbers in air. It is also possible to apply the Round Robin Test to compare the result of different techniques, from a quasi-stationary analysis to advanced dynamic data analysis methods, which can be used to characterize the thermal performance based on on-site collected data, as it is shown by the Authors in (Roels et al., 2017). Also, in the acoustic research field, the Round Robin test method was applied in order to evaluate experimental procedures and materials properties. In (Scrosati et al., 2016) a comparison between the default procedure and the low-frequency procedure made on the same façade sound insulation measurement was performed.
By means of a Round Robin Test procedure conducted in a full-scale experimental building, it was also possible to evaluate the uncertainty of a façade field measurements (Scrosati et al., 2015).
The novelty of this work deals with the employment of the RRT procedure on green building rating tool application. In particular, the aim of this paper is the assessment of the operator’s discretion during the sustainability labeling procedure. In fact, the choices made by the operators can have a significant effect on the final rate, and they need to be carefully evaluated. This study can provide users a more profound knowledge of the whole aspects that should be taken into account when a reliable and reproducible labeling procedure is needed. It also aims at offering some indications to assess sustainability aspects and topics that could be treated differently when different operators have to apply the same protocol to the same building in order to provide an objective sustainability certification and to compare the buildings sustainability level worldwide. In order to achieve this goal, the employment of a RRT procedure was needed.
In this study, the RRT was performed by different operators belonging to different research groups in the world, with the common aim of analyzing the results obtained by applying the same tool (LEED) to the same building with the same boundary conditions (same geographical location).
The features of the analyzed building were properly highlighted, described, and provided to each participant, with the final purpose of understanding which issues have more influence on the final performance rate provided by different research groups. Moreover, the Round Robin Test outcomes were accurately analyzed and compared.

The paper is structured as follows; Section 3 explains the LEED green building system; section 4 describes the study building for which the different versions of the LEED protocol were applied, and the energy simulations in dynamic regime carried out by the participants of the RRT; sections 5 and 6, respectively, illustrate the methodologies used and the results achieved by applying the LEED protocol and the energy analysis by the participants; section 7 compares the results obtained by the different research groups and, finally, section 8 reports the conclusions of the study.

3. LEED protocols for sustainable buildings

The version of the LEED green building system used for this study is LEED v4, developed in November 2013 by the U.S. Green Building Council (USGBC). LEED v4, launched in late 2013, (Kubba, 2016; U.S. Green Building Council., n.d.), it is one of the most diffuse and famous rating systems for the design, construction, maintenance, and operations of green buildings. This version of LEED was built on the basis of the previous one (LEED 2009) but it aims at implementing the number of criteria by considering other aspects and standardizing the methods for performance calculation, in order to make this tool suitable for different contexts around the World.
The most important innovative issues of LEED v4 are:

- The development of new requirements for different project types such as: data centers, warehouses and distribution centers, hospitality, existing schools, existing retail and mid-rise residential projects.
- The introduction of new impact categories and new credits and the reformulation of the existing ones: Climate change, human health, water resources, biodiversity, green economy, community and natural resources.

The maximum number of points achievable is 100 while 10 extra points can be obtained in the “Innovation” and “Regional priority” categories. Based on the number of points achieved, it is possible to obtain four different levels of certification: *Basic*, achievable with a score ranging between 40 and 49 points, *Silver*, if the case study achieves between 50 and 59 points, *Gold*, characterized by a score which range between 60 and 79 points and, finally, *Platinum*, which is the highest certification, can be obtained with scores over 80.
The versions of LEEDv4 differ among each other for the type and number of credits achievable in each macro area, however each operator was free to choose the LEED protocol to use in order to verify how much this choice affected the final result.

4. Description of the case study

The object of the Round Robin Test was the residential complex "Le Violette" (Fig. 1), located in the town of Foligno (climate zone D, according to the Italian zoning regulatory framework (Decree DPR 412/93., 1993)), in the Umbria region, Italy.

Figure 1. Bird view of the studied building.

The studied building is divided into twelve apartments; it is characterized by a compact shape with balconies aligned along the south facade and a flat roof, except for the area occupied by the duplex apartments (Fig. 2). Moreover, it is divided into an underground level and three levels above ground. The ground floor is employed as private garages and technical rooms, while the other parts of the building are for residential use only. There are six apartments on the ground floor and six on the first floor, with surfaces ranging from 71 m^2 to 95 m^2. The roof garden is properly insulated, and the duplex roof was designed to hold solar thermal and photovoltaic collectors.

Figure 2. Rendering of the studied building.

The orientation and the constructive choices respect the best bioclimatic needs of the site in terms of solar radiation and proper internal ventilation for each apartment. From the following figures (Fig.3 and Fig.4) it is possible to observe the North and South plants of the study building that were provided among the input data to the participants of the RRT. In order to pursue the energy saving objectives and the renewable energy exploitation, specific architectural and system solutions were implemented.

4.1 Architectural solutions

With the aim of improving the thermal-energy behavior of "Le Violette" building, a variety of advanced technical solutions were applied:

- 7.5 cm thick insulation layer, 2 cm of which are made up of air. Thanks to this solution, it was possible to achieve the standard of "energy-efficient building" by ensuring compliance with the heat dispersion limits imposed by the Italian Legislative Decree 311/06, in terms of new requirements since 1/1/2010;
- Increased building thermal inertia, which was possible thanks to higher wall thicknesses. The perimeter walls of the building are 43 cm thick. Besides, Table 1 summarizes the thermal characteristics of the different types of walls present in the study building;
- Passive systems for controlling sunlight. The direct solar radiation during summer causes an increase in terms of internal temperature, especially in the facing south apartments. To reduce this contribution, the installation of solar shading devices was evaluated for the South facing windows;
- Green roofs, in order to ensure higher insulation and improve thermal inertia, were installed;
- The hygrometric performance of the building components was verified using the Glaser test, following the UNI EN ISO13788 (Ente Italiano di Normazione (UNI)., n.d.).
- Certified biocompatible insulation materials were used. In particular, the Celenit panel was chosen, which is characterized by long and 65% resistant mineralized fir fibers coated with a mineral binder with high-performance thermal and acoustic insulation.

Table 1. Thermal characteristics of the different types of walls present in the study building.

	Thermal characteristics				
Type of wall	**Thickness [m]**	**Mass [kg/m^2]**	**Thermal Transmittance [W/m^{2}K]**	**Thermal Capacity [kJ/m^{2}K]**	**Thermal Resistance [m^{2}K/W]**
Perimeter wall with bricks on the outside	0.425	420	0.335	390.6	2.984
Perimeter wall with plaster on the outside	0.425	344	0.279	326.8	3.589
Internal partition wall	0.33	462	0.644	455.3	1.533
Floor	0.405	529.5	0.677	476.3	1.476
Garage floor	0.41	469.5	0.317	401.8	3.158
Attic ceiling (ID)	0.395	393	0.293	334	3.411
Roof garden	0.674	840.3	0.312	714.7	3.204

4.2 Plant solutions

Concerning plant solutions, the case study is characterized by:

- A centralized system with separate insulation systems, which allows for higher efficiency of the heat generator thanks to the scale effect and therefore significantly reduces fuel consumption during the winter season;
- The use of low-temperature heating systems. Radiant floor panels with low-temperature hot water supply have been provided within the individual housing units. The condensing central heating system has a modulating condensing mode of operation, the fuel is methane, and the maximum installed power is 56 kW;
- Solar thermal domestic hot water (DHW): DHW production occurs through the use of a natural gas condensing boiler, with generation efficiency ηgen equal to 0.96. Besides, the solar thermal system has been sized in order to cover 60% of the DHW needs;
- Photovoltaic (PV) panels were also installed for the self-production of electricity using solar radiation;
- The building is also equipped with a rainwater recovery system for irrigation and toilet purposes consisting of two tanks of 7,500 liters.

5. Methodology

In this study the results obtained through an international Round Robin Test are presented and discussed, with the aim of evaluating the reliability of the certification tools of the environmental sustainability of buildings.
In fact, the RRT consists of a test program in which several research groups conduct the same analyzes in order to evaluate the repeatability and reproducibility of the obtained results.
Therefore, in this work the RRT was performed by different operators belonging to nine different research groups, with the same goal of analyzing the results obtained by applying the same green building assessment tool (LEED) to the same study building located in Foligno (PG, Italy).
Participants were requested to apply the LEED version of their country or the one they considered most appropriate for the study to the Italian building proposed as a case study, as well as to choose the simulation software to use.
The modeling of the study building took place in compliance with the plant characteristics and the geometries and thermophysical properties of the walls and fixtures provided to the participants as part of the RRT.
Each group chose a dynamic simulation software in order to better represent the building behavior and to apply the performance approach, starting from the input received. Although, the same specifications taken into account for each group, while the same weather file used for the simulations was specifically developed for the building location in Foligno using the Meteonorm software based on database interpolation (Software, n.d.).
Generally, the number of thermal zones has been defined to simulate the analyzed building, subject to the same temperature and relative humidity conditions and assuming similar thermal behavior for each room contained in the different apartments. The need for such a significant number of thermal zones is also linked to the different geometry of the different apartments, for which the software sets a limit: each wall to be defined adjacent to that of another thermal zone must have the same surface. For each thermal zone, it was also necessary to specify the assumptions that used for all the research groups, and listed in Table. 2.

Table 2. Common assumption for the building simulation.

Common assumptions	Typical Values
Infiltration (Schedule type: On /Off)	0.3-0.5 [air changes/h]
Cooling setpoint (Schedule type: Temperature)	Indoor minimum temperature 26 °C
Heating setpoint (Schedule type: Temperature).	Indoor minimum temperature 20 °C
Occupancy (type of planning: fractional): variation during the day	Peak in the morning 8.00 a.m. to 5.00 p.m. decrease 6.00 p.m-00.00 a.m. increase
People's activity (Schedule type: Activity Level)	Most common activities (cooking, relaxing, sleeping, cooking etc.)
Ventilation (Schedule type: On /Off)	Natural ventilation

Regarding Table 3, three of the research groups (Roma TRE University, CIRIAF and Universitas Mercatorum) dynamic energy performance model has been developed by using the TRNSYS dynamic simulation tool (Trnsys, n.d.). By using the Energy performance model, the building annual energy consumption for heating, cooling, lightening, ventilation, and other components such as electro-electronic appliances have been calculated.

