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Editorial

Energy Efficiency of Historic Buildings

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Cultural heritage is recognized as a vital component of the sustainable development [1]. In this direction, the Sustainable Development Goals (SDGs) defined by the United Nations (UN) contain an explicit target on "*heritage*" that calls for making cities inclusive, safe, resilient, and sustainable by strengthening their efforts on protection and safeguarding [2]. Modern cities are the result of human settlements, which led to the coexistence of buildings from different ages through a series of transformations, conservation, and renewal processes [3]. Each historical period follows well-defined and differentiated features, according to local resources, economic opportunities, and traditional knowledge. Historic and traditional buildings, and consequently cities and towns, are inherently sensitive to the climate, thanks to the optimization of natural sources of heating, lighting, and ventilation. They use local and durable materials and construction techniques that are readily available, require low energy for transportation and production, and generate waste reduction. Every building is unique and must be deeper studied to be preserved, maintained, and retrofitted in a correct way.

More than 20% of the European building stock is built before 1945, with low energy performances and high energy consumption [4]. Only about 1% of this stock is renovated each year [5]. Thus, its energy saving potential is high. Based on these data, the European Union recognizes the importance of the improvement of energy efficiency and the decarbonization of the existing building stock. These strategies permit the mitigation of climate changes and favor the energy transition while also preserving heritage values and historical characters. The European policies focus on the instruments and the measures for increasing energy performance [6,7], renewable energy sources (RES) [8], building renovations [6,7,9–12], and quality of life [11], as well as for cutting greenhouse gas emissions [6–11] and generating new jobs in the green construction sector [11,12].

Starting form this framework, the Special Issue provides a forum for discussing and identifying new trends, problems, opportunities, challenges, and future developments in the energy efficiency of historic buildings. The published studies consider all the phases of the construction process: (i) energy auditing, (ii) energy and hygrothermal behavior, and (iii) energy retrofit. For each aspect, the main challenges are discussed suggesting innovative approaches for balancing conservation, energy efficiency, human comfort, and environmental sustainability issues.

Each intervention on historic buildings involves physical changes and may include visual and spatial impacts, altering irreversibly their authenticity [13]. Thus, their renovation requires a deep building knowledge, to support the selection of compatible retrofit solutions that balance energy efficiency, human comfort, heritage preservation, and environmental sustainability. Energy audits require the understanding of original construction techniques, heritage values, modifications over the time, actual performances, problems, and retrofitting opportunities. Its application on historic buildings must be carefully evaluated to avoid possible pathologies, physical damage, and possible legal claims because it entails the use of instrumentation and equipment that may stress, alter, or damage the buildings with sampling, thermal shocks, vibrations, or hydraulic flat jacks. Non-Destructive Technologies (NDT) are normally used in historic contexts. Infrared thermography (IRT) particularly is common applied for identifying thermal anomalies (e.g., structural state,

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thermal bridges, thermal insulation, detachments, moisture, rising damp, air leakages) thanks to the advantage of the contactless procedure. The spatial resolution of the thermal sensors is fundamental for capturing the presence of these critical points. Similarly, the interdependence between thermal images and building geometry permits the quick interpretation of damage phenomena. Normally, these issues have been solved by integrating multi-sensor instrumentation, generating high costs and computational times. To overcome these problems, Adamopoulos et al. [14] propose a workflow for cost-effective three-dimensional thermographic modeling. They use an infrared thermal camera and a consumer-grade RGB camera calibrated employing custom-made low-cost targets. These RGB spectrum images are used to reconstruct architectural features and building geometry.

In addition, a correct energy and hygrothermal evaluation of the performances of historic buildings permits the selection of tailored retrofit solutions, avoiding technological solutions that may generate a negative impact. Several tools are used for building energy simulations (BES) in steady-state and dynamic conditions, applying specific algorithms for the calculation and requiring different input and output data. Their application in historic constructions has several challenges related to input data selection, the calibration and validation processes, and the interface between building information models (BIM) and BES. In this direction, Al Rasbi et al. [15] investigate the thermal performance of new and traditional mosques in Oman using EDSL's Tas Engineering computer simulation software. The model is also calibrated with monitored data to obtain results close to the experimental data. The outcomes show that traditional constructions are better suited for free-running buildings, while contemporary mosques achieve less cooling load demand per area. These models are also used for defining a compatible retrofit. On hygrothermal evaluation, Martín-Garín et al. [16] use hygrothermal simulations for assessing different interior insulation systems for walls, without generating damage and moisture problems. They discover that the application of water-repellent impregnation becomes essential to guarantee the integrity of the building envelope.

Finally, energy retrofit is connected directly with heritage conservation and enhancement, social wellbeing, people engagement, and respectful economic growth [2]. Community engagement is fundamental for a successful regenerative design project, thanks to the definition of insights, needs, and alternative solutions by the collaboration of different stakeholders. On this topic, Lucchi and Delera [17] present a deep refurbishment of a heritage public housing neighborhood in Italy. Only a widespread knowledge of the local socioeconomic conditions through participatory actions permitted the selection of appropriate retrofit solutions also considering the high cultural, social, and economic values of the neighborhood. Functional and social mix, space flexibility, green design, RES, circular economy criteria, and continuative maintenance are applied for improving architectural quality, energy efficiency, human comfort, sustainability, and safety, also boosting the social revitalization of the area through the environmental responsible design.

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