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TOWARDS A NEW ETHICS IN BUILDING

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ECOLOGICAL TRANSITION FOR THE BUILT ENVIRONMENT: NATURAL INSULATING MATERIALS IN GREEN BUILDING RATING SYSTEMS

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Abstract

The regenerative concept of design and construction is gaining relevance, as it is changing the sustainability paradigm toward the ecological transition for the built environment, representing a track on which economic and financial support policies are currently being routed. One of the ways to achieve ecological transition is to use sustainable insulating materials in buildings. In addition, certification systems have been developed to actualize and renovate the concept of sustainability. The literature review showed that no studies deal with the influence of different insulating materials on green building rating systems. This research applies ITACA and LEED protocols to quantify the impact of insulating materials on certification levels. Starting from the comparison between these protocols and the analysis of credits related to sustainable building materials within LEED, the rating systems were applied to an existing multi-story residential building by varying the insulating materials for the building envelope, such as glass wool, expanded polystyrene (EPS), and two types of natural materials (e.g., mineralized wood fiber and kenaf). The results showed that every envelope configuration obtained the certification in both protocols, except EPS, which did not obtain the certification in LEED. However, although kenaf and mineralized wood fiber can be considered sustainable materials, they do not reach the maximum achievable category score influenced by the insulating material choice.

Keywords

LEED, ITACA, Renovation project, Sustainable envelope, Environmental protocols.

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1. INTRODUCTION

The conventional building design and construction process negatively impact the environment and natural resources [1]. With the current development speed of contemporary society, these issues cannot be fully addressed with the traditional concept of sustainability, which is primarily concerned with reducing environmental harm. Thus, regenerative design and construction are gaining relevance, as it is changing the sustainability paradigm toward the ecological transition for the built environment and the delivery of a human-centric environment, coupled with the circular economy, which aims to ensure the natural environment is renewed, restored, and revitalized [2]. In order to take these elements into account, a more thorough and integrated approach is needed, which allows for defining buildings' global efficiency. Energy and environmental certifications support this process and allow for building assessment in terms of energy consumption and efficiency and their impact on the environment and human health [3].

As new buildings are characterized by reduced operating energy utilization, additional consideration should be given to the embodied elements, e.g., the Embodied Energy and the Global Warming Potential (GWP) because of construction materials and systems [4, 5]. Embodied effects are the ecological burdens created by the purchase of raw materials, their handling, production, moving to location and construction during the entire lifetime. Embodied elements are important in energy-efficient constructions as demonstrated by several researchers: incorporated impacts are a percentage of the overall equal to 45% in [5], 50% in [6], and 57–74% in [7]. In several cases, burden shifting can also be produced, and LCA is a valuable method of assessment to avoid it [8, 9].

In general, two approaches exist in assessing building sustainability [10]. The qualitative or score-based method relies on certain requirements corresponding to weights and scores, the total sum of which indicates the level of building energy efficiency and environmental sustainability. These score-based assessment tools responded in a simple, accessible, and easily replicable way to the needs of the market and industry professionals. Differently, the quantitative method is related to LCA (Life Cycle Assessment), which quantifies the environmental impact of several indicators, including energy used by the building in its life cycle. Therefore, it is a rigorous environmental analysis of the entire construction process, including building management and end of life. For this reason, a recent study conducted by Tagliabue et al. [11] defined that the most influential rating systems worldwide available for building sustainability assessment (e.g., LEED, BREEAM, etc.) updated their checklists, including criteria related to the reduction in energy for extraction, production and materials transportation on the field.

Certification systems were developed globally to actualize and renovate the concept of sustainability degree [12]. Among the voluntary protocols around the world, including Building Research Establishment Environmental Assessment Method (BREEAM, UK), *Deutsche Gesellschaft für Nachhaltiges Bauen* (DGNB, Germany), *Haute Qualité Environnementale* (HQE, France), Green Star Rating Tools (Green Star, Australia) and *Istituto per l'innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale* (ITACA, Italy), the most used and widely recognized is Leadership in Energy and Environmental Design (LEED, USA). Many studies were carried out to analyze and compare different methodological approaches to green rating systems. At the end of this study, the analysis of previous research comparing LEED and ITACA is reported. Asdrubali et al. [13] proposed a comparative study between these two building environmental assessment methods applied to two residential buildings located in Italy. The authors demonstrated that there are no important technical differences between the two certification methods since the common scientific basis in both cases follows international standards and regulations. Buffoli et al. [14], after a deep analysis of the state of the art focusing on the previously mentioned evaluation systems, identified the main strengths and weaknesses of such tools concerning Sustainable Healthcare's project final objective. The authors concluded that both systems lack a multidisciplinary approach and the consideration of all three spheres of sustainability, not including, for instance, user-centrality, health outcomes, or managerial issues. Finally, Mattoni et al. [15] investigated the differences and similarities between LEED and ITACA. This allowed for the understanding of which factors most influence the final performance rate of each system and provided useful suggestions for improving the existing protocols.

