energies

MDPI

Review

Introductory Review of Energy Efficiency in Buildings Retrofits

Joana Fernandes [1], Maria Catarina Santos [2] and Rui Castro [3,*]

[1] IN+/IST, University of Lisbon, 1049-001 Lisbon, Portugal; joanabfernandes@yahoo.com
[2] GESTU, FAUTL, University of Lisbon, 1049-001 Lisbon, Portugal; santos.mcatarina@gmail.com
[3] INESC-ID/IST, University of Lisbon, 1049-001 Lisbon, Portugal
* Correspondence: rcastro@tecnico.ulisboa.pt

Abstract: Energy-efficient building retrofits must be approached from three perspectives: law regulation approach, financial incentives approach, and practice approach. The concepts of zero energy building and life cycle energy building are presented as the basis for energy retrofits. Multi-criteria boards to assess the decision-making process are reviewed, analysed, and categorised under an architectonic perspective. Some examples are presented, with different packages of measures, from deep to non-invasive energy retrofits. Passive and active energy generation systems, together with control and management strategies, are the physical elements identified with the potential to improve buildings' energy efficiency. From a practice approach, this literature review identifies the concept of performance-based architectural design to optimise the planning and design of buildings' energy retrofits. In addition, tools such as Building Information Modelling are described as part of optimisation processes, as they enable designers to rapidly analyse and simulate a building's performance at the design stage.

Keywords: energy efficiency; energy retrofits; building life cycle; envelope retrofit; renewable energy sources; optimisation

Citation: Fernandes, J.; Santos, M.C.; Castro, R. Introductory Review of Energy Efficiency in Buildings Retrofits. *Energies* **2021**, *14*, 8100. https://doi.org/10.3390/en14238100

Academic Editor: Benedetto Nastasi

Received: 10 November 2021
Accepted: 30 November 2021
Published: 3 December 2021

1. Introduction

Buildings currently consume 40% of the total primary energy in the United States (U.S.) and in the European Union (E.U.) [1] and are responsible for 55% of the greenhouse gas (GHG) emissions [2]. At least 30% of the built environment in the E.U. consists of historic buildings [3]. Therefore, there has been an increased interest in the definition of methodologies to improve the energy efficiency in existing buildings, especially the historic ones [3]. In fact, the Paris Agreement goals are to reduce global temperature rise below 2° Celsius above industrial levels this century and to reduce also CO_2 emissions by 80% in 2050 compared to 1990 [2]. By 2030, many countries, including Portugal, will have to reach at least 40% of the CO_2 emissions targeted by 2050 and improve energy efficiency by 20% compared to 1990 levels [4]. According to the Clean Energy for all Europeans package of proposals [5], around 75% of the buildings are energy inefficient, and the investment in this area is very short. The European Commission pointed out the several difficulties that are hindering the improvement of buildings' energy efficiency: lack of skilled workers and capital as well as insufficient information about the process and possible benefits. Public policies and support programs such as The Amendment of the Energy Performance of Buildings Directive [5] have the goal of accelerating building renovation rates, focused on reducing GHG emissions not only by providing information to stakeholders but also incentive-based regulations. The retrofit of existing buildings is an increasing activity and a unique opportunity to refurbish adequately current building stock, because they will not be renovated again in the following decades.

There are various definitions of 'zero energy' building, or ZEB. This is a design concept that takes into account the energy used in the building, balanced with the production of energy, which combines green and renewable energy resources [1]. Other authors add a life cycle perspective to the definition of ZEB, taking also into account the embodied energy of the building and the energy related to construction works, proposing a definition of life cycle zero energy building (LC-ZEB). "A LC-ZEB is defined here as a building whose primary energy use in operation plus the energy embedded in materials and systems over the life of the building is equal or less than the energy produced by renewable energy systems within the building." [6]. Under this perspective, the longer the life cycle of the building, the less carbon emissions will be released with efficient retrofits. In fact, it is estimated that an operational building in a 100-year period has 20% of its embodied energy [7]. On the other hand, the negative impact of the construction process of a new green building can take between 10 and 80 years to overcome [7]. When retrofitting historic buildings, it is important to conceal environmental variables to their intrinsic characteristics, including cultural values, as historic buildings were built to last for centuries and function independently of mechanic systems and technologies.

Therefore, this article will focus on the following research questions: Which criteria should be considered, from the point of view of the architect, when improving energy efficiency in building retrofits? What is the relative weight of buildings' architectonic characteristics? What is the role of optimisation processes in adopting energy-efficiency measures in building retrofits?

Although the present research intends to be a starting point for further research within this subject, its novelty goes to the analysis of to which extent architectonic constraints influence the application of energy-efficiency measures in the building and how optimisation processes can help to assess multi-criteria frameworks from early design stages. This paper also correlates the building's renovation process, from public policies to construction works, highlighting directions to its optimisation with the best architect tools and processes to understand the need for a retrofitting guide manual for the architecture profession.

This paper is based on a review of 88 articles considered relevant, which were published in the years 2001–2020. The search terms were the concepts identified in the research: energy efficiency in building retrofits, active and passive energy-efficiency systems, life cycle assessment tools, life cycle assessment in building retrofits and optimisation processes, considering an architectonic perspective, both combined and isolated. The paper is organised as follows. Section 2 presents the importance of building retrofits and architectural design in energy efficiency, both from top–down and bottom–up approaches. Some retrofitting examples are presented and analysed. In Section 3, a review literature was made of energy-efficiency systems, both active and passive, their efficiency, and future outcomes. A building's operation control is also highlighted, regarding its importance in energy management. Section 4 presents existing optimisation processes not only in building design but also along all retrofitting process. Finally, some conclusions are drawn.

2. Building Retrofits and Architectural Design

International and local policies, from regulation to practice approach [8], are essential to boost energy retrofits and guarantee efficient solutions, from design to construction and operation stages. By taking in account a building's life cycle and existing conditions and defining methodologies to assess possible solutions, using multi-criteria frameworks [9], architectural practice plays an important role in this process, since it integrates technical solutions within existing building retrofits, balancing heritage and energy.

2.1. Energy Policies and Building Renovation

In the past decade, the EU has developed a significant number of resources for the use of renewable energy in the energy system and a proactive climate policy. However, a deeper energy transformation is necessary for the Paris Agreement to be fulfilled. This could be accepted socially and implemented with the right policies and incentives to mitigate and control the effects of deeper decarbonisation. To this end, countries must implement measures that incorporate the carbon emission limit [10].

Construction materials are responsible for a large consumption of primary materials, as well as for large energy consumption. In view of this, for sustainable construction, it is necessary to take into account the characteristics and environmental impact of the materials to be used. Therefore, it will be important to analyse each material separately. The determination of the environmental impact of the materials can be evaluated based on several methodologies [11], such as Life Cycle Analysis (LCA), Carbon Footprint Analysis, Embodied Carbon, and Cradle-to-Cradle, among others. All these tools have the main objective of reducing the environmental impact of the production of construction materials, and consequently reducing the use of raw materials. Furthermore, the use of efficient energy is targeted, favouring the use of recycled and/or renewable materials of low environmental impact.