Moreover, in University of Perugia, Krakow University of Technology, University College of London and Ryerson University, in order to quantify building annual energy needs, the structure in University of Perugia, Krakow University of Technology, University College of London and Ryerson University was modeled within the EnergyPlus simulation environment (Crawley et al., 2001) with DesignBuilder graphical interface v6 (DesignBuilder Software, 2018). The dynamic simulation of the residential complex allowed calculating the annual primary energy consumption for heating, cooling and DHW demand and electrical components.

In Sapienza University the building modeling was carried out using a dynamic energy simulation software, Grasshopper/Archsim (a tool of Rhinoceros company) (Dogan, 2013), while the research group of Technical University of Crete with National and Kapodistrian University of Athens decided to use Sketch Up 2017 (Trimble, n.d.) and Open Studio 2.7 (OpenStudio, n.d.) dynamic software, in order to access building's energy needs.

In this study, the Performance approach was adopted in order to perform an energy simulation in the dynamic regime of the analyzed building, as it is required by the Round Robin Test guidelines. After the simulation, each research group were requested to apply the LEED protocol. Both the analyzed building and the reference building were modeled and compared according to the protocol Regarding Table 3, Roma TRE University, University of Perugia and Universitas Mercatorum applied the same version of LEED protocol, GBC (Green Building Council) Home for residential buildings 2011(Green Building Council Italia, 2011), the Italian version of US LEED protocol. Moreover, Krakow University of Technology, and University College of London decided to use LEED v4 for Building Operations Checklist in combination with the LEED v4 for Building Design and Construction manual-guide. GBC Home for residential buildings v2 revised in 2018 (Green Building Council Italia, 2018), the Italian version of the US LEED protocol was used by Sapienza University, while the Italian version of LEED 2009 protocol, GBC, for new residential buildings decided to be used by CIRIAF. Ryerson University decided to use the US LEED protocol and finally, Technical University of Crete & National and Kapodistrian University of Athens, decided to use LEED v4 for Building Operations Checklist in combination with the LEED v4 for Building Design and Construction manual-guide (U.S. Green Building Council, 2016) in the following sections, each of the different versions of LEED protocol, analyzed in detail. Table 3 shows the LEED version and the simulation tool used by the different research groups.

Table 3. Simulation software and LEED employed by the RRT participants.

Research Group	Simulation Software	LEED Version
Roma TRE University, Italy	TRNSYS dynamic software	GBC (Green Building Council) Home for residential buildings 2011, the Italian version of US LEED protocol
CIRIAF, Italy	TRNSYS dynamic software	Italian version of LEED 2009 protocol, GBC, for new residential buildings
University of Perugia, Italy	EnergyPlus engine with DesignBuilder graphical interface	GBC (Green Building Council) Home for residential buildings 2011, the Italian version of US LEED protocol
Universitas Mercatorum, Italy	TRNSYS dynamic software	GBC (Green Building Council) Home for residential buildings 2011, the Italian version of US LEED protocol
Sapienza University, Italy	Grasshopper/Archsim dynamic software	GBC Home for residential buildings v2 revised in 2018, the Italian version of the US LEED protocol
Technical University of Crete & National and Kapodistrian University of Athens, Greece	Sketch Up 2017 and Open Studio 2.7 dynamic software	LEED v4 for Building Operations Checklist in combination with the LEED v4 for Building Design and Construction manual-guide
Krakow University of Technology, Poland	DesignBuilder software with EnergyPlus engine	LEED v4 BD+C
University College of London, United Kingdom	EnergyPlus engine with DesignBuilder graphical interface	LEED v4 for v4 for Building Design and Construction: Homes and Multifamily Lowrise
Ryerson University, Canada	EnergyPlus engine with DesignBuilder graphical interface	v4 for Building Design and Construction (US LEED protocol)

Table 4. Comparison between the thematic sections of the LEED protocol versions used in the RRT

LEED protocol's sections	GBC Home v2011	GBC Home v4	GBC Home v2	LEED v4 for Building Operations and Maintenance Checklist	LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise
Integrative Process (IP)	0	0	0	0	2
Location and Transportation (LT)	0	0	0	15	15
Sustainable Sites (SS)	25	26	22	10	7
Water Efficiency (WE)	10	10	12	12	12
Energy and Atmosphere (EA)	30	35	32	38	38
Materials and Resources (MR)	15	14	14	8	10
Indoor Environmental Quality (IEQ)	20	15	20	17	16
Innovation in Design (ID)*	10	6	10	6	6*
Regional Priority (RP)	0	4	0	4	4
Total	110	110	110	110	110

*Only for the "LEED v4 for Building Design and construction: Homes and Multifamily Lowrise" protocol this section is named "Innovation (IN)".

Table 4 depicts the comparison between the different version of LEED protocols. The applied rating system promotes healthiness, durability, economy, and best environmental practices in the design and construction of buildings. In fact, the evaluation system is organized into the following five environmental categories that all the different versions consisted of: *(a); Sustainable Sites (SS), (b), Water Management (WM), (c); Energy and Atmosphere (EA), (d); Materials and Resources (MR), (e); Internal Environmental Quality (IEQ), (f) and Innovation in Design (ID).*

As it happens for the US LEED application, also each category of the GBC Home rating tool is characterized by prerequisites and credits. All credits counted at least 1 point, the prerequisites have to be satisfied mandatory and do not provide the score. The evaluation system allows achieving 100 points, while the Innovation in Design and Regional Priorities categories allow obtaining further 10 points, which is a bonus. By adding up the scores obtained for each credit of each section, it can be calculated the overall score achieved by the analyzed building. If the project checklist score is 40 to 49 points, the project result is: certified, 50 to 59 points - silver, 60 to 79 points - gold and 80 to 110 points - platinum.

On the other hand, the US LEED's categories "Innovation" and "Regional Priorities" are included within the four credits of the GBC Home last section, the so-called "Innovation in Design". Furthermore, the first section of the "LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise", Integrative Process (IP), is considered into the GBC Home protocol as a credit of the last section (Innovation in Design (ID)).

Finally, once the results of all the applications of the LEED protocol of the various research groups were obtained, a comparison was made with the aim of identifying if and which sections of the protocol were most affected by the subjectivity of the operator.

To this end, the statistical indicators of variance and absolute error relating to the results obtained for the various sections of the protocols of the various research groups were also calculated.

The variance (eq.1), one of the main indices of variability of a sample of data, was calculated as the arithmetic mean of the squares of the differences between value (X_i) of the distribution considered and its average value:

$$\sigma^2 = \frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{N} \quad (1)$$

In particular, in this study X_i indicates the score obtained by the single i-th research group for that specific section of the LEED protocol considered, $\overline{X}$ the average value of the scores obtained among the various participants in relation to the section considered and finally N is the number of scores considered for the analysis of that thematic section.

The LEED protocol is influenced by subjective evaluations and therefore is influenced by random errors whose uncertainty cannot be predetermined. Furthermore, the analysis was conducted with a limited number of studies. Therefore, it is not possible to validate the protocol as if it were a mathematical model. However, the sensitivity ΔS of the determined result (score) for each protocol's thematic area was also established in terms absolute error (2):

$$\Delta S_i = \frac{S_{i,max} - S_{i,min}}{2} \quad (2)$$

Where $S_{i,max}$ and $S_{i,min}$ are respectively the maximum and minimum points given to each item (thematic section of the protocol). Hence, total sensitivity was determined according to the following expression (3):

$$S_t = \sum_{i=1}^{n} \Delta S_i \quad (3)$$

5.1 GBC (Green Building Council) Home

Roma TRE University, University of Perugia and Universitas Mercatorum research groups applied the Italian version of US LEED protocol, the so-called GBC (Green Building Council) Home for residential buildings 2011 version (Green Building Council Italia, 2011). This tool was developed by the Green Building Council Italia association, which is joined by the most competitive companies and the most qualified Italian professional communities operating in the sustainable construction segment. The GBC Home derives from the US LEED but taking into account the housing characteristics and the differences in the construction model typical of the Italian reality.

5.2 Italian version of LEED 2009 protocol, GBC

The CIRIAF research group at University of Perugia participated in the International Round Robin Test for LEED certification. The objective of this study consisted of applying the Italian version of LEED 2009 protocol, GBC, for new residential buildings, on the Italian residential buildings (Green Building Council Italia, n.d.). A LEED 2009 protocol rating system is applied to a residential building located in Foligno (PG), Italy, to investigate the impact on the environment, economy, design, and construction of buildings. To understand the impacts of the GBC Home rating system and to evaluate the work Taking into account the Sustainable Sites selection (SS) macro-area, the location and public transport were assessed by using Geo-referencing supports from local city maps, Google map or other mobile base GPS apps.

5.3 GBC Home for residential buildings v2

Differently from the other partners of the project, The Sapienza research group applied the protocol the GBC Home for residential buildings v2 revised in 2018 (the Italian version of the US LEED protocol) which represents a revised version of the GBC Home published in 2011(Green Building Council Italia, 2018). The main differences between the two versions are: the distribution of the maximum achievable scores per category and the credits which each category is divided into. The results were compared to the ones obtained with the energy simulation of the reference building, “GBC Home Reference Design Home”, which is characterized by the same geometry of the real one but with standard characteristics defined by the GBC rating tool.

5.4 LEED v4 for Building Operations Checklist in combination with the LEED v4 for Building Design and Construction manual-guide

In the framework of this project the LEED v4 for Building Operations Checklist in combination with the LEED v4 for Building Design and Construction (U.S. Green Building Council, 2016) manual-guide were applied by the two Greek research groups (TUC and NKUA). The applied rating system promotes the uniqueness of different projects, brings smart grid thinking to the forefront, focuses on performance throughout a project’s life cycle, as well as delivers a more comprehensive and holistic approach regarding the materials, water use-supply and indoor air quality.