Since the built environment contributes about 40% of global carbon emissions, and emissions embodied in building materials and construction contribute about 11% of global emissions (as much as all automobiles), it is up to architects and other building professionals to reduce harm, and, when possible, contribute to environmental regeneration and restoration [16, 17]. In order to achieve these objectives, one of the ways is to use sustainable materials for building construction projects [18]. Regarding the sustainable properties of materials used in green buildings, it is necessary to check whether they are renewable, reusable, or recyclable [19]. Renewable materials can be manufactured or generated quickly enough to keep pace with the use speed. These materials can be derived from natural or synthetic products and often include recycled components. They could also be from natural, renewable sources such as plantation forests and those made from agricultural waste products. The reuse potential of a construction material is another criterion by which the sustainable property of a material could be analyzed. Reusing a certain material means using it again for the same purpose that it was originally made for or an entirely different purpose (adaptive reuse). Reusing building materials ensure they do not become waste and end up in landfills. Salvaged, refurbished, and reused materials can all contribute to reducing the demand for virgin materials. Finally, recyclable materials, components, and assemblies play a significant role in conserving limited and depleting resources while eliminating waste from landfills.

Various previous research is aimed at evaluating the ability of alternative insulation materials, although their usage is still limited. The interest is in naturally derived materials, normally realized from agricultural residues [20] or waste recycling [21]. Other works have previously obtained data regarding Embodied Energy and GWP of plants or animal-developed insulation boards: Asdrubali et al. [22], for example, suggested a study on the acoustic, thermal, and environmental characteristics of alternative natural insulation materials; Schiavoni et al. [23] examined the thermal, acoustics, environmental, fire and water vapor resistance of conventional, natural, and advanced insulation materials. It was demonstrated that some natural materials (e.g., cork) have elevated Embodied Energy and GWP, while some commercial materials, such as stone wool, showed great environmental characteristics with decreased Embodied Energy and GWP.

While there was a wide range of research mainly focused on the energy use and emission production during the operation phase of LEED-certified buildings and on the analysis of the weight of specific items on the environmental rating assessment [24], research on the role of building envelope materials in green rating systems considering the environmental aspects is a growing field of interest. Yu et al. [25] compared the bamboo-structure building with an alternative brick-concrete building to distinguish the intrinsic differences between Embodied Energy and carbon emission. The authors conducted a comprehensive life cycle assessment along material flows based on technical potentials and the current LEED standard. Alshamrani et al. [26] developed an integrated LCA-LEED model for the enhanced sustainability assessment of structure and envelope types of Canadian School Buildings. Various combinations of structure-envelope options are tested by using concrete, masonry, steel, and wood as structural materials, and precast panels, steel stud, wood stud, and cavity wall as envelope systems by considering all the life cycle phases for a life span of 75 years.

The literature review showed that no studies deal with the influence of different insulating materials on green building rating systems, especially when natural materials are used to reduce environmental impacts. In addition, most of the previously described studies evaluated and compared different protocols only from a theoretical point of view without considering real case studies, mainly focusing on new construction building projects. In order to fill these knowledge gaps, this research aims to apply ITACA (the most used protocol in Italy) and LEED (the most used protocol worldwide) to quantify the impact of natural insulating materials on the certification levels. After a major renovation intervention, an existing Italian residential building was chosen as a case study to validate the methodological approach. The sustainability rate was evaluated by simulating different insulating materials applied to the external surface of the building envelope: e.g., glass wool, expanded polystyrene (EPS), and two types of natural materials (mineralized wood fiber and kenaf). Due to national incentives, installing the thermal insulation layer on the external wall surface is the most common technique currently used in Italy for building energy renovation. Therefore, this case study is representative of the existing buildings undergoing renovation interventions.

2. METHODOLOGY

The categories and credits influenced by the variation of building materials were analyzed for ITACA and LEED to evaluate the impacts on the partial (single category) and final scores. Starting from the comparison between the protocols using the approach developed by Asdrubali et al. [13] and the analysis of prerequisites and credits driving the use of sustainable building materials within LEED, the two different rating systems were applied to an existing multi-story residential building located in Catania, Sicily, by varying the insulating material for the building envelope.

2.1. LEED AND ITACA SYSTEM COMPARISON

For the description of the protocol structure, refer to the technical guidelines. LEED categories related to building materials are “Energy and Atmosphere” (EA), “Materials and Resources” (MR), and “Indoor Environmental Quality” (IEQ) (Tab. 1). The first category includes the “Optimization of energy performance” parameter influenced by the variation of insulating materials and allows a maximum of 27 points over the total category score equal to 30. Therefore, it strongly weighs on both the partial category score and the final score. Most of the parameters included in the MR category are affected by the change of insulating material, having a high impact on the partial category score, counting up to 10 points over the total category score equal to 15, and, therefore, they have a remarkable impact on the final score. These parameters are described in the next paragraph. Focusing on the IEQ category, only the “Acoustic” parameter is influenced by the variation of insulating materials, counting up to 2 points over the total category score equal to 20, so it has a not significant impact on both the partial category and final scores (up to 100). Therefore, the impact of the insulating materials on the acoustic performance was neglected.