Carbon emissions from building materials have a short-term climate impact. The Incorporated Carbon Review reports that even by de-energizing energy networks, buildings can continue to be a major generator of emissions in the long term due to the carbon incorporated in the materials used [10]. Research conducted by Bionova Ltd. Helsinki, Finland (One-Click LCA) and sponsored by Saint-Gobain shows that the energy efficiency has increased as well as the use of renewables; however, the proportion share of incorporated carbon also increased [12].

To determine the environmental impact of a single material, a Life Cycle Assessment (LCA) is to be performed. The analysis of the life cycle of materials is usually carried out in buildings that seek sustainability certifications, and therefore that seek low-energy consumption. However, there are few studies on the applicability of this analysis to traditional buildings, which are mostly found in built environments [13].

According to Barbiero and Grillenzoni (2019) [8], there are three approaches to raise efficient renovation buildings rates: the law regulation approach, financial incentives approach, and practice approach. The E.U. Clean Energy for all Citizens package (COM(2016) 860) [5], which was delivered in 2016 after the Energy Performance of Buildings Directive (EPBD 2010/31/UE) [14], intended to accelerate building renovations not only by providing financial incentives to energy-efficient retrofits in buildings and the use of renewable energy resources but also by providing technical information regarding energy performance to stakeholders of industrial and public buildings. By using this framework, the E.U. develops long-term strategies, involves the financial and construction sectors, and improves environmental and living conditions while generating a skilled workforce and jobs. In fact, the incorporation of non-energy benefits for building energy efficiency is introduced as an important feature of the energy productivity by some researchers [15].

The Work Programme 2018–2020 for "Secure, clean and efficient energy" [16] intends to support the priorities in the Energy Union Strategy: renewable energy; smart energy systems; energy efficiency; and, as an additional priority, Carbon Capture Utilisation and Storage (CCUS) with several calls for projects [16]. From the actions included in each call, we can highlight the development of materials and technologies for energy efficiency in retrofits, optimisation processes in deep renovations, innovations in technology and in design, integration of various disciplines and stakeholders along the process, creation of replicable solutions, and smart buildings operation.

Regarding national projects on energy-efficient buildings, we can highlight the Swedish research project 'Potential and Policies for Energy Efficiency in Swedish Historic Buildings' [9], with a top–down approach, evaluating the implementation of national energy policies in historic buildings and conflicting situations between efficiency solutions and preserving buildings' characteristics. Those challenging situations were also studied by the Royal Swedish Academy of Engineering Sciences. Both entities highlight methodological interdisciplinary approaches in the decision-making process to assess and choose the most appropriate construction and performance measures [9].

Italian case studies also demonstrate the need to invest and improve energy efficiency in historic buildings, which represent a large portion of Italian building stock and energy consumption. Some difficulties were also analysed in the Italian case [17]: the best construction measures for passive and active energy systems in buildings are many times conflicting with the conservation of buildings' historic character and heritage protection regulations; energy-efficiency actions must be evaluated case by case, because each building is unique; regulations and external conditions vary from one area to another.

The best solution in terms of energy is not always the best solution in terms of heritage. Some authors [18,19] have suggested the development of guidelines to professionals, owners, and tenants to help them adopt the best technical and cost–benefit solutions to their buildings. Guidelines and support mechanisms need to be included in the incentives and energy policies, so that passive solutions packages can be associated to different discount rates.

Several methodologies were presented in the literature about retrofitting processes. A generic transversal method with five phases [20] was selected: (1) project setup and pre-retrofit survey; (2) diagnosis; (3) identification of retrofit options; (4) site implementation and commissioning; (5) validation and verification of results. In stage (3), a model-based approach or model-free approach can be used. In model-based approaches, options must match the maximum targeted goals [20]. Several goals were identified in 40 different systems for buildings retrofits [21]: "reducing energy consumption and CO_2 emissions, improving indoor living conditions/comfort, assessing refurbishment needs, estimating costs, other environmental impacts".

2.2. Assessment Tools

The selection of a multi-criteria board to assess the decision-making process is essential to define the type of approach to energy retrofits for buildings. We attempted to categorise the articles analysed, regarding the criteria used in the definition of frameworks for retrofit processes. Four different categories were identified alongside their corresponding efficiency measures: (1) energy performance assessment; (2) pathological and typological; (3) cost-efficiency energy assessment throughout the life cycle of a building; (4) fleet-based life cycle assessment applied to building stock.

The most basic approach is energy performance-based, which addresses all the main factors affecting energy efficiency: the building envelope, active systems, and renewable energy resources. This approach usually uses algorithms and model-based simulations [22].

Piderit, Agurto, and Marín-Restrepo (2019) [3] suggest a pathological diagnosis combined with a different analysis of energy and heritage issues. The authors support that buildings' refurbishment must occur to correct pathologies, which should be ranked by severity and used as a tool to select the most appropriate energy-efficiency measures. This is a multidisciplinary case-by-case method.

Some intervention plans may include building envelope insulation, airtightness, and moisture protection, shading, heat recovery ventilation, and lighting optimisation through passive architectural design and the incorporation of renewable energy sources. In addition, [23] approach retrofit strategies by type of renovation: whole house, fabric first, room-by-room, step-by-step, and measure-by-measure. Another bottom–up approach using typology criteria was applied to Italian building stock. Ref [24] identified 120 building types, which were classified into six construction ages, four building sizes, and five climatic zones, and they also defined energy efficiency measures, conducted cost–benefit analyses, and scaled up the results.

In order to accomplish the goals set out in the EPBD Directive, the third approach, which integrates also a building's life cycle when determining the most cost-efficient package of solutions, is applied by [19] to a reference building representative of the Portuguese residential building stock. Ref [25] also incorporated the embodied energy of buildings in their analyses, from the construction phase to operation phase, to reduce GHG emissions, respectively, in Australian, Chinese, and Portuguese buildings. Ref [26] also added the building's end-of-life stage to a framework to assess the best retrofit options in Portuguese historic buildings, concealing energy efficiency and heritage.

The last one is a variation of the previously described life cycle approach, as it presents a fleet-based life cycle assessment applied to building stock, as it identified a gap in the connection between direct emissions in the operation stage and indirect emissions in the production, construction, and waste management phases [2].

2.3. Deep Retrofits versus Non-Invasive Retrofits

A deep retrofit of existing building stock is the strategy indicated by some authors to achieve long-term energy efficiency [18].

Deep retrofits include not only improving a building's envelope but also optimising their basic infrastructures, such as heating, ventilation, and air-conditioning (HVAC) systems or domestic hot water (DHW) heating sources. However, energy efficiency is not an isolated criterion. If taking into account architectural and heritage constraints and the embodied energy of the buildings, other scenarios must be considered. If the goal is to improve existing conditions, life cycle assessment gains importance not only in a cost-effectiveness solution but also in CO_2 emissions. In replacement scenarios, 52.4% energy savings are achieved compared to light retrofitted (21.5%), but according to Barbiero and Grillenzoni (2019) [8], 48.8% of light retrofits costs would be recovered in 30 years, whereas only 21.8% of costs would be recovered in deep renovations. Adaptive thermal comfort models (18–27 °C) are compatible with light refurbishment of traditional buildings in Portugal [26].