5.5 LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise

To perform LEED protocol calculations, Krakow University of Technology and University College in London, used the "v4 for Building Design and Construction: Homes and Multifamily Lowrise" calculator, is considered into the GBC Home protocol as a credit of the last section.

5.6 US LEED protocol, v4 for Building Design and Construction

The participation of Ryerson University was strategic as Canada is the country outside the United States where the LEED protocol has the largest adoption. The BeTOP group of Ryerson University joined the international effort and used the "v4 for Building Design and Construction" version of the US LEED protocol.

The dynamic model of the studied building, required in the Energy and Atmosphere section of the LEED protocol for estimating energy consumption, was created using Design Builder v4. This tool uses a graphical user interface which takes advatanges of EnergyPlus engine to perform all the calculation. This means that no template of typical usage was considered and the data were manually set. The opportunity to model tridimensionally the building offered the possibility to model thermal bridges with high accuracy. For example, the wooden window frames were equipped with aluminum shutters, which resulted in main thermal bridges within the envelope. A particularly challenging element in the modelling was the green roof, whose energy behavior is heavily affected by the water saturation levels of the soil. For this, the researchers assumed a dry Mediterranean climate, modelling dry soil based on David Sailor and Umberto Berardi heat transfer models within green roofs (La Roche & Berardi, 2014).

6. Results

6.1 Roma Tre University, Italy

Through the GBC Home application to the case study, the Roma TRE University research group obtained a score of 89/110 (Table 5), pursuing the highest level of "Platinum" certification.
(a); Sustainable Sites (SS): in this section it was obtained an overall score of 21 points out of 25. It was not possible to reach the maximum score with the regard to Credit 5 and Credit 11, "Proximity to public transport" and namely "Common areas: spaces for relations and common spaces", respectively. In the first case, due to a minimum distance for the achievement of public stops higher than the minimum value imposed by the protocol, the second one, since the building complex "Le Violette" did not satisfy the requirement "Spaces for internal relations". In particular, the latter involves the construction of common spaces aimed at playful activities, meeting and communication with particular attention to the elderly, but “Le Violette” is not provided with these facilities.
(b); Water Management (WM): this section achieved the maximum score (10 points). Both Credit 1 GA “Reduction of water consumption for domestic use” and Credit 2 GA “Reduction of water consumption for irrigation purposes” are fully satisfied. In particular, the analyzed building obtained a water saving of 20% compared to a reference building, with characteristics and consumption set by the protocol. Assuming the use of low-flow devices, a water saving higher than the 36 % was achieved. Furthermore, the option requesting the installation of a rainwater recovery system for internal non-drinkable uses, such as those intended for toilet use, was also satisfied.
Finally, also the credit "Reduction of water consumption for irrigation purposes" was assumed as satisfied, taking into account both its phases, namely "Characteristics of the soils, the species used and the irrigation systems" and "Presence of a collection and accumulation system of rainwater ".
c); Energy and Atmosphere (EA): here the performance approach was adopted, which consider 2 credits: "Optimization of energy performance" (1EA) and "Efficient production and distribution of domestic hot water" (6 EA). The dynamic energy simulation of the studied building showed an improvement of the energy performance index equal to 56.2% compared to the estimated primary energy consumption value of the reference building "GBC Home-Reference Design Home ", leading to a final score of 23/27 points.
The energy modeling of the" Le Violette "residential complex, carried out by Trnsys dynamic software, allows assessing the annual primary energy consumption due to heating and cooling demand, electrical component and production of domestic hot water.
The obtained result underlines the effectiveness of the plant solutions employed in the studied building. In fact, a primary energy consumption decrease leads to lower management costs, lower environmental impact and reduced greenhouse gases emissions, due to the combustion of fossil sources and their supply. Furthermore, with regard to the “Efficient distribution of hot water”, “Insulation of piping” and “High efficiency domestic hot water production devices” requirements were assumed as satisfied. This choice was made paying attention to energy efficiency and savings. Therefore, a total score of 26 out of 30 points was obtained.
(d); Materials and Resources (MR): this section obtained 10 over a total of 15 points. Despite the use of certified and low-emission materials, three credits were not fully satisfied, namely: the 1 MR "Reuse of structural and non-structural elements of buildings" (0 points), the 2 MR "Construction waste management" and the 4 MR "Recycled content" which obtained 1 out of 2 points.
(e); Indoor Environmental Quality (IEQ): here 17 out of 20 points were achieved. The building is characterized by design features aimed at protecting against pollutants and controlling indoor contaminants. Moreover, certified biocompatible and sound-absorbing construction materials were employed and a good building orientation (North-South) was chosen, also ensuring satisfactory internal lighting The compact shape is able to minimize the external dispersing surface, with sunshades in order to protect the internal environment from direct solar radiation during the summer and guarantee it during the remainder of the year. Credit 1 QI "Ventilation with external air" does not obtain the maximum score, assuming the "Dual flow ventilation" option not verified and Credit 5 QI "Distribution of heated and cooled spaces", assuming that only one over three options was satisfied. This one provides for the use of "HVAC" systems without pipes or hydronic systems such as fan coils with or without internal fan and heating panels.

(f); Innovation in Design (ID): here it was possible to obtain only 5 out of 10 points. Table 5 shows the maximum achievable score and that obtained for each section of the GBC Home rating tool by the Roma Tre University research group application.

Table 5. Maximum score and score achieved by the application of the Roma Tre University for each section of the GBC Home protocols.

Roma Tre University		
Section	**Maximum Score**	**Score obtained**
Sustainable Sites (SS)	25	21
Water Efficiency (WE)	10	10
Energy and Atmosphere (EA)	30	26
Materials and Resources (MR)	15	10
Indoor Environmental Quality (IEQ)	20	17
Innovation in Design (ID)	10	5
Total	**110**	**89**

6.2 CIRIAF, Italy

The CIRIAF research group at Perugia University applied LEED 2009 Protocol and GBC Home application on a residential building located in the locality of Sterpete, at Violette street in Foligno Italy, taken as a case study and achieved a score of 85/110 (Table 6), obtaining the highest level of "Platinum" certification.

a); Sustainable site (SS): the score achieved in the selection of the sustainable site is 18/26. The selected building does not achieve the maximum score because of Credits 2, 3, 4.1, 4.3, 4.4, and 6.2, which are corresponding to building density and proximity services, recovery and requalification of contaminated sites, alternative transport (access to public transport, low emission transport, limited capacity, and space, and rainwater quality control, respectively). The conditions imposed by the protocol was not fully satisfied by the building, as the proximity services, access to the public transport and low emission transport, parking capacity and open space for meeting and gathering was not sufficient, and proper management for the rainwater quality control is lacking the constraints, therefore, the points were deducted.

b); Water management and efficiency (WME): in this section, the total score achieved by the building is 8/10. Efficient water management for irrigation: 4 credit points were given to the building as in the building the water management and its efficiency is reached. Innovative technologies reduced by 30% the water consumption in wastewater through smart water scheduling technology, hence, 2 credit points were given for the water management. Reduction of water use: 2 points were given as water metering system and smart scheduling reduce the water utilization in the building, so the total water reduction is 30%.

c); Energy and Atmosphere (EA): for the Energy and Atmosphere section the building achieved a total score of 27/35. For Credit 1, 1EA, "optimization of energy performance", a performance approach is implemented, and it achieved 19 points. According to the LEED 2009 protocol if the energy reduction reaches 48% for new construction and 44% for renovation, then the full points will be given. In the energy model of the residential building, the energy demand is reduced by 52%, which is higher than the protocol benchmark. For Credit 2, on-site renewable energy production, a value higher than the protocol set value (13%) was reached, so the 7 maximum points were assigned, thanks to the installation of integrated solar panels and hot water collectors. According to the given building datasheet, the Credit 3, 4 and 5, the projected building does not satisfy the set values of LEED 2009 protocol, so 0/2, 0/2, 0/3 points were given for each credit respectively. The building hot water distribution system pipes were properly covered by an insulation material, which makes the distribution of hot water efficient, so it achieved the maximum score of 3/3.

d); Materials and Resources (MR): for materials and resources the building achieved a total score of 7/14. The four credits that did not fully satisfy the requirements, because the information given in the datasheet was not fully satisfied to reach the full score: they are Credits 1.1, "reuse of building" achieve 1/3 credits, Credits 2, "construction waste management" achieve 1/2, Credits 4, "recycled contents" achieved, 1/2, while the credit 5, "regional materials extracted, processed and produced at a limited distance" achieved 1/2 points, because of the limited information given in the building datasheet.

e); Internal Environmental Quality (IEQ): in this section, the total score achieved by the building is 15/15 maximum points. The two prerequisites and all the 8 credit points were satisfied by the building design topographies, prevention against pollutants, and internal contamination control. The material used is certified and biocompatible, and the internal air quality control and ventilation system satisfied the building requirements, as per the LEED protocol.

f); Innovation in design and Planning (IP): for this section, the building achieved the maximum score of 6/6. For the innovation in design of the building, there is a total of 5 Credit points which are achieved by following and satisfying all prerequisites and PATH 1 of the LEED 2009 GB rating system. As Credits 1.1, to Credits 1.5, respectively, building design, exemplary performance, strategies of IAQ improvement, integration of renewables, and thermal comfort improvement by geothermal energy each have achieved 1/1 credit points and for Innovation and design, all points were given to the building, since, following the PATH 1 of LEED 2009 protocol and building, they satisfy all the proposed credits. Credits 2, LEED Accredited Professional, obtained 1 point of 1, given because one principal participant is LEED Accredited Professional.

g); Regional Priority (PR): for the Regional priority section the score achieved is 4/4 points. According to the database of the Italian Green Building Council, the regional priority section is divided into four specific credits, and each has 1 specific credit point: geographically specific environment, public health, social safety, and social equality. The building is located in the well-developed part of the city, and, according to the given building information, satisfies each and every specific credit point, of GBC Italian LEED 2009 protocol, hence, all 4 credit points were selected for the building. The Table 6 presents the score for the analysed residential building, with the score of each category separately; the overall score is 85, so achieving the highest level of certification level “Platinum”.