Among ITACA categories, the ones influenced by the change in insulating materials are “Resource Consumption” (RC) and “Indoor Environmental Quality” (IEQ) (Tab. 2). Unlike LEED, the RC category includes building energy performance and materials parameters. This category counts for 53.60% of the final score. Insulating material variation influences five of the nine parameters, accounting for 29.40% of the total score. Like LEED, the IEQ category is affected by insulating material change, impacting the partial category score of 18.20% and the total score of 4.55% through the “Acoustic insulation of building envelope” parameter. In this case, too, this parameter was neglected.

The comparison between the two methods was developed based on the procedure described by Asdrubali et al. [13]. By observing Table 1 and Table 2, it is easy to notice the differences between the macro-areas of LEED and ITACA protocols because they are not defined in the same manner; thus, comparing results is difficult. In order to make the two methods comparable, the common items included in each LEED and ITACA category were identified to define five macro areas: Site, Water, Materials, Energy, and Indoor Environmental Quality. Refer to Asdrubali et al. [13] for more information about parameters included in LEED and ITACA categories and how they were grouped to create the new macro areas.

The scores obtained in Site, Water, and Indoor Environmental Quality categories are not influenced by the change in insulating materials. However, these categories were analyzed to evaluate the effect of the building renovation project on the partial score related to these categories compared to the total achievable score. Table 3 shows the new distribution of the parameters into five categories, highlighting the differences between the scores achievable with LEED and ITACA.

LEED categories	Maximum score
Sustainable Sites	23
Water Efficiency	12
Energy and Atmosphere	30
Materials and Resources	15
Indoor environmental quality	20
Total	**100**

Tab. 1. *Areas and scores of LEED certification.*

ITACA categories	Maximum score
Site quality	4.0%
Resource consumption	53.6%
Environmental loads	17.5%
Indoor environmental quality	18.2%
Service quality	6.7%
Total	**100%**

Tab. 2. *Areas and scores of ITACA certification.*

System	Site	Water	Materials	Energy	Indoor Environmental Quality	Total
LEED	23	12	15	30	20	100
ITACA	4,3	18,2	10,4	47,6	19,5	100

Tab. 3. *New macro-areas and scores for LEED and ITACA.*

2.2. "MATERIALS AND RESOURCES" CATEGORY IN THE LEED PROTOCOL

Within the MR category in LEED rating systems, some prerequisites and credits drive sustainable building materials' use. They include, amongst others, storage and collection of recyclables, building life cycle impact reduction, and sourcing of raw materials.

2.2.1. STORAGE AND COLLECTION OF RECYCLABLES

Storing and collecting recyclables is a mandatory requirement in LEED. The intent is to reduce the landfills and incinerators burden generated when building occupants haul and dispose of waste through reduction, reuse, and recycling service and education. The approach involves providing dedicated areas accessible to waste haulers and building occupants to collect and store recyclable materials for the entire building. Recyclable materials must include mixed paper, corrugated cardboard, glass, plastics, and metals. Access to the recycling location should be as convenient as possible to ensure employees participate in the recycling program.

2.2.2. BUILDING LIFE CYCLE IMPACT REDUCTION

This LEED credit intends to encourage adaptive reuse and optimize material environmental performance. The aim is to demonstrate the reduction in environmental impacts during initial project decision-making by reusing existing building resources or reducing materials use through life cycle assessment. The first approach involves maintaining the existing building structure, envelope, and interior non-structural elements. Materials reused or recovered off-site and incorporated into the building can also contribute to the calculation of credits. The whole-building approach to credit involves cradle-to-grave life cycle assessment of the designed building structure and envelope.

2.2.3. SOURCING OF RAW MATERIALS

This credit requirement encourages the use of products and materials for which life cycle information is available, and they have environmentally, economically, and socially preferable life cycle impacts. Project teams are rewarded for selecting products that are extracted or sourced responsibly. Some LEED practices encourage responsible sourcing of raw materials, including extended producer responsibility, use of biobased products, use of certified wood, and reuse and recycling of materials.

2.3. "ECO-FRIENDLY BUILDING MATERIALS" CATEGORY IN THE ITACA PROTOCOL

ITACA indicates the characteristics of "eco-friendly building materials". The ones usually deemed eco-friendly are not toxic, reusable, renewable, recycled, or locally found.

ITACA encourages the reuse of materials or the usage of recycled materials. Hence the criteria: Recycled/Salvaged Materials intends to assess the percentage of recycled/salvaged material that is required. Additional points are allocated when materials are derived from renewable resources, that is, those products whose makeup partially comes from plants or animals.