According to [24], depending on the size of the building and its location, isolating the building's opaque envelope can be a more expensive measure for the total renovation budget than glazing. This happens not because of the cost of the material itself but because of the installation costs that must be added, such as scaffolding and labour, as well as the extent of the material use. However, the most satisfactory results, in terms of energy savings, have been associated with the refurbishment measures of the building envelope.

In the reviewed literature, some researchers recommend non-invasive retrofits rather than whole building deep renovations [18]. The implementation of packages of energy-efficiency measures, without interfering with the building's intrinsic characteristics, as a result of a multi-criteria approaches, should be complemented with changes in behaviour and the building's operation, namely temperature setpoints and lighting.

In Jordan, optimising the building envelope by the external walls and roof can save 72% of the energy spent on the heating and cooling loads [27]. In 363 residential buildings in the region of Calabria, divided into two different groups (apartments and single houses), the retrofit strategy was to improve exterior walls and replace windows for more efficient ones, with an overall saving of 770,392 tCO_2/year [28]. In Bernardas' Convent retrofit, in Lisbon, Martins and Carlos (2014) [29] adopted an integrated conservation approach by assessing the impact of changing the form, function, and materials in the interior and preserving the authenticity of the exterior of the building. The attic was insulated, and exterior windows were replaced by others with identical design. In a brick building from 1902 at Vassar College in Poughkeepsie, New York, the authors decided to refurbish historic wood windows and install storm protection in order to respect the character of the building and adopt the best economic solution [18]. In the retrofit of the historic Zrenjanin brewery in Serbia, the external envelope was upgraded by insulating the inner face of external walls, eliminating thermal bridges, and introducing double glazing and external window protection. This intervention was limited to the external envelope in order to preserve the building's authenticity [7]. Another study was developed in a typical 1920s Swedish building [9]: a 1.5 storey, single-family house with wooden structure. Three degrees of intervention can be highlighted: reducing CO_2 emissions by 20% (by implementing a package of measures: heat pump, weather stripping, attic insulation, and adding a pane of glass to some of the windows); reducing 50% of CO_2 emissions (with the installation of a wood-pellet boiler, weather stripping, attic insulation, and external wall insulation) and saving 74% of energy, when taking in account life-cycle techno-economic optimisation (with the installation of a wood-pellet boiler, attic floor, wall, and crawl space insulation, and window replacement). The author concluded that to reduce 50% or more CO_2 emissions, the appearance of the building would be affected. On the other hand, with the package of measures to save 74% of energy, the attic and crawl space would need regular monitoring because of risk of mould growth. In a case study office building located in Carbonia, Sardinia, a PV system was installed with some retrofit actions to reduce the payback time. The authors identified the most appropriate retrofit solutions, which were in line with governmental financing incentives. Although the retrofitting of the building envelope can be a good energy-efficiency solution, it has a very large payback time. Cost–benefit analyses determine that this is ineffective when considered isolated [17].

Table 1 provides an overview of the above-mentioned case studies, highlighting the criteria subjacent to the corresponding energy retrofit.

Table 1. Building energy retrofits and retrofits: multi-criteria decision.

Case Study	Country	Goal	Passive System	Active System	Results	Criteria
Amman building stock [27]	Jordan	improve energy efficiency	building envelope optimised by external walls and roof		reduced 72% energy saving on the heating and cooling loads	energy efficiency; architectonic authenticity
363 residential buildings in the region of Calabria [28]	Italy	improve energy efficiency	exterior walls improved; window replacement		saved 770,392 tCO_2/year	energy efficiency; architectonic authenticity
Bernardas' Convent retrofit, Lisbon [29]	Portugal	improve energy efficiency	attic insulation; window replacement by others with identical design			energy efficiency; architectonic authenticity; change of function
1902 building in Vassar College [18]	USA	improve energy efficiency	refurbish historic wood windows refurbished; storm protection installed			energy efficiency; architectonic authenticity; best economic solution
Zrenjanin brewery [7]	Serbia	improve energy efficiency	inner face of external walls insulation; thermal bridges elimination; new double glazing and external window protection			energy efficiency; architectonic authenticity
Typical 1920s Swedish building [9]	Sweden	reduce CO_2 emissions by 20%	package of measures: weather stripping; attic insulation; adding a pane of glass to some of the windows	installation of a heat pump	reduced 20% of CO_2 emissions	energy efficiency; architectonic authenticity; reducing CO_2 emissions
		reduce 50% of CO_2 emissions	package of measures: weather stripping; attic insulation; external wall insulation	installation of a wood-pellet boiler	reduced 50% of CO_2 emissions; appearance of the building affected	
		save 74% of energy, when taking in account life-cycle techno-economic optimisation	attic floor, wall, and crawl space insulation; window replacement	installation of a wood-pellet boiler	saved 74% of energy; risk of mould growth in the attic and crawl space (regular monitoring needed)	
Office building located in Carbonia, Sardinia [17]	Italy	improve energy efficiency	package of retrofit actions to reduce the payback time	installation of a PV system		energy efficiency; architectonic authenticity; best economic solution regarding governmental financing incentives

3. Energy Efficiency in Building Design

ZEB technologies can be divided into passive systems, active generation energy systems, and energy-efficient building service systems [1]. Passive systems regard the building's envelope and decrease energy consumption, while active systems comprehend efficient and renewable energy generation techniques, both in the form of heat and electricity [8]. The efficiency of building systems can also be achieved by control and management strategies during operation.

3.1. Passive Systems

Passive systems can be responsible for reducing an energy demand up to 90%, even if the initial investment can increase the cost of the building, the energy saving through its lifespan can make the return of the initial investment profitable [1].

We currently spend most of our time indoors, which increases the demand of heating and cooling of indoor spaces. Due to this, "improving building envelopes is crucial for reducing energy usage and CO_2 emissions with the trend in global warming. Advanced designs of building envelopes could reduce heating and cooling loads by 40%. Air-sealing systems and highly insulated windows are the two most cost-effective technologies for reducing space heating and cooling demands" [1].

The building envelope can refer to improvements or the addition of insulation, the introduction of heat-insulation doors and new window fixtures, colours used in the external building, shade system, solar films on glasses, qualities of cavities, exchanging clay tiles with innovative reflective, cool tiles, adaptive thermal comfort models, and building shaping [1].

These systems involve improving structures envelopes, by lessening thermal transmittances (U-value ratio) joined with uninvolved passive warming or cooling systems. Diminishing thermal transmittances can be accomplished with thermal insulation improvement and low U-values fenestration, together with the decrease in window-to-wall proportion [30]. Bringing down the U-values to reduce the warmth increase/decrease is a minimal effort arrangement [31]. In any case, it is better under the low atmosphere and in envelope–load commanded structures. When considering energy-saving glazing innovations, it is essential to find the harmony between sun gains and daylight [32].