Table 6. Maximum score and score achieved by the application of the CIRIAF Perugia University for each section of the GBC Home protocols.

CIRIAF Perugia University		
Section	**Maximum Score**	**Score obtained**
Sustainable Sites (SS)	26	18
Water Efficiency (WE)	10	8
Energy and Atmosphere (EA)	35	27
Materials and Resources (MR)	14	7
Indoor Environmental Quality (IEQ)	15	15
Innovation in Design (ID)	6	6
Regional priority (RP)	4	4
Total	**110**	**85**

6.3 University of Perugia, Italy

The application of the GBC Home protocol carried out by the research group at University of Perugia led to a score of 82/110 for the case study building (Table 7). Accordingly, the building obtained the highest level of "Platinum" certification.

(a); Sustainable Sites (SS): this category reached a score of 15 points out of 25. The case study complex is located in a rural area intended for edification according to the local zoning plan. It was not possible to achieve any point for Credit 2 “Settlement methods”, Credit 4 “Proximity to services”, Credit 5 “Proximity to public transport”, and Credit 11 “Common areas: spaces for relations and common spaces”. In the first case, neither Option 1 nor Option 2 are respected, namely (i) there is no indication regarding the fact that the site was previously a brownfield site and, from the orthophoto, (ii) it seems that the perimeter of the lot is less than 75% bordering on land already developed (a large part seems still under development). As regards the second in the list, according to Google maps/Google earth search, there appear to be less than ten basic services, i.e. a tobacconist, a hairdresser, a primary school, a church, a bar, and a municipality office building within 500 m from the building. The area, indeed, seems mainly residential. As of Credit 5, the minimum distance between the building and the closest train station higher than the minimum value imposed by the protocol. There is no metro in the area and there seems to be only one bus line crossing the area. Finally, the complex "Le Violette" is not provided with indoor nor outdoor common areas. Also, there seems to be no bike parking.

(b); Water Management (WM): taking into account this category, a score of 7 points out of 10 is obtained. In fact, only Credit 2 “Reduction of water consumption for irrigation purposes” is fully satisfied, since the surface of the green areas is at least 20% of the external areas, including the green roof, and fits the protocol requirements. As regards Credit 1 “Reduction of water consumption for domestic use”, only 3 out of 6 points are achieved since the building is provided with a rainwater recovery system for washing machine and toilet use, also thanks to the presence of the roof garden. Accordingly, Option 2 is achieved, while Option 1, i.e. the adoption of specific strategies for water saving in building equipment, is not considered based on the available information on the building.

(c); Energy and Atmosphere (EA): the Performance approach was implemented, as previously mentioned, which involves two credits: Credit 1 “Optimization of energy performance” and Credit 6 “Efficient production and distribution of domestic hot water”. The results of dynamic simulation showed an energy performance improvement in the analyzed building compared to the reference building equal to 54.1% in terms of estimated primary energy consumption as defined in the protocol, leading to a score of 22 out of 27 for Credit 1 and stressing the effectiveness of the energy efficiency solutions implemented in “Le Violette” complex. Moreover, Credit 6 about the efficiency of the DHW system is assumed to be fully satisfied thanks to the efficient design and installation, the existence of a proper thermal insulation of piping, and the fact that the building was provided with a solar thermal system able to cover 60% of the DHW requirement. In conclusion, the total score reached in this category is equal to 25 out of 30 points.
(d); Materials and Resources (MR): in this section almost the full score was achieved, with 13 out of 15 points. In the building design and construction, indeed, particular attention was paid to the use of certified, sustainable, and durable materials and the collection and recycling of waste. Only two credits were partially satisfied, i.e. Credit 2 “Construction waste management”, since it is assumed that during the construction phase 75% of waste was recycled or recovered, and Credit 4 “Recycled content”, where 10% recycled content is considered.
(e); Indoor Environmental Quality (IEQ): this category obtained 18 out of 20 points, given the attention paid in the building design to comfort and healthiness in inhabited environments, also thanks to the requirements of the related Italian building regulation in force. In particular, certified construction materials and the green roof were implemented to unsure biocompatibility and acoustic insulation. Also, building sunshades, shape, and orientation were properly designed to ensure the optimal use of solar radiation, natural daylight, and natural ventilation, in addition to advanced systems for mechanical ventilation. Finally, the installed low temperature radiant floor panels for heating are the best solution in terms of thermal comfort, since they minimize the vertical temperature gradient working mainly by irradiation. However, Credit 4 “Extraction systems” is not achieved, since no indication about advanced air extraction systems was provided.
(f); Innovation in Design (ID): in this section 6 out of 10 points were reached, also considering the fact that the building received a price for green and sustainable value. Table 7 summarizes the total scores for each category vs. the maximum achievable scores according to the GBC Home v4 rating tool obtained by the research group at the University of Perugia.

Table 7. Maximum score vs. score achieved for each section of the GBC Home protocol by the application of the University of Perugia.

University of Perugia		
Section	**Maximum Score**	**Score obtained**
Sustainable Sites (SS)	25	15
Water Efficiency (WE)	10	7
Energy and Atmosphere (EA)	30	25
Materials and Resources (MR)	15	13
Indoor Environmental Quality (IEQ)	20	18
Innovation in Design (ID)	10	6
Total	**110**	**84**

6.4 Universitas Mercatorum, Italy

"Platinum" certification” was achieved with a score of 82/110 by Unimercatorum research group analysis through GBC Home application.
(a); Sustainable Sites (SS): this first section obtained an overall score of 20 points out of 25. Transports information data highlighted that just 2 bus stops (with a stop a day) are in proximity (distance less than 200 m) to the building instead of 60 stops a day. No common spaces are available. Therefore, the building complex "Le Violette" did not fulfill the requirement "Spaces for internal relations". Just 1 point was given thanks to the availability of the parking for the bicycles at a common area.
(b); Water Management (WM): this section achieved 9 points out of 10. The low earth thickness on the roof (0.3 m) involves that no tall trees can be planted on the roof. Therefore, according to the GBC protocol criteria, Credit 2 GA “Reduction of water consumption for irrigation purposes” can reach 3 points out of 4.
(c); Energy and Atmosphere (EA): The performance approach was adopted for Energy and Atmosphere section. In particular, 1EA:"Optimization of energy performance” obtained 20 points out of 27 due to an improvement of energy

performance index equal to 52%. The renewable energy produced by thermal solar and PV system, solar shading use and the higher efficiency of heat and cooling system allowed to reach such percentage.

"Efficient production and distribution of domestic hot water" (6 EA) got the maximum score (3 points) thanks to use of insulation thickness of heating and cooling pipelines higher than ones recommended.

(d); Materials and Resources (MR): 9 points out of 15 were awarded to the Materials and Resources section. The building taken into account is a new construction and no information about structural elements is known. Therefore, no score is assigned to 1 MR "Reuse of structural and non-structural elements of buildings " and 2 MR" Construction waste management".

e); Indoor Environmental Quality (IEQ): Just 1 point was assigned to Credit 1 "Ventilation with external air" due to the absence of a dual ventilation system. The employment of heat pump allows to avoid flue gases production adding 1 point to the final score. Air pollution and humidity control is guaranteed by the presence of a cooling system with radiant floor and WC without windows (+2 points). The choice of radiant floor for the heating and cooling gains other 3 points for the Credit 5 QI "Distribution of heated and cooled spaces". Thanks to the independent entrance of garages, thanks to the low risk for radon contamination in Foligno territory and thanks to the buildings shape and materials that allow a good use of sunlight and a good acoustic insolation levels, the other QI credits obtained the maximum score.

(f); Innovation in Design (ID): regarding the Innovation in Design section, it was possible to obtain only 5 out of 10 points. Table 8 shows the maximum score and the one for each section of the GBC Home rating tool by the Universitas Mercatorum research group application.

Table 8. Maximum score and score achieved by the application of the Universitas Mercatorum for each section of the GBC Home protocols.

Roma Tre University		
Section	**Maximum Score**	**Score obtained**
Sustainable Sites (SS)	25	20
Water Efficiency (WE)	10	9
Energy and Atmosphere (EA)	30	23
Materials and Resources (MR)	15	9
Indoor Environmental Quality (IEQ)	20	16
Innovation in Design (ID)	10	5
Total	**110**	**82**

6.5 Sapienza University, Italy

The building "Le Violette" obtained the highest score "Platinum level" with the GBC Home protocol for residential buildings v2 2018 (Green Building Council Italia, 2018), presenting an overall score of 83 credits (Table 12). As expected, this result is in line with the applications of the other participants.

(a); Sustainable Sites (SS): the first category reaches a score of 21 points out to 22. All the credits (SS 1-2-3-4-5) achieved the maximum points, except the "Common space: spaces for relations and common spaces" (SS 6), due to the absence of a shared space inside the building. Regarding the SS 1 (Site selection) credit, which involves the calculation of the average building density, a value of 1.56 m^2/m^2 was obtained: it is higher than the threshold value of 0.4 m^2/m^2. The SS 2 regards the proximity with basic services (pharmacy, bar, gym, supermarket etc) within 500 m; regarding the "Site Management" (SS 3) and the "Rainwater and Green Space Maximization" (SS 4) credits, the building achieved a score of 3 and 4, respectively. The "Heat Island Effect" (SS 5) includes multiple strategies involving the use of flooring and roofing materials with high solar reflection properties, the construction of green roofs and shaded areas. Those solutions (roof garden and the reduction of surface extension paved) were applied and estimated in line with the GBC Home guide.