The supply of building materials from local manufacturers reduces the distance of the route that a certain element takes to reach the construction site. This would help decrease the emissions generated during the transport of the material. To determine this indicator, "locally sourced material" is considered, meaning a distance of 300 km from the location. In addition, the percentage of components treated with ornamental materials of regional manufacture is considered, i.e., materials produced within a distance of 150 km. One more criterion is "eco-sustainable materials", which determines the percentage of eco-sustainable materials, i.e., construction materials whose eco-friendly attributes are accredited.

2.4. CASE STUDY

A building constructed in the early 1970s was chosen to represent typical multi-story residential buildings in European cities undergoing energy renovation intervention. This study was developed in the city of Catania,

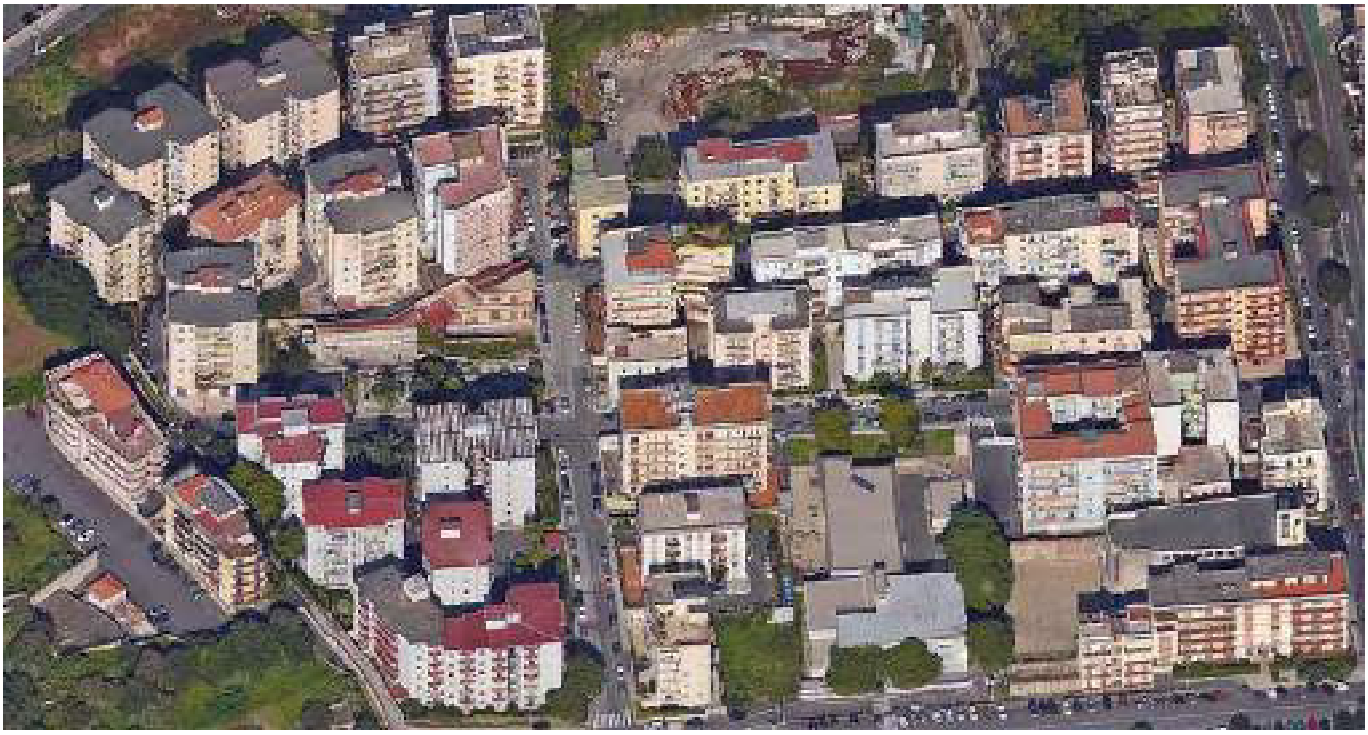

Fig. 1. *Aerial view of the urban area where the reference building is located (Catania, Italy).*

Southern Italy (37.52° N, 15.07° E). The Mediterranean climate typical of this geographical area is characterized by hot summers and mild winters. The case study used as a reference consists of a seven-floor multi-story building, a widespread type in the densely urbanized area close to the city center of Catania (Fig. 1) and, therefore, located near the mass transport systems. Each floor consisted of two residential apartments (Fig. 2). The structure of the building is reinforced concrete, while the floors are reinforced concrete with hollow bricks.