Thermal insulating plaster is an excellent example of a non-invasive technique for improving insulation, which can be applied to the inside of the building's envelope (Bianco et al., 2015), without compromising existing architectonic elements, such as stone masonry trims. The use of thermal insulating plaster can decrease the annual percent for energy demand (Bianco et al., 2015). Whenever technically and architectonically viable, the use of External Thermal Insulation Composite Systems (ETICS) in building envelopes is a more effective measure, which can be used to give thermal protection to a structure when there is a need to expand the thermal performance of an existing wall or to update the insulating layer by decreasing the thermal bridges. The optimal insulation thickness for building walls has been studied by several authors [33–35]. Depending on the thickness of thermal insulation, the implementation of ETICS, in terms of increasing the economic value, was analysed in [36] under three criteria: profitability indicator; net present value; and payback period. It was proved that the payback period would be two years after the initial cost; the use of optimum thickness of thermal insulation increased the net present value, and it showed a profitability over 20 (in a scale 0 to 21).

Windows and glazing areas have a significant impact on a building's energy consumption [37] not only in terms of thermal and visual comfort but also in air-tightness. Moreover, they can represent, in some cases, a large area of the building envelopes that have high window-to-wall-ratios. According to Yousefi et al. (2020) [38], a building's energy consumption can rise about 40% only by changing the window-to-wall ratio from 0.15 to 0.75. In fact, as an example, air leakage is reduced when replacing windows with air-sealing technologies [39] and single-glazing layers windows' U-values (a measure of how effective a material is as an insulator) can be three times higher than double glazing windows [40]. In hot climates, replacing single by triple Low-e glazing (vacuum glazing with low-emissivity) can reduce cooling loads up to 31% [41,42]. When choosing the appropriate retrofit measures regarding windows, glazing technologies and colours must be pondered in order to have a corrected balance between natural light and thermal comfort.

Natural light can be maximized through the placement of windows and other openings but also by calculating the correct dimensions of these openings. The use of reflective surfaces can also help the distribution of light inside a building. The use of natural light can increase the performance of the energy used and decrease the use of artificial lighting [32].

The consumption of artificial lighting is responsible for 14% of electrical consumption in Europe and 19% worldwide [32]. Fenestration is a fundamental factor for both visual connection and cooling loads in building conditions. To correctly choose the optimal glazing area and systems, there should be considered a balance between daylight and solar gains and, consequently, an optimal dimensioning of the window-to-wall ratio. The proper use of daylight in cooling-dominated buildings can reduce the electrical energy consumption for lighting and cooling systems, and at the same time, it can improve the visual and thermal comfort of the inside areas [32]. To minimize heating losses in the building, it is also important to use low U-value materials in windows. Vacuum glazing with low emissivity (Low-E), dynamic glazing, and electrochromic glass are some examples of the latest energy-saving innovations. Electrochromic glass is an electronically tintable glass utilized for exterior windows, which can be legitimately constrained by building tenants. It is well known for its capacity to improve inhabitant comfort, boost access to light and open outdoor views, lessen vitality costs, and give drafting technicians more structure opportunities. Electrochromic glass is a useful solutions for structures that need to reduce energy cost and where daylight is a challenge; by use of a correct zoning, it can control the glare without reducing the outside views [43].

Passive heating and cooling systems look towards the bioclimatic architecture and use principles that include the climate of the zone, amount of sun in the plot, orientation of the building, incorporation of cool coatings, control of solar gains, electrochromic glazing, and the introduction of green roofs.

The incorporation of control of solar gains is one of the essential technologies to apply passive heating. One example is the Trombe Walls [1], which diminishes the need to warm the building by utilizing conventional strategies, for example, heaters or other space radiators, decreasing the amount of energy to warm the building. A study conducted in Tehran shows that the use of Trombe Walls can actually reduce the energy load by up to 42% in a large room [44].

Passive thermal energy storage is another practical approach for building thermal control that primarily relies on latent heat storage and release by a building's thermal mass or Phase-Change Materials (PCMs) [1].

Passive thermal energy storage can be structured to boost their effect on a particular building design target, for example, reducing the indoor temperature by storage and lately release heat and cold in the building. Thermal Energy Storage (TES) [45] uses the thermal mass or phase-change materials to optimally reduce space heating and cooling energy consumption. It is crucial to identify a design objective, since it can result in optimal designs. Bastien and Athienitis (2018) [46] compare several design concepts and identify the most efficient ones, taking into account the potential design targets for thermal mass design and the most appropriate metrics for isolated gain spaces, such as solaria and greenhouses.

Passive cooling can assist the building by keeping it agreeable all through summer without utilizing a forced mechanical system. Usually, these systems take into consideration ventilation, ground cooling, shading, and green roofs. This system works by utilizing shade and protection to keep heat out the building in summer, utilizing heat-storing materials, for example, cement to retain heat, or utilizing breeze and air development inside of the building to keep it cold. Night-time building ventilation diminishes cooling loads by temperature differences among day and night in the summer [47].

Earth-to-Air Heat Exchangers (EAHE) is a promising system that can adequately be utilized to decrease the heating/cooling load of a structure by preheating the air in winter and the other way around in summer, and the systems form an underground cooling system that creates cold air by recirculating the air in the underground pipes [48].

Cold ventilated air through green rooftops can provide several features in a building, such as producing the filtration of contaminated air in urban conditions, absorbing rainwater, and minimizing the building's energy consumption by thermal reduction and energy conservation. It can also create a habitat for wildlife as well as more space for recreation, improve the microclimate and lower air temperatures, mitigate the heat island effect, and provide shading and protection from solar radiation. Spala et al. (2008) argue that green roofs can be categorised in two ways. The first one takes into consideration the larger territorial stratum to embrace a larger number and variety of plant species, which results in disadvantage due to the need for maintenance: this category is called intensive. The second category, called extensive, is characterised by a smaller territorial stratum, which demands less maintenance. In Athens, a study on green roof systems emphasises that the impact on the energy demand during the winter period is not significant [49].

Natural ventilation is one other factor to take into consideration while designing a building to achieve a high-performance energy efficiency. This feature enables proper ventilation, avoiding in this way the need for mechanical ventilation devices, increasing the ventilation rate. In office buildings, the proper use and control of natural ventilation can save up to 44 kWh/m^2 per year in cooling net energy in Stuttgart, Turin and Istanbul [50].

3.2. Active Systems and Building Service Systems

Although NZEBs are always equipped with an advanced HVAC system and energy-efficient ventilation strategies [51], sometimes, it is not possible to install new HVAC systems or totally remodel existing ones, if not taking deep retrofits, especially when there are architectonic or heritage constraints [52]. However, it is feasible to upgrade existing active systems by changing equipment or adding renewable energy generation systems as heating and/or cooling sources. Some sources of renewable energy comprise not just solar energy but also geothermal, aerothermal, hydrothermal energies, and bioenergy (clean bioenergy) [1].

Regarding solar energy, Photovoltaic modules (PV), Building-Integrated Photovoltaics (BIPV), Photovoltaic–Thermal (PV-T), Photovoltaic Materials (PV-M), and Third Generation Photovoltaics (3GPV) were the reviewed technologies. Photovoltaic technology is divided into two groups. The Crystalline Silicon (c-Si) group includes polycrystalline cells (14–18% efficiency) and monocrystalline cells (16–24% efficiency) [53]. This technology is the most effective and reliable. Amorphous silicon cells or thin-film silicon cells (TFSC) have a lower thickness but also a lower efficiency (4–10%). However, TFSC provide a wide range of application possibilities in different materials.