(b); Water Management (WM): Both the two credits involved in this section obtain the maximum score. The first one "Reduction of water consumption", which foresees the installation of two rainwater recovery system for internal non-drinkable uses each one of 7500 litres capacity, was satisfied allowing a consistent reduction of water usage (about 50%). The other one, the "Efficient water management for irrigation purposes", reached the maximum score (7), thanks also to the presence of different vegetation types in the green areas.

(c); Energy and Atmosphere (EA): Regarding this third section, an overall score of 21 points out to 32 was achieved. Dynamic simulations were carried out using Grasshopper/Archsim, a free plug-in of Rhinoceros. This software uses as energy engine Energy Plus and as a graphic interface Grasshopper (Dogan, 2013). A reference building was firstly modelled, characterized by the same geometry of the case study and provided with thermal proprieties established by the manual.

Lately, a model of the real building was developed, to be compared with the reference one. Results highlighted a considerable improvement in term of the energy performance (including the HDW) up to 30%, providing a score of 12 points. The second credit, the “Availability of renewable energy sources”, was completely satisfied due to the presence of photovoltaic panels on the roof, which guarantee an electricity production able to cover the 55% of the building energy demand. Due to the adoption of high-efficiency household appliances, EA 3 (Electrical appliances) obtained 1 point out to 2. In general, those results are in line with the building energy systems, able to guarantee high performances and to reduce the amount of energy consumption.

(d); Materials and Resources (MR): In this category the building got a score of 9 over a total of 14 points. As aforementioned, this section is divided into 5 credits: the “Reuse of structural and non-structural elements of buildings” (MR 1), the “Construction waste management “(MR 2), the “Multicriteria Certification” (MR 3), the “Environmental optimization of products” (MR 4) and the “Materials extracted, processed and produced remotely” (MR 5). The MR 1 could not be satisfied since it is a new construction and any recycled material was used of previous buildings. Both credits MR 2 and MR 5 obtained a score of 1 out of 2. In the other credits (M3 and M4) building reached the maximum points due to the use of biocompatible materials able to satisfy the requirements of the Multicriteria certification defined in the protocol.

e); Indoor Environmental Quality (IEQ): Moving to the Indoor Environmental Quality (QI) section, the application of those six credits allowed to obtain 13 points out to 20. In details, only three credits, the Low-emission materials (QI 3), the Balancing of distribution networks (QI 5) and the Indoor air quality under construction (QI 2), were satisfied, reaching 3, 5 and 2 points respectively.

(f); Innovation in Design (ID): this last section provides a score of 8 out of 10 points. Below, Table 9 reports the final ranking of the GBC Home for residential buildings v2 applied by the Sapienza University research group to the building “Le Violette”.

Table 9. Maximum score and score achieved by the application of the Sapienza University for each section of the GBC Home for residential buildings v2 protocol.

Sapienza University		
Section	**Maximum Score**	**Score obtained**
Sustainable Sites (SS)	22	21
Water Efficiency (WE)	12	11
Energy and Atmosphere (EA)	32	21
Materials and Resources (MR)	14	9
Indoor Environmental Quality (IEQ)	20	13
Innovation in Design (ID)	10	8
Total	**110**	**83**

6.6 Technical University of Crete (TUC) & National and Kapodistrian University of Athens (NKUA), Greece

The main goal of this project is to calculate the building’s energy needs by taking into consideration the Round Robin Test Guidelines. The building consists of 14 different thermal zones that belong to all the apartments. The energy needs differ for each operating month because of the external climatic conditions, as well as for each thermal zone due to the location of the building (the floor, how many external walls it has etc.), the construction materials and the occupancy. Apart from the building simulation, through the LEED v4 for Building Operation and Maintenance Checklist application to the case study, the Greek team (TUC and NKUA) obtained a score of 82/110 (Table xx), pursuing the highest level of "Platinum" certification. Many hypothesis and assumptions have been made due to the lack of real/actual data about many aspects concerning the building itself and the surrounding area.

(a); Location and Transportation (LT): this section obtained an overall score of 12 points out of 15. The residential building is located in the municipality of Sterpate, at “Violette Street”, in a new neighborhood of Foligno (PG, Italy). Foligno is an ancient town in Italy in the province of Perugia in east central Umbria, on the Topino river where it leaves the Apennines and enters the wide plain of the Clitunno river system. It is located 40 kilometers (25 miles) south-east of Perugia, 10 km (6 mi) north-north-west of Trevi and 6 km (4 mi) south of Spello. Foligno railway station forms part of the main line from Rome to Ancona, and is the junction for Perugia; it is thus an important rail centre. The city's position in the plain and again its rail connections have led to a considerable suburban spread with the attendant problems of traffic and air pollution, as well as a severe encroachment on the Umbrian wetlands. Foligno is on an

important interchange road junction in central Italy and 2km (1 mi) away from the centre of the city there is the Foligno Airport.
(b); Sustainable Sites (SS): this section obtained an overall score of 7 points out of 10. In the Foligno area a great percentage (close to 40%) of the land is preserved as greenfield areas. Also, the building under study has a green roof.
(c); Water Efficiency (WE): in this section 9 points out of 12 were achieved. We assume that there are water meters especially for the domestic hot water due to the solar collectors that can cover the 60% of the total DHW demand. Apart from that, the building is occupied with a rainwater recovery system for irrigation and toilet use.
(d); Energy and Atmosphere (EA): here it was achieved almost the maximum score (36/38 points). The total points in this category mainly arise from the EnergyPlus simulation and analysis and the usage of solar collectors, PVs and the presence of green roof in the flat parts of the roof. Furthermore, the bioclimatic architecture of the building plays an important role to its microclimate impact.
(e); Materials and Resources (MR): here 4 over a total of 8 points were obtained. The total points in this category mainly arise from the thermal and hygrometric characteristics of the opaque components of the building envelope.
(f); Indoor Environmental Quality (IEQ): in this section 9 out of 17 points were achieved. The building is characterized by its design features aimed at protecting against pollutants and controlling indoor contaminants. Moreover, certified biocompatible and sound-absorbing construction materials were employed and a good building orientation (North-South) was chosen, also ensuring satisfactory internal lighting. The compact shape is able to minimize the external dispersing surface, with sunshades in order to protect the internal environment from direct solar radiation during the summer and guarantee it during the remainder of the year. Furthermore, according to the dynamic simulation and thermal comfort analysis the indoor air quality is quite satisfactory.
(g); Innovation (I): Regarding this section, it was possible to obtain a score of 5 out of 6 points. The total grades of this category was achieved because of the exemplary performance point, which is typically earned for achieving both the credit requirements and the next incremental percentage threshold.
(h), Region Priority (RP): in this last section there is no rating due to the lack of data/information about this part. Table 10 depicts the maximum score and obtained one for each section by the Greek team application.

Table 10. Maximum score and score achieved by the application of Greek Team.

Technical University of Crete (TUC) & National and Kapodistrian University of Athens (NKUA)		
Section	**Maximum Score**	**Score Obtained**
Location and Transportation (LT)	15	12
Sustainable Sites (SS)	10	7
Water Efficiency (WE)	12	9
Energy and Atmosphere (EA)	38	36
Materials and Resources (MR)	8	4
Indoor Environmental Quality (IEQ)	17	9
Innovation (I)	6	5
Region Priority (RP)	4	0
Total	**110**	**82**

6.7 *Krakow University of Technology, Poland*

The results of annual energy end use in the analyzed building calculated by the Krakow University of Technology team in DesignBuilder application are given in Table 11.

Table 11. Building energy end uses calculated in Design Builder application of the Krakow University of Technology.

Krakow University of Technology		
	Electricity [kWh/yr]	**Natural Gas [kWh/yr]**
Heating	22	56061
Cooling	3805	0
Interior Lighting	34018	0
Interior Equipment	15928	0
Fans	3791	0
Pumps	71	0
Water systems	17941	0
Total End Uses	**75575**	**56061**

The electricity coming from Photovoltaic cells is equal to 20243 kWh/yr, which is 26.8% of total annual building electricity use. The water use of the building equals 304 m^3/yr.
The results of filling the LEED project checklist are listed in Table 12. The results show the maximum required number of points and the obtained score.

Table 12. Maximum required score vs. score achieved for each section of the GBC Homes and Multifamily Lowrise protocol by the application of the Krakow University of Technology.

Krakow University of Technology		
Section	**Maximum Score**	**Score obtained**
Integrative Process (IP)	2	0
Location and Transportation (LT)	15	15
Sustainable Sites (SS)	7	4
Water Efficiency (WE)	12	7
Energy and Atmosphere (EA)	38	38
Materials and Resources (MR)	10	5
Indoor Environmental Quality (IEQ)	16	9
Innovation in Design (ID)	6	4
Regional Priority (RP)	4	4
Total	**110**	**88**

6.8 University College London, United Kingdom

The application of the "v4 for Building Design and Construction: Homes and Multifamily Lowrise" version of the LEED protocol allowed the University College London group to award the study building an overall score of 85/110 points, also pursuing the maximum “platinum” certification level.
The only sections that recorded a null score are Integrative Process (IP) and Innovation (IN): in fact, they require the adoption of an integrated approach and innovative solutions for sustainable design and construction, which the “Le Violette” studio building complex is lacking.
(a); Localization and Transport (LT): this section achieved an average score of 10 points out of 15. Although the location of the building is adequate and it is not situated in an alluvial area, this section is not performing particularly well in terms of alternative transport, reachability on foot, and in the minimization of environmental damage through development of the territory.
(b); Sustainable Sites (SS): in this section 5 points were granted compared to the maximum of 7, by matching credits related to the reduction of heating caused by the “Urban Heat Island” phenomenon, the management of rainwater and the reduction of problems due to parasites and the risk of exposure to pesticides.
(c); Water Efficiency (WE): this section, which aims to reduce the use of drinking water and promote integrated recovery strategies, achieved a high score, 11 points out of 12, due to the reduction of the total consumption of internal water and external by at least 10% compared to standard practices through highly efficient appliances and efficient landscape practices.
(e); Energy and Atmosphere (EA): the energy section of the Protocol recorded a high score, 36 out of 38. This result was obtained thanks to the performance of an energy analysis in dynamic regime using the Design Builder software of the study building, which made it possible to quantify the annual consumption of primary energy due to the heating and cooling needs, the electrical component and to the production of domestic hot water.
(f); Materials and Resources (MR): this section achieved a score of 7 points compared to the total 10. The uncertainties found in the attribution of the score relate to the management of construction waste and the reduction of the consumption of materials, exploiting minimum quantities of recycled and recyclable material, similar to what has been verified in other applications.
(g); Indoor Environmental Quality (IEQ): this section achieved a high score too, 13 out of 16, ensuring the promotion of indoor air quality, comfort and well-being of people.
(h); Regional Priority (RP): Finally, the fulfilment of the credits relating to this last section allowed the achievement of 3 additional points.
Table 13 summarizes the maximum achievable scores for each section of the Protocol used and those obtained.