The building walls are described in Table 4. This type of vertical envelope, widespread in buildings belonging to the same period, is characterized by low thermal performance (U-value 0.975W·m^{-2}·K^{-1}). Single transparent

Fig. 2. *Typical floor distribution (on the left) and perspective view (on the right).*

panes of glass were used with a thickness of 3mm and thermal transmittance Ug=5.89W·m^{-2}·K^{-1}. The window frame was aluminum without a thermal break and with a thermal transmittance of UF=5.88W·m^{-2}·K^{-1}. The overall thermal transmittance U of the existing flat roof was 1.12W·m^{-2}·K^{-1}.

Apart from the thermal insulating material applied to the external wall surfaces (without changing windows), the energy renovation project concerns the installation of a new and high-efficiency heating system in each apartment, photovoltaic panels, electric charges for cars, and a new elevator. No interventions were designed to improve the water supply's efficiency and reduce water consumption.

The energy performance assessment in LEED is based on the whole building's performance, involving a dynamic simulation. In this paper, DesignBuilder with EnergyPlus engine was utilized. LEED requires to exhibit a percentage increase in the energy performance of the analyzed building, compared to the evaluation of energy utilization of a reference building. The latter should be modeled following the creation of a prototype described in Appendix G of ASHRAE 90.1-2007 [27] with some modifications to adjust the model to the Italian condition. The comparison among the energy performance of the analyzed building and the reference one has to exhibit an increase of a minimum percentage of 10%; it is possible to achieve the highest result demonstrating an increase of 66%.

In ITACA, the energy performance evaluation is separated into four sheets that assess the thermal transmittance of the envelope, the primary energy for heating, the net energy for cooling, and the CO_2 emissions that need computations based on the method defined by the UNI TS 11300: 2008 [28].

The important difference between ITACA and LEED lies in the method: the tool sheets need specific outcomes resulting from a simulation of the projected building, while LEED necessitates the simulation of two models, one corresponding to the real building and the other with features established by the Appendix G of ASHRAE 90.1-2007 [27].

Material	Thickness [mm]	Oven Dry Density [kg·m^{-3}]	Thermal Conductivity [variable]	Specific Heat [kJ·kg^{-1}·K^{-1}]	Thermal transmittance [W·m^{-2}·K^{-1}]
Plaster	20	1860	λ = 0.72 W·m^{-1}·K^{-1}	0.84	36.00
Hollow brick	120	-	R = 0.31 m^2·K·W^{-1}	-	3.23
Air gap	60	-	R = 0.18 m^2·K·W^{-1}	-	5.55
Hollow brick	120	-	R = 0.31 m^2·K·W^{-1}	-	3.23
Plaster	20	1860	λ = 0.72 W·m^{-1}·K^{-1}	0.84	36.00

Tab. 4. *Stratigraphy of the existing external wall in the case study building.*

2.5. INSULATING MATERIALS

Table 5 shows the insulating material properties of the building envelope, e.g., glass wool, expanded polystyrene (EPS), mineralized wood fiber, and kenaf, as identified by Schiavoni et al. [23] because they have comparable thermal conductivities but diverse environmental characteristics: EPS has higher embodied energy than the glass wool, while wood fiber and kenaf have lower embodied energy. These insulating materials are applied to the external surface of the existing building envelope, which is the most common technique for existing building retrofitting in the Italian context.

Material	Density [kg·m^{-3}]	Specific heat [kJ·kg^{-1}·K^{-1}]	Thermal conductivity [W·m^{-1}·K^{-1}]
Glass wool	21	1.0	0.035
EPS	22	1.3	0.035
Mineralized wood fiber	533	1.8	0.065
Kenaf	100	1.7	0.030

Tab. 5. *Insulator input data used for thermal calculation of the case study.*

The first material, glass wool, is produced by mixing natural sand and glass (usually recycled). The transformation in fibers occurs thanks to centrifugation and blowing processes. Then, the fibers are bounded thanks to the addition of resins. Several studies demonstrated that the thermal insulation performance of glass wool materials for building applications seems to be not affected by high temperature and moisture conditions. The producing manufacturers can recycle used glass wool.

The second material is expanded polystyrene (EPS), usually obtained by evaporating the pentane added into polystyrene grains. This process allows the realization of a white, rigid, and closed-cell foam characterized by low thermal conductivity. Research activities demonstrated that the thermal conductivity of EPS is affected by moisture. They are usually commercialized as panels, easily handled and cut without losing performance. Specialized industries perform the recycling process of these kinds of materials.

Mineralized wood fibers are obtained by applying a mineralizing process to wood materials derived from poplar, fir (or other fast-growing plants), or residues of the sawmill industry. This process improves the fibers' resistance to fire, rodents, and insects. Portland cement is used as a binder to create panels that are quite heavy. These materials could be recycled even as concrete aggregates.

Finally, kenaf fibers are obtained from the *Hibiscus cannabinus*, a fast-growing plant able to reach 3.5 m of height in 2 years. Fibers are usually mixed with polyester and fire retardants. The absence of protein makes kenaf not attractive to rodents or insects. Concerning the environmental impacts, the kenaf fiber insulation board proved that if the plants are cultivated near the factory, and the disposal scheme of the exhaust panels consists of incineration with energy recovery, this material is less impacting than glass wool.