The four main options for building integration of PV modules are on sloped roofs, flat roofs, facades, and shading systems. PV modules are independent structures installed above a building's exterior envelope. Usually, their architectonic integration does not meet the designers' goals. BIPV are part of the building's envelope, acting as a material that generates power. They are architectonically integrated but less efficient than PV modules. Their durability and mechanical and hygrometric characteristics must also be taken into account. BIPV and PV modules need a gap underneath to control temperature performance [53,54]. Integrated modules with small-scale solar cooling applications are also being developed [55].

PV-T converts solar energy simultaneously in electricity and heat through the absorption by a thermal fluid, of heat dissipated, which can be used for domestic hot water. A solar-assisted heat pump is also referred by Aledo and Quiles (2016) [56] as a more efficient system. PV-M are construction elements produced by materials companies that can be used in building envelopes, shading, or lighting and produce electricity. However, according to the same author, power conversion decreases in these [54]. Polyurethane-based thickness-insensitive spectrally selective (TISS) paints are an example of PV-M [57].

3GPV include dye-sensitised solar cells (DSSC), organic photovoltaics (OPV), and lead halide-based perovskite solar cells [58]. These are low-cost solutions, because they are produced with mixtures of materials dissolved in organic solvents. They are flexible, lightweight, use printing technologies, and can be applied vertically in walls and windows, offering a high architectonic integration in buildings.

Photovoltaic technology should also be linked to energy storage systems to reduce the energy consumed from the grid. Solar energy is a cost-efficient active energy system that can be installed in existing buildings with proper existing architectonic solutions for its integration. St. Barnabas Church roof, at Hove, is an example of solar energy integration [59]. Four solar systems were analysed in the design stage: PV modules (monocrystalline), TFSC, BIPV, and OPV. As OPV generated around 9 MWh, compared to 60 MWh of PV modules [59], it was not considered. Among the three technology options, solar tiles/slate are the most preferred when considering visual impact and heritage values but are simultaneously the last preferred if economic benefit and net GHG emission savings are considered. Monocrystalline technology is the most preferred option, when considering those two factors. Additionally, a battery storage should be considered, because there is a high electricity consumption in the evenings. As there is a significant heating demand in spring and winter, the electricity generated should be also used for heating, combined with roof insulation.

Wind energy is less predictable than solar energy and also less architectonically integrable; therefore, it is less likely to be considered in retrofit operations. There are three types of wind turbines for buildings: horizontal axial wind turbines, vertical axial Darrieus, and Savonius turbines [1].

Ground source heat pumps (GSHP) use the earth's temperature both as a heating and cooling source. The geothermal energy in buildings has a better performance in balanced climates [1]. According to Belussi et al. (2019) [55], air-to-water technology shall be evaluated in building retrofits, because air exists everywhere, with a potential energy saving between 20% and 40%. Bioenergy's source is waste products from agriculture and forests, which can be used for power, cooling, and heating. Bioenergy reduces CO_2 emissions and improves economic savings by reusing waste. Bioenergy systems should be design together with proper ventilation systems due to particles from biomass combustion [55].

In summary, according to the reviewed literature and, from an architecture perspective, heat pumps, combined with PV, are the most cost-effective and realistic options for existing buildings in dense European cities such as Lisbon. That is why the authors gave more importance to this technology. Geothermal energy is a more expensive [9] and difficult technology to implement in an urban context, due to the lack of unbuilt and permeable areas [55].

3.3. Control and Management Strategies

The Building Automation System (BAS) and Building Management System (BEM) are tools for managing and controlling central buildings central systems such as HVAC, domestic hot water, indoor temperature, lighting, shading, and appliances. According to Belussi et al. (2019) [55], 40% energy savings can be reached if using control technologies in HVAC. These automation systems can also be used to connect to the grid through the Internet of Things and smart devices.

4. Optimisation Processes

In the 20th century, building performance has become a big concern due to the environmental challenges and the rise of sustainable ideas in construction. To evaluate building performance and enhance interactions between stakeholders in the design process, some optimisation procedures have been implemented. They consist essentially in certification programs, which take into consideration efficiency performance issues and establish standards to develop green buildings, and they also encourage architects, engineers, construction companies, and stakeholders to go towards a more sustainable design and higher performance construction type of building.

The use of optimisation processes is essential for organising operations and designing a project that wants to achieve better performance and final utilisation. The main goal of this procedure is to minimise costs and maximise the efficiency of the building. Indeed, once it is used in an early stage, the design phase of a project, it has the ability to reduce costs and create more efficient solutions that would not have such a big impact on the overall project costs [60].

4.1. Performance-Based Architectural Design

The idea of performance-based architectural design was developed in the 1970s by Negroponte. He proposes in his book, "The Architecture Machine," a new approach for architecture design performance. He would consider three variables to achieve an optimal design: generation, evaluation, and adaptation. In the generation phase, the environment would be the main focus; In the evaluation phase, he would look at the various aspects of the project design, and then, in the adaptation phase, the different possibilities of this final uses of the building would be outlined [61].

The process of performance-based architectural design should interrogate and debate the decisions, taking in more consideration the different needs, and not isolate the design process, as a single act for architects. Each design should be unique and sensitive to the place where it is located but also account for environmental, social, and economic aspects, including a whole life cycle costing analysis. To solve all the performance problems of a building, from the standpoint of sustainability, comfort, and safety for all who inhabit or use it, architects could use optimisation processes in the design process as a way to better identify solutions [62].

To better understand how to achieve performance in architecture design and how to integrate optimisation processes into the design process, we should identify the main performance issues. Those performance issues are mentioned in many green building standards and can be categorised into three main performance issues: structural, physical environment, and aesthetic and cultural [62].

Structural performance looks towards the safety that structures provide to the users of buildings, which should take into consideration the impact of the structure in terms of the life cycles of buildings. The performance of the physical environment ensures the best conditions in terms of comfort and quality of habitability indoor and outdoor of the structure obtained by maximising all the crucial factors for the building. In the study of physical environment performance, it includes solar, thermal, moisture, acoustics lighting, wind and air, energy, and others, and those are now becoming the primary focus on designing a project. In fact, before the global awakening for climates change, there were secondary concerns on the creative process. These are the mains concerns to achieve world efficiency certification.

Hamdy et al. (2013) [63] used a performance simulation-based optimisation algorithm to design a Net Zero Energy Building (N-ZEB) that considers a case study of a single-family house in Finland. A diversity of options is explored in terms of design to an optimal combination between economic viabilities and environmental concerns.

Bre et al. (2016) [64] developed a performance-based architectural design to improve energy efficiency and thermal comfort in a building located in the Argentine Littoral region. The study focused on the building envelope and showed that the optimal design improved thermal comfort by 95% and energy performance by 82% for the use of air-conditioned systems.

The expanding affirmation and understanding that the way to sustainability goes through the more extensive setting of the urban condition prompted the ongoing advancement of a few worldwide manageability evaluation frameworks on the local level. These can be isolated into two principal classifications. The first incorporates the frameworks that rose out of existing structures and built up outsider evaluation and confirmation frameworks for them. This approach is based on expert and input knowledge, which can come from national or international institutes, such as the U.S. Green Buildings Council (USGBC) and Building Research Establishment Environmental Assessment Method (BREEAM). The subsequent class incorporates the frameworks implanted into neighbourhood-scale plans and maintainability activities proposed to be utilised as arranging and basic leadership bolster instruments (first gathering and second-party appraisal frameworks). This can be simplified in Certification Systems and Decision Support Tools [65].