Table 13. Maximum score and score achieved by the application of Greek Team.

University College London		
Section	**Maximum Score**	**Score obtained**
Integrative Process (IP)	2	0
Location and Transportation (LT)	15	10
Sustainable Sites (SS)	7	5
Water Efficiency (WE)	12	11
Energy and Atmosphere (EA)	38	36
Materials and Resources (MR)	10	7
Indoor Environmental Quality (IEQ)	16	13
Innovation (IN)	6	0
Regional Priority (PR)	4	3
Total	**110**	**85**

6.9 Ryerson University, Canada

In this section, the challenge encountered by Ryerson researchers during the assessment of the building are reported and in particular, the attention will be given to the possible variations in the building's energy calculation. The building "Le Violette" obtained the highest score "Platinum level" with the GBC Home protocol for residential buildings an overall score of 83 credits (see Table 14), a result in line with the applications of the other participants.

Table 14. Maximum score and score achieved by the application of Canadian participant.

Ryerson University		
Section	**Maximum Score**	**Score obtained**
Sustainable Sites (SS)	25	18
Water Efficiency (WE)	10	8
Energy and Atmosphere (EA)	30	26
Materials and Resources (MR)	15	9
Indoor Environmental Quality (IEQ)	20	17
Innovation in Design (ID)	10	5
Total	**110**	**88**

(a); Sustainable Sites (SS): this category reached a score of 18 points out to 25. The building lost some available points in the criteria about site selection (SS1) and (SS2) as for the proximity to public transportation (SS5) and urban heat island mitigation strategies (SS8). In particular, the reason behind this was that the site is not a contaminated site and the density of the housing is not particularly high; moreover, the exterior bricks suggest partial consideration of UHI issues. This last aspect was controversial as "Heat Island Effect" may include multiple strategies involving the use of flooring and roofing materials with high solar reflection properties, the construction of green roofs and shaded areas. Among these solutions, some were applied (roof garden and the reduction of surface extension paved), in line with the GBC guide, but the dark bricks were considered an element that prevent to award the full available points.
(b); Water Management (WM): for both the credits in this category, the maximum points were assigned. I particular, the "Reduction of water consumption" was positively assessed based on the rainwater recovery system for internal non-drinkable uses, which represented a consistent reduction of water usage; moreover, the green roof planning demonstrated an "efficient water management for irrigation purposes";
(c); Energy and Atmosphere (EA): this category reached a score of 26 points over the 30 available ones. Dynamic simulations were carried out using Design Builder which uses as energy engine Energy Plus. A reference building was firstly modelled, characterized by the same geometry of the case study; then, a model of the final building was developed and compared with the reference one. In general, those results are in line with the building energy systems, able to guarantee high performances and to reduce the amount of energy consumption. Results highlighted a considerable improvement in term of the energy performance. Looking at the results and their comparison with other researchers, it emerges that a different inlet temperature of the water was used by Ryerson team, which assumed the temperature of the water to be 15 C; another major difference regarded the quantity of DHW that Ryerson team assumed to be 100 liters per day, a quantity below that assumed by other researchers;
(d); Materials and Resources (MR): In this category, the building obtained 9 points over a total of 15 points. The criteria in which the building was not able to obtain the maximum available points were: the use of material with low emissions (MR3), and the use of recycled materials (MR4), together with the net point obtained against the thee available ones for the "Reuse of structural and non-structural elements of buildings" (MR 1);

(e); Indoor Environmental Quality (IEQ): In this category, the building obtained 17 points over a total of 20 points. In particular, the ventilation with exterior air (IEQ 1) and the effective floorplan distribution for ventilation (IEQ 5) were two indicators were the researchers did not award the total available points, as they were considered not fully satisfactory;
(f); Innovation in Design (ID): this last section provides a score of 5 out of 10 points, due to the lack of a strong emphasis to regional priorities in the design approaches.

7. Discussion

This section compares and discusses the results of an international Round Robin Test on the application of the LEED protocol.
The version of the LEED protocol to be adopted was not specified to the international research groups involved in the RRT in order to assess whether this could affect the final assessment and, therefore, the level of certification achieved by the study building. Therefore, five different versions of the LEED protocol were used in this study, shown in table 4 with the relative distribution of scores between the thematic sections.
Comparing all LEED protocol versions considered in this study, it is possible to observe that the section with the highest overall score is always the Energy and Atmosphere, characterized by maximum achievable scores between 30 and 38 points. In addition, by combining the section Location and Transport for homogeneity of the themes with the section Sustainable Sites, it is noted that the maximum scores for each section respect the following hierarchy: Energy and Atmosphere, Sustainable Sites, Indoor Environmental Quality, Materials and Resources, Water Efficiency.
Instead, the Location and Transportation section is present only in the LEED v4 for Building Operations and Maintenance Checklist and LEED v4 for Building Design and construction: Homes and Multifamily Lowrise versions while in the Italian versions GBC Home 2011, v4 and v2 is included in the form of credits directly in the Sustainable Sites section. The Integrative Process section, contained in the LEED v4 for Building Design and construction: Homes and Multifamily Lowrise version, is also present in the form of credit in the Innovation in Design sections of the other versions of the LEED protocol analyzed in this analysis.
The research has shown that, although the used versions of the LEED protocol have a different distribution of credits and of the maximum scores obtainable among the various thematic sections, the set of sections and credits present address the same issues, also giving similar weights. Consequently, the choice of the LEED protocol's version used in the RRT did not significantly affect the level of certification achieved by the various research groups.
In addition, the use of different versions and in particular the incidence of the score relating to the areas of Design Innovation (ID) and Regional Priority (RP) could have made significant changes to the overall score. This would have highlighted how a different choice of the version of the protocol was a strong discriminant.
The results of the study show that this incidence did not have a significant influence on the global mean score.
The following paragraph summarize and compare the results pursued among the participants in the RRT.
In order to make the results of the various applications comparable, the percentage value was used; this was calculated as the ratio between the score obtained and the maximum achievable for each section of the protocol. Finally, a percentage value relative to the sum of the maximum achievable scores of the sections compared to the total ones was also attributed in a similar way.

7.1 Results comparison among RRT participants

The Italian research groups involved in the Round Robin Test belong to the following universities: Roma Tre University, University of Perugia, Universitas Mercatorum, CIRIAF and Sapienza University.
The Italian participants adopted the local versions of the LEED protocol, specifically the GBC Home 2011 version, GBC Home v4 and GBC Home v2. In addition to the Italian research groups, the other participants involved in the Round Robin Test belong to the following universities: Technical University of Crete -TUC- and National and Kapodistrian University of Athens (Greece), University College London (United Kingdom), Ryerson University (Canada) and Krakow University of Technology (Poland). These research groups applied different versions of the LEED protocol, in particular the LEED v4 for Building Operations and Maintenance, the LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise and the GBC Home 2011 version.
Table 19 summarizes the dynamic energy simulation software used, the versions of the LEED protocols adopted and the results of their applications. From Table 15 it is possible to observe that all the applications have reached a score higher than 80/110, thus reaching the maximum certification level, “Platinum”.
The research groups that obtained the highest score belongs to Roma TRE University (89/100) and to the Krakow University of Technology (88/110), followed by the CIRIAF research group and the University College London (85/110), the University of Perugia (84/110), the Ryerson University (83/110), the Sapienza University (83/110) and by the Universitas Mercatorum and the Technical University of Crete (TUC) & National and Kapodistrian University of Athens (NKUA), who obtained a score of 82/110.
The dynamic energy simulation software used for the compilation of the Energy and Atmosphere section of the LEED protocol were Trnsys, DesignBuilder, Grasshopper/Archsim and Sketch Up 2017 and Open Studio 2.7 dynamic software. Instead, the versions of the LEED protocol adopted are the Italian local versions GBC Home 2011, GBC Home v4 and GBC Home v2 and the two different LEED v4 for Building versions, LEED v4 for Building Operations and Maintenance and LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise. However, the use of different dynamic simulation software for building energy analysis did not significantly affect the score in the Energy and Atmosphere section to the different versions of the LEED protocol.

Table 15. Summary table of the dynamic energy simulation software, the LEED protocols’ versions used and the results of their applications by the different research groups.