3. RESULTS AND DISCUSSION

Concerning the comparison between LEED and ITACA, it is noticeable that LEED gives more importance to material selection since a specific category (MR) has been assigned to this item (Table 1), and a maximum of 39 points depends on the insulation material properties (29 points in EA, 10 points in MR and 2 points in IEQ), while in ITACA they can reach up to 33.95% of the total score (29.40% in RC and 4.55% in IEQ). In addition, although in both certification methods, "Materials from renewable resources" and "Local materials" parameters are considered, LEED pays attention to using recycled materials as a strategy for reducing waste. This aspect is not considered in ITACA.

Both rating systems were applied to the examined building by analyzing the effects of different insulating materials on the partial and final scores. Tables 6 and 7 show the results considering the original categories before normalization. By observing the total scores, every building configuration obtained LEED certification (except the case with EPS) and Class C certification in ITACA. As a result, the impact of changing the insulating materials is very similar for both procedures, and the effects are about the same. In LEED, when EPS is installed as an insulating material, the building project does not reach enough points to obtain the certification, and, therefore, the proper choice of the insulating material is fundamental in achieving the certification.

As stated in the previous section, the insulating materials affect the results of two original LEED categories: "Energy and Atmosphere" and "Material and Resources", while in ITACA, only the "Resource Consumption" category is affected. Regarding LEED, in EA and MR categories, the use of EPS leads to a reduction of the partial score compared to the other cases. On the contrary, kenaf and mineralized wood fiber solutions have the highest scores in both categories. Regarding ITACA, in the RC area, EPS results as the worst choice as in LEED, while kenaf and wood fiber reach the highest partial score. These differences are mainly related to the different origin of the raw materials and the possibility of recycling or reusing them at the end of their life cycle. In addition, considering the material properties shown in Table 5 and the specific climate conditions of Catania, mineralized wood fiber is the most performing material in the energy categories because it is characterized by higher thermal conductivity and higher density related to thermal mass. As observed in Section 2.2, the proximity of materials production to the building construction site is relevant. For instance, kenaf, which can be found locally, allowed achieving a higher score compared to the other materials. Therefore, when selecting an insulating material, it is important to look at the environmental and energy performance they provide.

LEED	Glass wool	EPS	Mineralized wood fiber	Kenaf
Sustainable Sites	13	13	13	13
Water Efficiency	2	2	2	2
Energy and Atmosphere	17	16	20	18
Materials and Resources	4	3	6	7
Indoor environmental quality	5	4	4	4
Total	40	38	45	44
Rating level	**Certified**	**-**	**Certified**	**Certified**

Tab. 6. *Results for the LEED protocol.*

ITACA	Glass wool	EPS	Mineralized wood fiber	Kenaf
Site quality	3.00	3.00	3.00	3.00
Resource consumption	24.19	23.42	26.45	25.51
Environmental loads	5.50	5.50	5.50	5.50
Indoor environmental quality	5.48	5.48	5.48	5.48
Service quality	3.52	3.52	3.52	3.52
Total	41.69	40.92	43.95	43.01
Class	**C**	**C**	**C**	**C**

Tab. 7. *Results for the ITACA protocol.*

After the normalization process described in Asdrubali et al. [13] and the definition of the new five categories (Tab. 3), the results of the two rating systems were compared in Figure 3 and Figure 4. The total values refer to the maximum score achievable for each category, and it shows that LEED continues paying more attention to the "Materials" category (15 total points) compared to ITACA (10.4 total points). Differently, LEED pays less attention to the "Energy" category (30 total points) compared to ITACA (47.6 total points).

The only two areas affected by the materials change are "Materials" and "Energy", similar to LEED. Focusing on the "Energy" category, the energy consumption of the building case study with glass wool was 30.73 kWh/m^2 calculated with DesignBuilder, while in the configurations characterized by the use of EPS, kenaf, and mineralized wood fiber, the energy demands were, respectively, 31.27, 31.15 and 30.75 kWh/m^2. In LEED, it results in different scores achieved by the insulation materials in the "Energy" category. Glass wool obtained about 63% of the maximum achievable category score influenced by changing the insulating material, the EPS obtained the lowest score (about 59%), while kenaf and mineralized wood fiber allow obtaining the highest score as design solution (about 67% and 74%, respectively). As described in the previous section, in ITACA, the impact on the "Energy" category is less accurate than LEED due to the energy assessment method adopted by modeling the real building and using a performance scale to assign points. Concerning "Materials" category in LEED, glass wool and EPS obtained, respectively, 40% and 30% of the maximum achievable category score influenced by changing the insulating material. Kenaf achieved 70% and wood fiber about 60%, resulting in the best performing in this category. However, these results show that, although kenaf and mineralized wood fiber can be considered sustainable and energy-efficient materials, they do not reach the maximum achievable category score influenced by changing the insulating material. Therefore, future research should consider alternative materials optimized for specific climate conditions.