4.2. Multi-Objective Optimisation

According to Ascione, Bianco, Mauro, and Vanoli (2019) [66], the multi-objective optimisation processes is a complex process and requires a vast set of variables that can be subcategorised into two groups. The first group comprises the design variables that address the building envelope and geometry and the integration of active systems. The second one comprises the objective functions that integrate the environmental, economic, energy, and comfort indicators. Those processes and tools are aimed to calculate and analyse the performance of a building.

Azari et al. (2016) [67] used a multi-objective optimisation algorithm that intended to minimise energy demand by integrating the life cycle of building components. The results from the multi-objective optimisation algorithm show that the ideal design scenario for a building located in Washington should incorporate fiberglass-framed triple-glazed window in 60% of the window-to-wall ratio in the south facades.

Gossard et al. (2013) [68] proposed a multi-objective optimisation obtained by an algorithm and data collected by an artificial network. The authors decided to categorise energy performance in dwellings with two criteria of optimisation: the annual energy consumption and the summer comfort degree. The algorithm has the job of giving quick and very precise evaluations of the objective functions, while the multi-objective is utilised to locate the most appropriate solution to thermophysical building external walls.

Ferrara et al. (2014) [69] proposed a strong strategy for overseeing a high number of simulation models, comparing the relation between the design variables and the conceptual design of N-ZEBs, to find the ideal one. The results show that finding an optimal solution reduces energy demand by 20% after incorporating N-ZEB's design principles.

Abdallah et al. (2015) [70] built up a system for limiting the energy demand and CO_2 emissions of the existing building. The authors used the quick energy simulation tool to identify the optimal retrofit of energy systems, integrating renewable energy sources (RESs), solar thermal systems, and photovoltaics. This tool requires the input of design variables and objective functions, and the output would be several design alternatives that are suitable for achieving energy conservation.

Mostavi et al. (2017) [71] proposed a multi-objective optimisation model for minimising life cycle cost and CO_2 emissions and improving the thermal comfort of the buildings. Schito et al. (2018) [72] also used a multi-objective analysis to increase energy efficiency and thermal comfort as well as preserve artwork for the case study in a museum in Italy. Wu and Cervera (2017) [73] reduce the life cycle costs and life cycle emissions of GHGs by also using the multi-objective optimisation in the whole building energy retrofit.

4.3. Building Information Modelling (BIM)

The incorporation of the design process and computer tools such as BIM into the design phase of a project enables architects and engineers to analyse its performance rapidly and then better achieve higher results of building efficiency. The integration of this tool and process also influences the operational phase of a building by giving more information about the life cycle energy and cost of the building [74].

This wide range of solutions created by these tools has saved time and effort in the architecture job, creating space for developing new solutions. BIM simulation results were not possible to be used for a long time, as it would increase the initial cost of the project, since the technologies available at the time were not enough to develop a model that could calculate and analyse the performance of the building [75].

BIM has been playing an essential role in achieving better and more capable building efficiency, since "sustainable design analysis could be referred to as rapid and quantifiable feedback on diverse, sustainable alternatives and 'what if' questions posed by a design team and client during the early stages of the project." [76]. In addition, a good approach that would help to establish the standards for a more integrative design, is a chronologic design [77] that looks to the following aspects:

- Understanding climate, culture, and place;
- Understanding the building typology;
- Reducing the resource consumption need;
- Using free local resources and natural systems;
- Using efficient human-made systems;
- Applying renewable energy generation systems;
- Offsetting negative impacts.

These programs and tools aim to transform how we think about every single act of design and construction as an opportunity to positively impact and integrate the different building retrofits and energy efficiency conditions in order to obtain a more cohesive sustainable building.

Even today, although there are plenty of simulation programs created to help architecture design, the process is still relatively new, and it requires a sophisticated software solution that architects are not fully involved in. Even so, many programs were designed to achieve a high-performance-based architecture, such as Integrated Environmental Solutions©, Autodesk ©Revit, Ecotect, Vasari, and Green Building Studio, Graphisoft © EcoDesigner STAR, etc. [60].

Gou et al. (2018) [78] used three programs to minimise energy demand and maximise thermal comfort. These programs were EnergyPlus [79], MATLAB® [80], and SIMLAB [81]. The optimisation process was created in three steps: defining objective and variables functions, sensitivity analysis of variables, and multi-objective optimisation. In addition, Bamdad et al. (2018) [82] used EnergyPlus to analyse energy demand and developed new scenarios to internal loads and infiltration rate.

Smarra et al. (2018) [83] also used EnergyPlus [79] and MATLAB® [80] programs to adjust energy demand and thermal comfort by using historical building data. It has been applied to different case studies in order to highlight the efficiency and robustness of the envelope. Li and Wen (2017) [84] also used the same two programs above and GenOpt to develop an optimisation based on the energy performance improvement of residential buildings.

García Kerdan et al. (2017) [85] used a new simulation tool to improve energy and exergy use as well as Exergy destruction. This tool, called ExRET-Opt, enables performing multi-objective optimisation based with multi-variables. In this paper, the results show that the implementation of this tool can strongly improve the design of building retrofit. A simulation-based optimisation was used by Delgarm et al. (2016) [86] to reduce cooling and lighting energy demand in a case study in Iran. To achieve this result, five different programs were used (EnergyPlus [79], MATLAB® [80], and jEPlus).

5. Conclusions

This paper offers a literature review about energy-efficiency measures to be taken in account when retrofitting existing buildings, in a holistic approach, from the point of view of the architect, considering, but not compromising, their architectonic and constructive characteristics. The renovation process was analysed as a whole, from public policies to construction works, together with specific retrofit actions, highlighting directions to optimisation.

In conclusion, a multi-criteria decision analysis should be performed to assess the energy efficiency in building retrofits, considering location and climate, operational energy, embodied energy, architectonic constraints, control, and management, under a life cycle perspective. As the architectonic characteristics of a building are, in most cases, the most demanding criteria, optimisation processes should be adopted from the design stage to evaluate which are the best energy-efficiency measures to be implemented. Software simulation tools, such as BIM, can be of extreme importance in testing and measuring building design options and energy-efficiency solutions.

At a policy level, it is important to establish a common definition of LC-ZEB in retrofits, together with common frameworks, policies, and best practices in extended territories, because of countries' specific laws, policies, and incentives. There are already some guidelines for professionals, owners, and tenants and support mechanisms included in the incentives and energy policies. However, they should be enhanced so that the best technical and cost-efficient solutions can be chosen and implemented.

From an architectural practice approach, non-invasive retrofits are generically recommended, rather than deep renovations, with the implementation of packages of measures, for passive and active systems, taking in account a building's life cycle and embodied energy.