University	Roma Tre University		University of Perugia		Universitas Mercatorum		CIRIAF		Sapienza University	
Energy simulation software	Trnsys		EnergyPlus		Trnsys		Trnsys		Grasshopper/ Archsim	
LEED protocol's versions	GBC Home 2011 version		GBC Home 2011 version		GBC Home 2011 version		GBC Home v4		GBC Home v2	
Sustainable Sites (SS)	21/25	84%	15/25	60%	20/25	80%	18/26	69%	21/22	95%
Water Efficiency (WE)	10/10	100%	7/10	70%	9/10	90%	8/10	80%	11/12	92%
Energy and Atmosphere (EA)	26 /30	87%	25 /30	83%	23 /30	77%	27 /35	77%	21/32	66%
Materials and Resources (MR)	10/ 15	67%	13/ 15	87%	9/ 15	60%	7/ 14	50%	9/14	64%
Indoor Environmental Quality (IEQ)	17 /20	85%	18 /20	90%	16 /20	80%	15/15	100%	13/20	65%
Innovation in Design (ID)	5/10	50%	6/10	60%	5/10	50%	6/6	100%	8/10	80%
Regional Priority (RP)	-	-	-	-	-	-	4/4	100%	-	-
Total	89/110	81%	84/110	76%	82/110	75%	85/110	77%	83/110	75%

University	Technical University of Crete (TUC) & National and Kapodistrian University of Athens (NKUA), Greece	University College London, United Kingdom	Ryerson University, Canada	Krakow University of Technology, Poland
Energy simulation software	Sketch Up 2017 and Open Studio 2.7 dynamic software	DesignBuilder software with EnergyPlus engine	DesignBuilder software with EnergyPlus engine	DesignBuilder software with EnergyPlus engine

LEED protocol's versions	LEED v4 for Building Operations and Maintenance		LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise		GBC Home 2011 version		LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise	
Integrative Process (IP)	-	-	0/2	0%	-	-	2/2	100%
Location and Transportation (LT)	12/15	80%	10/15	67%	-	-	15/15	100%
Sustainable Sites (SS)	7/10	70%	5/7	71%	18/25	72%	4/7	57%
Water Efficiency (WE)	9/12	75%	11/12	92%	8/10	80%	7/12	58%
Energy and Atmosphere (EA)	36/38	95%	36/38	95%	26/30	87%	38/38	100%
Materials and Resources (MR)	4/8	50%	7/10	70%	9/ 15	60%	5/10	50%
Indoor Environmental Quality (IEQ)	9/17	53%	13/16	81%	17 /20	85%	9/16	56%
Innovation in Design (ID)	5/6	83%	0/6	0%	5/10	50%	4/6	67%
Regional Priority (RP)	0/4	0%	3/4	75%	-	-	4/4	100%
Total	82/110	75%	85/110	77%	83/110	75%	88/110	80%

Figure 3 reports total results and scores obtained by participants from different countries for each section in the LEED protocol's applications; in particular Fig. 3 a shows the results of the Italian applications and Fig. 3b illustrates those coming from other countries.

Among Italian applications it can be observed (Fig. 3a) that the Energy and Atmosphere section obtained an average percentage score of 78%. The Universitas Mercatorum and the CIRIAF University of Perugia achieved a score of 77%, the University of Perugia of 83 %, the Roma Tre University of 87% and the Sapienza University of Rome 66%. Furthermore, in this section the lowest level of variability was reached in the overall score achieved by the different universities involved (variance equal to 0.005).

The Materials and Resources section has the lowest average percentage score among the various applications, equal to 66%, followed by the Innovation in Design section, characterized by values between 50% and 60%, except for the University application La Sapienza di Roma which reaches a percentage score of 80% and an average percentage value of 68%. Instead, the sections with the highest percentage scores are Water Efficiency and Indoor Environmental Quality, with an average percentage score of 86% and 84% respectively.

The Water Efficiency section has in fact a percentage score between 80% and 100%, except for the University of Perugia which reaches a percentage score of 70%, and an average value of 86%.

The Indoor Environmental Quality section also obtained the same percentage score range, apart from the La Sapienza University of Rome which reaches a percentage score of 65%, and an average value of 84%. Finally, the Sustainable Sites sections obtained an average percentage score of 78% from the applications of Italian universities.

By analyzing the results obtained for each section by the Italian participants, the sections can finally be ordered according to the level of diversity assumed in the attribution of the scores (variance): Innovation in Design (0.038), Sustainable Sites (0.015), Materials and Resources (0.014), Indoor Environmental Quality (0.013) Water Efficiency (0.011) and Energy and Atmosphere (0.005). Therefore, it can be concluded that among the Italian applications, the section most affected by variation in assigned score is Innovation in Design (0.038).

Comparing the LEED applications' results of the other countries (Fig.3b), an average percentage value of 94% was found in the energy section and scores equal to 87% for the Ryerson University, 95% for the Technical University of Crete (TUC) & National and Kapodistrian University of Athens (NKUA) and the University College London, and 100% for the Krakow University of Technology. Furthermore, also from this comparison, it emerged that the lowest level of variability in the attribution of the score of the various universities involved belongs to this section (variance equal to 0.002).

The Innovation in Design section has the lowest percentage score with an average value of 50%. Only in the application of the Technical University of Crete (TUC) & National and Kapodistrian University of Athens (NKUA) was the percentage score of 83%. Furthermore, the sections that follow the Energy and Atmosphere thematic area for the average percentage score achieved in the various applications of the LEED protocol are Location and Transportation

(82%), Water Efficiency (76%), Indoor Environmental Quality (69%), Sustainable Sites (68%), Materials and Resources and Regional Priority (58%).

By analysing the results obtained for each section by participants from different countries, it is possible to order the various sections according to the level of diversity assumed in the attribution of scores (variance) as fallows: Regional Priority (0.181), Innovation in Design (0.097), Indoor Environmental Quality (0.021), Location and Transportation (0.019), Water Efficiency (0.014), Materials and Resources (0.007), Sustainable Sites (0.004) and Energy and Atmosphere (0.002). Therefore, it can be concluded that the sections most affected by the variation in the score obtained are Regional Priority and Innovation in Design.

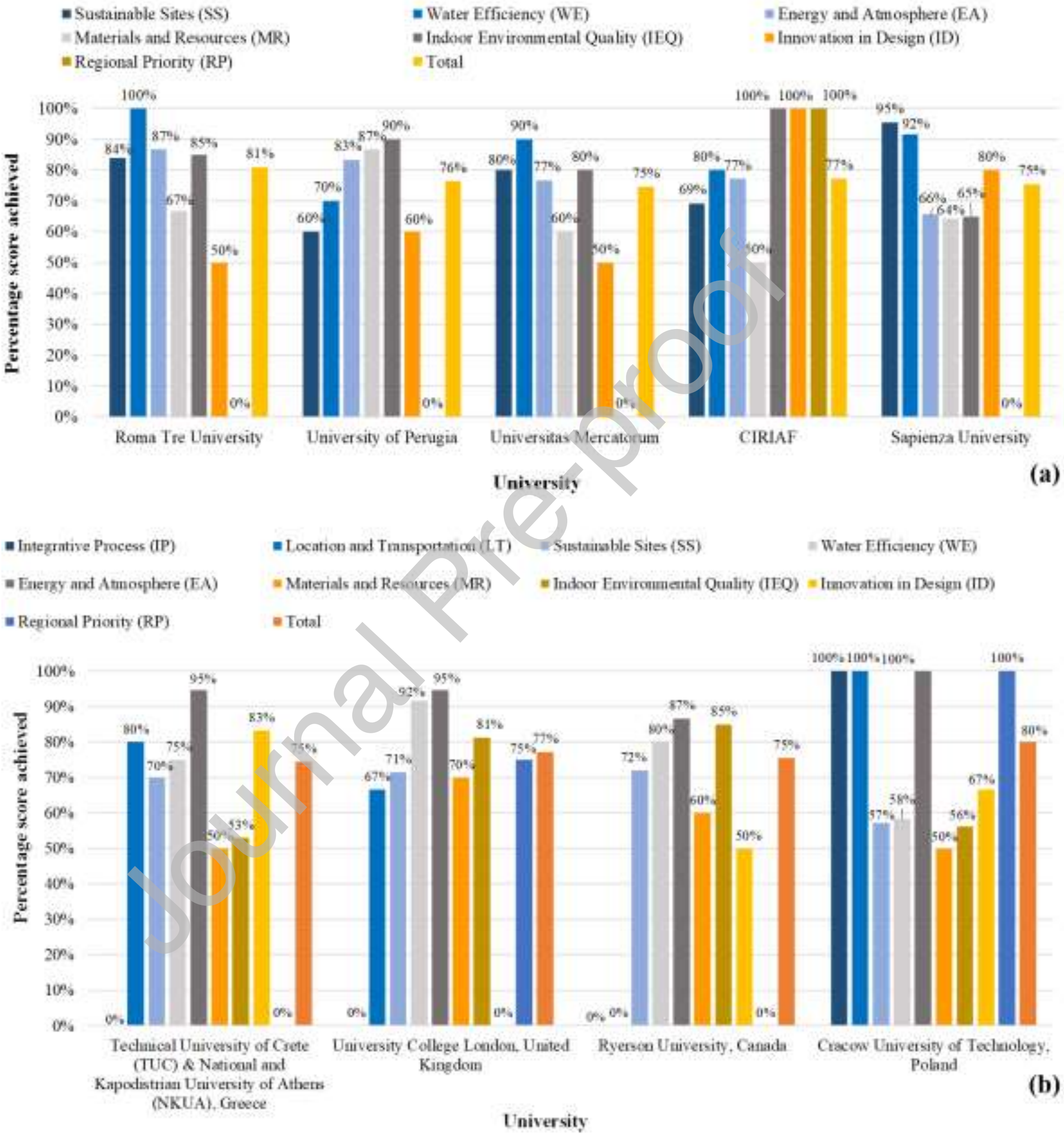

Figure 3. Total results and scores obtained for each section for the LEED protocol applications.

Table 16 summarizes the dynamic energy simulation software used, the versions of the LEED protocols adopted and the results obtained from the applications of all the research groups involved. The purpose of this research was in fact to verify whether the hypotheses formulated by operators from different parts of the world, using the same protocol, albeit with different declinations, could affect the level of certification achieved.