Finally, in LEED, as can be seen in Figure 3, the renovation design project allowed to achieve about 57% in "Site", about 17% in "Water", and about 20% in "Indoor Environmental Quality" on the total achievable score for each category. Differently, in ITACA, the renovation design project obtained higher scores in "Site" and "Water" (more than 65% and 35% of the total achievable score, respectively), while in "Indoor Environmental Quality", it was lower than 30% of the total score (Fig. 4). These

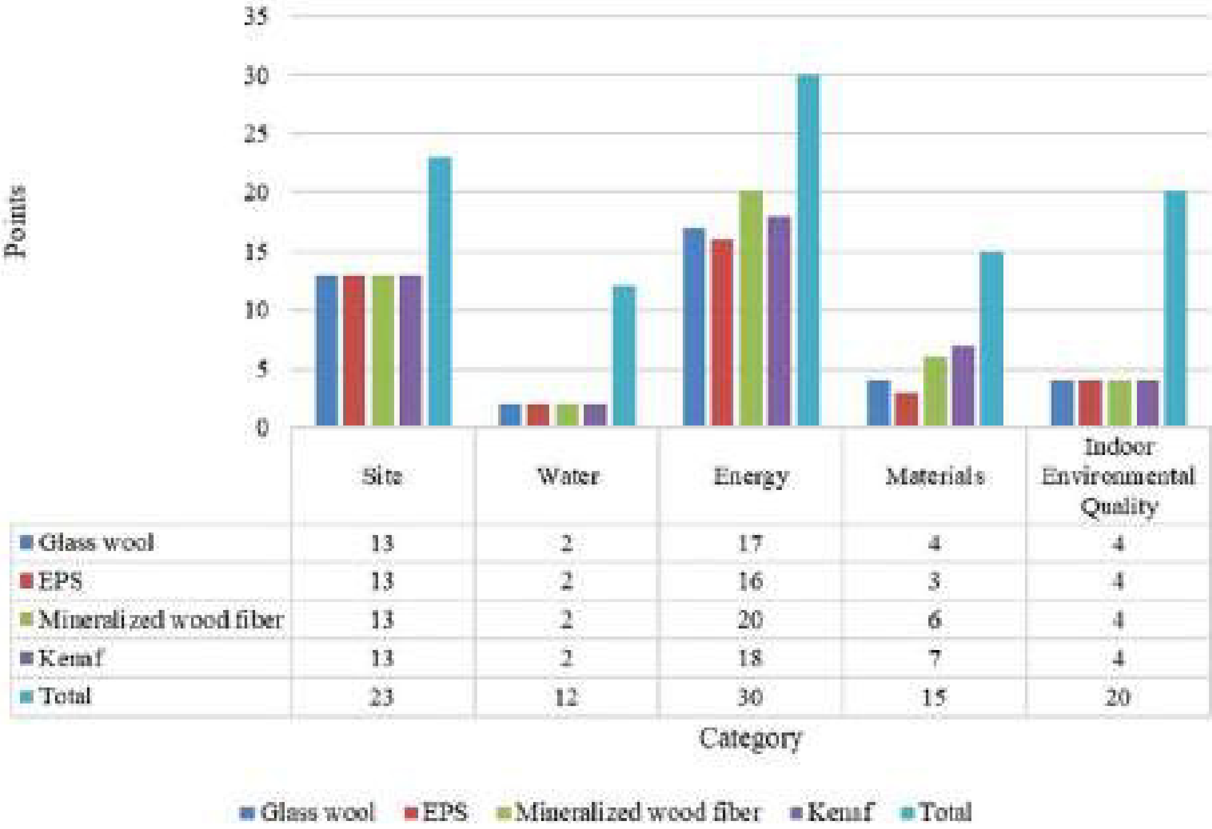

Fig. 3. *Comparison among the insulating materials in LEED.*

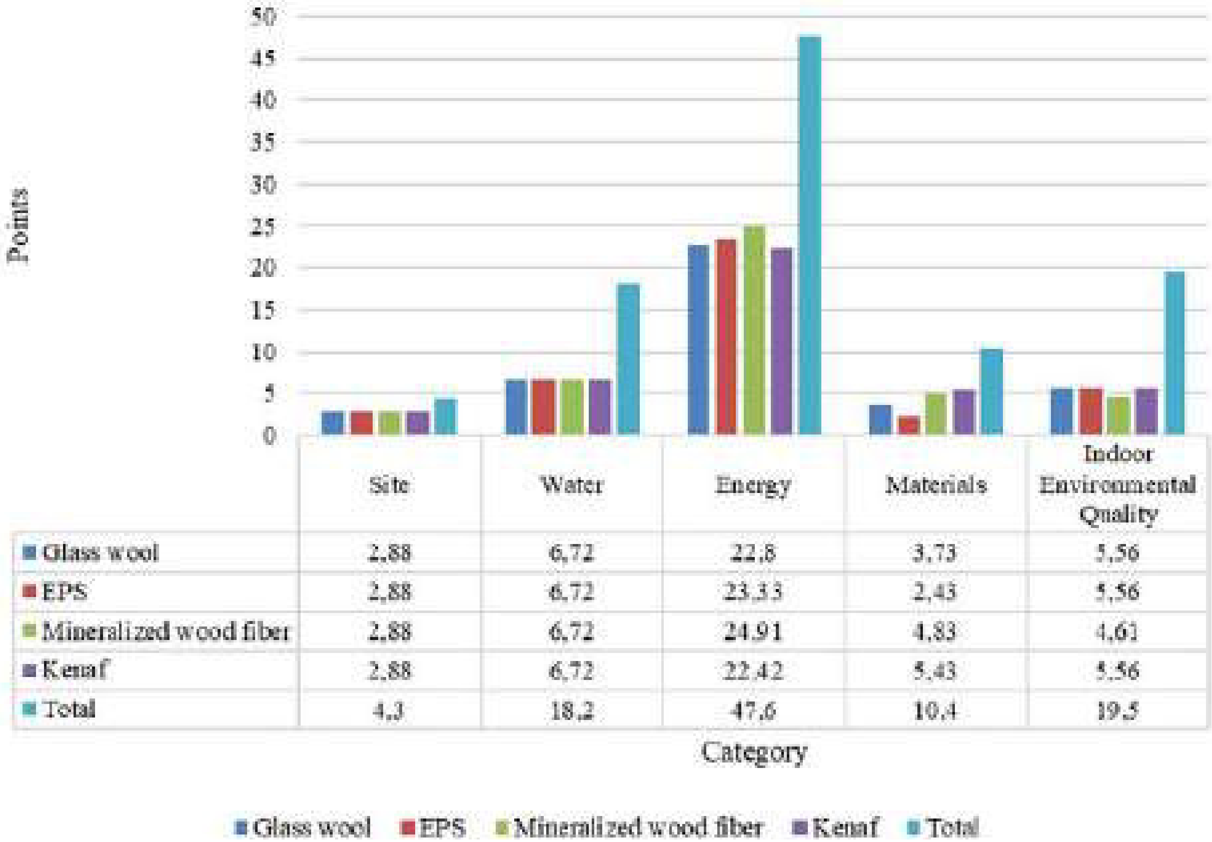

Fig. 4. *Comparison among the insulating materials in ITACA.*

results are not influenced by the change in insulating material and, therefore, their analysis is out of the scope of this research. However, it can be concluded that the building obtained many points in the categories related to the position of the building thanks to its closeness to both the urban city center and the mass transportation systems. At the same time, few points were obtained in the water and indoor quality categories because no intervention was included in the renovation project.

4. CONCLUSIONS

In this paper, a comparison between ITACA and LEED protocols applied to a renovation project in an Italian residential building was carried out. Five new categories were defined (Site, Water, Energy, Materials, and Indoor Environmental Quality) for comparing the two methods and their scores, according to previous research [13]. In addition, this research showed how and to what extent the insulating materials' characteristics can affect the two methods in the partial category and final scores. The sustainability rate of the building chosen as a case study was evaluated by simulating different configurations of the building envelope, characterized by thermal insulation made of glass wool, EPS, and two types of natural materials, mineralized wood fiber and kenaf. The following are the main results:

- after normalization, LEED pays more attention to the "Materials" category (15 total points) compared to ITACA (10.4 total points). Differently, LEED pays less attention to the "Energy" category (30 total points) compared to ITACA (47.6 total points);
- by observing the total scores, every building configuration obtained LEED certification (except for the case with EPS) and Class C certification in ITACA, demonstrating that the proper choice of the insulating material was fundamental in achieving the certification level desired;
- the mineralized wood fiber was the most performing material in the energy categories because it is characterized by higher thermal conductivity and higher density related to thermal mass. At the same time, kenaf, which can be found locally, allows for achieving a higher score in material categories thanks to the closeness of materials production to the building construction site;
- although kenaf and mineralized wood fiber can be considered sustainable materials, they do not reach the maximum achievable category score influenced by changing the insulating material because some of the points attributed to the "Materials" category directly depend on the building and the manufacturer locations and none of the materials proposed are manufactured close to the site.

Future research on this topic should consider other natural insulating materials (such as hemp, sheep wool, straw bale, etc.) that can allow for reaching the maximum scores attributed by the rating systems to the insulating materials. In addition, historic buildings represent most of the buildings located in the city center in which it is not possible to apply the thermal insulation layer on the exterior wall surface and, therefore, innovative materials should be explored to increase the thermal resistance of the envelope (such as aerogels, vacuum insulated panel, etc.).

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