On a technical level, more investment should be made in more efficient solutions to improve a building envelope's energy performance and develop new active solar energy generation systems, as they were the most used in the different approaches reviewed. In this field, there might be some interesting possibilities of developing innovative construction elements that combine architectonic integration with the high efficiency standards of PV technology. Integrating PV cells in a materials manufacturing process, such as concrete, can also be an option. Paint layer solar cell materials can also be explored, as they are easy to use in building envelopes, as well as smart PV glasses in windows for shading purposes.

Taking advantage of new technologies, such as the Internet of Things, to connect the buildings to the grid will help to control and reduce energy demand and, therefore, can be an efficient measure.

Although there are already some architectonic approaches on energy efficiency in building retrofits, there are still some gaps that warrant future research work. The creation of assessment tools, based on multi-criteria frameworks, to enable practitioners to choose the optimal solution from early design stages should be explored.

Author Contributions: Conceptualisation, J.F., M.C.S. and R.C.; methodology, J.F. and M.C.S.; software, J.F.; validation, R.C.; formal analysis, R.C.; investigation, J.F. and M.C.S.; resources, R.C.; data curation, J.F. and M.C.S.; writing—original draft preparation, J.F. and M.C.S.; writing—review and editing, R.C.; visualisation, R.C.; supervision, R.C.; project administration, R.C.; funding acquisition, R.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Fundação para a Ciência e a Tecnologia (FCT), grant number UIDB/50021/2020 and doctoral degree grant SFRH/BD/151363/2021.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Cao, X.; Dai, X.; Liu, J. Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. *Energy Build.* **2016**, *128*, 198–213. [CrossRef]
2. Goswein, V.; Silvestre, J.D.; Freire, F.; Habert, G. Fleet-based LCA applied to the building sector—Environmental and economic analysis of retrofit strategies. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *323*, 12172. [CrossRef]
3. Piderit, M.B.; Agurto, S.; Marín-Restrepo, L. Reconciling energy and heritage: Retrofit of heritage buildings in contexts of energy vulnerability. *Sustainibility* **2019**, *11*, 823. [CrossRef]
4. European Commission. *COM(2014) 15 Final: A Policy Framework for Climate and Energy in the Period from 2020 to 2030*; European Environment Agency: Copenhagen, Denmark, 2014; pp. 1–18.

5. European Commission. *Clean Energy for All Europeans—Unlocking Europe's Growth Potential*; COM(2016) 860 final communication; European Environment Agency: Copenhagen, Denmark, 2016; p. 13. Available online: http://ec.europa.eu/energy/sites/ener/files/documents/com_860_final.pdf (accessed on 9 December 2019).
6. Hernandez, P.; Kenny, P. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). *Energy Build.* **2010**, *42*, 815–821. [CrossRef]
7. Blagojević, M.R.; Tufegdžić, A. The new technology era requirements and sustainable approach to industrial heritage renewal. *Energy Build.* **2016**, *115*, 148–153. [CrossRef]
8. Barbiero, T.; Grillenzoni, C. A statistical analysis of the energy effectiveness of building refurbishment. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109297. [CrossRef]
9. Broström, T.; Eriksson, P.; Liu, L.; Rohdin, P.; Ståhl, F.; Moshfegh, B. A method to assess the potential for and consequences of energy retrofits in Swedish historic buildings. *Hist. Environ. Policy Pract.* **2014**, *5*, 150–166. [CrossRef]
10. Papadopoulos, A.M. Forty years of regulations on the thermal performance of the building envelope in Europe: Achievements, perspectives and challenges. *Energy Build.* **2016**, *127*, 942–952. [CrossRef]
11. Giama, E.; Papadopoulos, A.M. Assessment tools for the environmental evaluation of concrete, plaster and brick elements production. *J. Clean. Prod.* **2015**, *99*, 75–85. [CrossRef]
12. Bruce-Hyrkäs, T.; Pasanen, P.; Castro, R. Overview of whole building life-cycle assessment for green building certification and ecodesign through industry surveys and interviews. *Procedia CIRP* **2018**, *69*, 178–183. [CrossRef]
13. Cabeza, L.F.; Rincón, L.; Vilariño, V.; Pérez, G.; Castell, A. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. *Renew. Sustain. Energy Rev.* **2014**, *29*, 394–416. [CrossRef]
14. EU. Labelling and standard product information of the consumption of energy and other resources by energy-related products & energy performance of buildings. *Off. J. Eur. Union* **2010**, *53*, 40.
15. Krarti, M.; Dubey, K.; Howarth, N. Energy productivity analysis framework for buildings: A case study of GCC region. *Energy* **2019**, *167*, 1251–1265. [CrossRef]
16. European Commission. *Horizon 2020 Work Programme 2018–2020 10. Secure, Clean and Efficient Energy*; European Commission: Luxembourg, 2018; Volume 2019.
17. Galatioto, A.; Ricciu, R.; Salem, T.; Kinab, E. Energy and economic analysis on retrofit actions for Italian public historic buildings. *Energy* **2019**, *176*, 58–66. [CrossRef]
18. Lidelöw, S.; Örn, T.; Luciani, A.; Rizzo, A. Energy-efficiency measures for heritage buildings: A literature review. *Sustain. Cities Soc.* **2019**, *45*, 231–242. [CrossRef]
19. De Vasconcelos, A.B.; Cabaço, A.; Pinheiro, M.D.; Manso, A. The impact of building orientation and discount rates on a Portuguese reference building refurbishment decision. *Energy Policy* **2016**, *91*, 329–340. [CrossRef]
20. Ma, Z.; Cooper, P.; Daly, D.; Ledo, L. Existing building retrofits: Methodology and state-of-the-art. *Energy Build.* **2012**, *55*, 889–902. [CrossRef]
21. Ferreira, J.; Pinheiro, M.D.; de Brito, J. Refurbishment decision support tools review—Energy and life cycle as key aspects to sustainable refurbishment projects. *Energy Policy* **2013**, *62*, 1453–1460. [CrossRef]
22. Ascione, F.; Bianco, N.; Mauro, G.M.; Napolitano, D.F. Retrofit of villas on Mediterranean coastlines: Pareto optimization with a view to energy-efficiency and cost-effectiveness. *Appl. Energy* **2019**, *254*, 113705. [CrossRef]
23. Topouzi, M.; Killip, G.; Fawcett, T.; Owen, A. Deep retrofit approaches: Managing risks to minimise the energy performance gap. In Proceedings of the ECEEE 2019 Summer Study on energy efficiency: Is efficient Sufficient? Presqu'ile de Giens, France, 3–8 June 2019; pp. 1345–1354.
24. Ballarini, I.; Corrado, V.; Madonna, F.; Paduos, S.; Ravasio, F. Energy refurbishment of the Italian residential building stock: Energy and cost analysis through the application of the building typology. *Energy Policy* **2017**, *105*, 148–160. [CrossRef]
25. Wang, T.; Seo, S.; Liao, P.C.; Fang, D. GHG emission reduction performance of state-of-the-art green buildings: Review of two case studies. *Renew. Sustain. Energy Rev.* **2016**, *56*, 484–493. [CrossRef]
26. Mourão, J.; Gomes, R.; Matias, L.; Niza, S. Combining embodied and operational energy in buildings refurbishment assessment. *Energy Build.* **2019**, *197*, 34–46. [CrossRef]
27. Shamout, S.; Boarin, P.; Melis, A. Correction to: Energy retrofit of existing building stock in Amman: State of the art, obstacles and opportunities. *Adv. Stud. Energy Effic. Built Environ. Dev. Ctries.* **2019**, C1. [CrossRef]
28. Carpino, C.; Bruno, R.; Arcuri, N. Statistical analysis of the heating demand in residential buildings located in Mediterranean climate and proposals for refurbishment. *Energy Procedia* **2017**, *133*, 16–27. [CrossRef]
29. Martins, A.M.T.; Carlos, J.S. The retrofitting of the Bernardas' Convent in Lisbon. *Energy Build.* **2014**, *68*, 396–402. [CrossRef]
30. Shehabi, A.; DeForest, N.; McNeil, A.; Masanet, E.; Greenblatt, J.; Lee, E.S.; Masson, G.; Helms, B.A.; Milliron, D.J. U.S. energy savings potential from dynamic daylighting control glazings. *Energy Build.* **2013**, *66*, 415–423. [CrossRef]
31. Hee, W.J.; Alghoul, M.A.; Bakhtyar, B.; Elayeb, O.; Shameri, M.A.; Alrubaih, M.S.; Sopian, K. The role of window glazing on daylighting and energy saving in buildings. *Renew. Sustain. Energy Rev.* **2015**, *42*, 323–343. [CrossRef]
32. Gago, E.J.; Muneer, T.; Knez, M.; Köster, H. Natural light controls and guides in buildings. Energy saving for electrical lighting, reduction of cooling load. *Renew. Sustain. Energy Rev.* **2015**, *41*, 1–13. [CrossRef]
33. Anastaselos, D.; Giama, E.; Papadopoulos, A.M. An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions. *Energy Build.* **2009**, *41*, 1165–1171. [CrossRef]