From the comparison of the various applications, it emerged that the use of different versions of the LEED protocol did not lead to evident variations in terms of the total scores achieved, in fact all the research groups achieved a score higher than 80 points, pursuing the certification level "Platinum".
In terms of variations found in the attribution of scores between the common sections of the protocols, the one with the greatest dispersion is Innovation in Design, followed by Materials and Resources, Sustainable Sites, Indoor Environmental Quality, Water Efficiency and Energy and Atmosphere.
Even the energy section (EA), characterized by the highest possible score in all versions, although influenced by the use of different dynamic software, was the one with the lowest level of variability in terms of percentage score achieved from the various universities. This section is also characterized by the highest average percentage score, equal to 85%, followed by the Water Efficiency and Location and Transportation sections with a score of 82%, the Indoor Environmental Quality with 77%, Sustainable Sites with 73%, Regional Priority with 69%, Materials and Resources with 62%, Innovation in Design with 60% and finally the Integrative Process section with a percentage score of 50%.
Furthermore, by comparing the applications of the participants who used the local Italian versions of the LEED protocol (GBC Home) with the US LEED ones, minimal variations in the average percentage values were recorded. In particular, the common sections of these two macro-groups recorded the following percentage differences: 26.5% for the Innovation in Design section, 21.0 % for Energy and Atmosphere, 18% for Indoor Environmental Quality, 13% for Sustainable Sites, 12.2% for Materials and Resources and 11.7% for Water Efficiency.
To compare and analyze in more detail the results obtained by the participants and therefore to identify the thematic sections of the LEED protocol most affected by the variability of the results, in addition to the percentage differences between the scores of the various sections, the statistical indicator of variance was therefore used (par. 5 Methodology).
The LEED protocol is influenced by subjective evaluations and therefore by random errors whose uncertainty cannot be predetermined. In addition, the analysis was conducted with a limited number of studies (nine). Therefore, it was not possible to validate the protocol as if it were a mathematical model.
However, as described in the methodology section (par. 5), the total sensitivity of the specific sections of the LEED protocol was also determined. In particular, the total sensitivity of a specific thematic area of the protocol was calculated as the overall sum of the absolute errors obtained from the applications of all nine research groups.
In terms of sensitivity, the analysis revealed more pronounced values for the Sustainable Sites (SS), Energy and Atmosphere (EA) and Materials and Resources (MR) sections, equal to 21.5, followed by Indoor Environmental Quality (IEQ), with a sensitivity of 18.5 and Innovation in Design (ID) with a value of 15.
Instead, lower values were recorded for the Water Efficiency (WE) sections, equal to 9, Regional Priority (RP), equal to 2.5, (section present in 4 out of 9 applications), Location and Transportation (LT) equal to 4 (thematic area present in 3 applications out of 9) and finally Integrative Process (IP) equal to 1 (section present in 2 applications out of 9).
However, those sections characterized by the highest sensitivity, such as Sustainable Sites (SS), Energy and Atmosphere (EA), Materials and Resources (MR), also recorded the lowest variations in the attribution of scores, demonstrating the insensitivity of the protocol to the subjectivity of the operators as key validation finding.
Therefore, the research showed that although the sections of the LEED protocol present different distributions of scores and credits, they nevertheless manage to contain all the elements necessary for a homogeneous assessment of the concept of environmental sustainability applied to buildings. This study therefore confirmed the effectiveness of these important environmental certification systems for buildings, regardless of the assumptions adopted by the operator, the version of the protocol chosen and the energy software used for the dynamic energy simulation of the study building.

Table 16. Summary table of the dynamic energy simulation software, the LEED protocols' versions used and the results of their applications by all RRT research groups.

University	**Roma Tre University -Italy-**		**University of Perugia -Italy-**		**Universitas Mercatorum-Italy-**		**CIRIAF -Italy-**		**Sapienza University -Italy-**		**Technical University of Crete & National and Kapodistrian University of Athens -Greece-**		**University College London -United Kingdom-**		**Ryerson University -Canada-**		**Krakow University of Technology - Poland**	
Energy simulation software	Trnsys		DesignBuilder software with EnergyPlus engine		Trnsys		Trnsys		Grasshopper/ Archsim		Sketch Up 2017 and Open Studio 2.7 dynamic software		DesignBuilder software with EnergyPlus engine		DesignBuilder software with EnergyPlus engine		DesignBuilder software with EnergyPlus engine	
LEED protocol's versions	GBC Home 2011 version		GBC Home 2011 version		GBC Home 2011 version		GBC Home v4		GBC Home v2		LEED v4 for Building Operations and Maintenance		LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise		GBC Home 2011 version		LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise	
Integrative Process (IP)	-	-	-	-	-	-	-	-	-	-	-	-	0/2	0%	-	-	2/2	100 %
Location and Transportation (LT)	-	-	-	-	-	-	-	-	-	-	12/15	80 %	10/15	67 %	-	-	15/15	100 %
Sustainable Sites (SS)	21/25	84%	15/25	60%	20/25	80 %	18/26	69%	21/22	95%	7/10	70 %	5/7	71 %	18/25	72%	4/7	57 %
Water Efficiency (WE)	10/10	100%	7/10	70%	9/10	90 %	8/10	80%	11/12	92%	9/12	75 %	11/12	92 %	8/10	80%	7/12	58 %
Energy and Atmosphere (EA)	26 /30	87%	25 /30	83%	23 /30	77 %	27 /35	77%	21/32	66%	36/38	95 %	36/38	95 %	26/30	87%	38/38	100 %
Materials and Resources (MR)	10/ 15	67%	13/ 15	87%	9/ 15	60 %	7/ 14	50%	9/14	64%	4/8	50 %	7/10	70 %	9/ 15	60%	5/10	50 %
Indoor Environmental Quality (IEQ)	17 /20	85%	18 /20	90%	16 /20	80 %	15/15	100%	13/20	65%	9/17	53 %	13/16	81 %	17 /20	85%	9/16	56 %
Innovation in Design (ID)	5/10	50%	6/10	60%	5/10	50 %	6/6	100%	8/10	80%	5/6	83 %	0/6	0%	5/10	50%	4/6	67 %
Regional Priority (RP)	-	-	-	-	-	-	4/4	100%	-	-	0/4	0%	3/4	75 %	-	-	4/4	100 %
Total	**89/110**	**81%**	**84/110**	**76%**	**82/110**	**75 %**	**85/110**	**77%**	**83/110**	**75%**	**82/110**	**75 %**	**85/110**	**77 %**	**83/110**	**75 %**	**88/110**	**80 %**

8. Conclusions

Building environmental certification protocols are internationally established tools for assessing environmental, ecological and social quality in the construction sector. In fact, they were born in the 90s with the aim of spreading the culture of sustainable building and of guaranteeing and evaluating the application of strategies aimed at reducing the environmental impact of the building during the entire life cycle of the building: its disposal or redevelopment.

By incorporating various aspects, they are very popular tools to measure the sustainability rate of buildings and compare different alternatives. In particular, energy efficiency is the thematic area that generally has the greatest weight on the overall assessment of the building. Other common aspects, albeit with different declinations, are the management of waste, materials and resources, internal environmental quality, water management, internal environmental quality, design and executive innovation, sustainability and location of the site and finally the proximity to public and green transport systems.

This research aimed to assess whether the certification systems for the environmental sustainability of buildings were reliable tools, capable of returning reliable and comparable certification levels. Starting from the same initial input information, the sustainability level of a building should be the same, regardless of the hypotheses formulated by the operators, the protocol local version and the dynamic energy simulation software employed.

Consequently, through an international RRT on the application of the LEED environmental building certification protocol, one of the most widespread, to the same study building, the issues that most influence the final performance rate were studied, providing users have a deeper understanding of the aspects included in these procedures. In fact, by virtue of the great detail of the inputs necessary for their compilation, it was assessed whether and how the hypotheses formulated by each operator can influence the final score and whether the different versions affect the final evaluation.

Operators of different nationalities from Italy, Greece, England, Canada and Poland were involved in the RRT. Furthermore, after providing the documents and information relating to the same study building, the participants were given the opportunity to choose the most appropriate version of the LEED protocol and the dynamic software for future energy analysis.

In particular, the participants used 3 local Italian versions of the Protocol (GBC Home 2011, GBC Home v4 and GBC Home v2) and two different LEED v4 for Building versions (LEED v4 for Building Operations and Maintenance and LEED v4 for Building Design and Construction: Homes and Multifamily Lowrise) while, with regard to different dynamic energy simulation, four softwares were used (Trnsys, Grasshopper / Archsim, Sketch Up 2017 and Open Studio 2.7 and Design Builder). However, this did not significantly affect either the level of variability of the scores obtained in the different thematic sections or the final scores achieved as all the applications obtained the highest level of certification, namely Platinum, getting total scores over 80 points. Even the Energy and Atmosphere section, which constitutes the most critical part in terms of the overall score, has not undergone particularly significant changes, obtaining homogeneous results and even the lowest variability between the various applications and the various versions of the Protocol.

Therefore, this study has allowed showing the potential of these building environmental certification systems, in terms of reliability of the certification level, regardless of the protocol version and the energy simulation software employed.

As possible future developments, it would be interesting to repeat and extend this approach through an international RRT on the application of different sustainability protocols in order to verify if all the issues contained in each of them are realistic and complete for a similar attribution of the level of sustainability of the study building.

Furthermore, an extensive study of the similarities and differences of the concept of building sustainability assumed by the various protocols would allow identifying the essential problems for correct attribution of the building sustainability level with the final aim of proposing a future Cost Action for the identification of a unique sustainability protocol, unmatched in any country in the world.

Credit author statement

Francesco Asdrubali: Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Data Curation, Writing – Original Draft, Writing - Review & Editing and Supervision. ***Claudia Guattari:*** Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Data Curation, Writing – Original Draft, Writing - Review & Editing and Supervision. ***Marta Roncone:*** Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Data Curation, Writing – Original Draft, Writing - Review & Editing and Supervision. ***Giorgio Baldinelli:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Eid Gul:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Cristina Piselli:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Anna Laura Pisello:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Andrea Presciutti:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Francesco Bianchi:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Laura Pompei:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Benedetta Mattoni:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Fabio Bisegna:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Dionysia Kolokotsa:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Elisavet Tsekeri:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Margarita-Niki Assimakopoulos:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Chrysanthi Efthymiou:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Nikolaos Barmparesos:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Agnieszka Lechowska:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Jacek Schnotale:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Francesco Aletta:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft. ***Umberto Berardi:*** Methodology, Software, Validation, Formal analysis, Resources, Data Curation and Writing – Original Draft.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.