34. Bolattürk, A. Optimum insulation thicknesses for building walls with respect to cooling and heating degree-hours in the warmest zone of Turkey. *Build. Environ.* **2008**, *43*, 1055–1064. [CrossRef]
35. Ozel, M. Effect of wall orientation on the optimum insulation thickness by using a dynamic method. *Appl. Energy* **2011**, *88*, 2429–2435. [CrossRef]
36. Dylewski, R.; Adamczyk, J. Economic and ecological indicators for thermal insulating building investments. *Energy Build.* **2012**, *54*, 88–95. [CrossRef]
37. Li, H.X.; Li, Y.; Jiang, B.; Zhang, L.; Wu, X.; Lin, J. Energy performance optimisation of building envelope retrofit through integrated orthogonal arrays with data envelopment analysis. *Renew. Energy* **2020**, *149*, 1414–1423. [CrossRef]
38. Yousefi, F.; Gholipour, Y.; Saboohi, Y.; Yan, W. Interaction of glazing parameters, climatic condition and interior shadings: Performing energy and cost analysis in a residential building in Iran. *Energy Effic.* **2020**, *13*, 159–176. [CrossRef]
39. Luddeni, G.; Krarti, M.; Pernigotto, G.; Gasparella, A. An analysis methodology for large-scale deep energy retrofits of existing building stocks: Case study of the Italian office building. *Sustain. Cities Soc.* **2018**, *41*, 296–311. [CrossRef]
40. Serghides, D.K.; Michaelidou, M.; Christofi, M.; Dimitriou, S.; Katafygiotou, M. Energy refurbishment towards nearly zero Energy multi-family houses, for Cyprus. *Procedia Environ. Sci.* **2017**, *38*, 11–19. [CrossRef]
41. Edeisy, M.; Cecere, C. Envelope retrofit in hot arid climates. *Procedia Environ. Sci.* **2017**, *38*, 264–273. [CrossRef]
42. Ariosto, T.; Memari, A.M.; Solnosky, R.L. Development of designer aids for energy efficient residential window retrofit solutions. *Sustain. Energy Technol. Assess.* **2019**, *33*, 1–13. [CrossRef]
43. Ardakan, A.M.; Sok, E.; Niemasz, J. Electrochromic glass vs. fritted glass: An analysis of glare control performance. *Energy Procedia* **2017**, *122*, 343–348. [CrossRef]
44. Eshraghi, J.; Narjabadifam, N.; Mirkhani, N.; Khosroshahi, S.S.; Ashjaee, M. A comprehensive feasibility study of applying solar energy to design a zero energy building for a typical home in Tehran. *Energy Build.* **2014**, *72*, 329–339. [CrossRef]
45. Kenisarin, M.; Mahkamov, K. Passive thermal control in residential buildings using phase change materials. *Renew. Sustain. Energy Rev.* **2016**, *55*, 371–398. [CrossRef]
46. Bastien, D.; Athienitis, A.K. Passive thermal energy storage, part 1: Design concepts and metrics. *Renew. Energy* **2018**, *115*, 1319–1327. [CrossRef]
47. Campaniço, H.; Hollmuller, P.; Soares, P.M.M. Assessing energy savings in cooling demand of buildings using passive cooling systems based on ventilation. *Appl. Energy* **2014**, *134*, 426–438. [CrossRef]
48. Benhammou, M.; Draoui, B. Parametric study on thermal performance of earth-to-air heat exchanger used for cooling of buildings. *Renew. Sustain. Energy Rev.* **2015**, *44*, 348–355. [CrossRef]
49. Spala, A.; Bagiorgas, H.S.; Assimakopoulos, M.N.; Kalavrouziotis, J.; Matthopoulos, D.; Mihalakakou, G. On the green roof system. Selection, state of the art and energy potential investigation of a system installed in an office building in Athens, Greece. *Renew. Energy* **2008**, *33*, 173–177. [CrossRef]
50. Schulze, T.; Eicker, U. Controlled natural ventilation for energy efficient buildings. *Energy Build.* **2013**, *56*, 221–232. [CrossRef]
51. Feng, W.; Zhang, Q.; Ji, H.; Wang, R.; Zhou, N.; Ye, Q.; Hao, B.; Li, Y.; Luo, D.; Lau, S.S.Y. A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109303. [CrossRef]
52. Cabeza, L.F.; de Gracia, A.; Pisello, A.L. Integration of renewable technologies in historical and heritage buildings: A review. *Energy Build.* **2018**, *177*, 96–111. [CrossRef]
53. Jelle, B.P.; Breivik, C.; Røkenes, H.D.; Jelle, B.P.; Breivik, C.; Røkenes, H.D. Building integrated photovoltaic products: A state-of-the-art review and future research opportunities. *Sol. Energy Mater. Sol. Cells* **2012**, *100*, 69–96. [CrossRef]
54. Cerón, I.; Caamaño-Martín, E.; Neila, F.J. State-of-the-art' of building integrated photovoltaic products. *Renew. Energy* **2013**, *58*, 127–133. [CrossRef]
55. Belussi, L.; Barozzi, B.; Bellazzi, A.; Danza, L.; Devitofrancesco, A.; Fanciulli, C.; Ghellere, M.; Guazzi, G.; Meroni, I.; Salamone, F.; et al. A review of performance of zero energy buildings and energy efficiency solutions. *J. Build. Eng.* **2019**, *25*, 100772. [CrossRef]
56. Aguilar, F.J.; Aledo, S.; Quiles, P.V. Experimental study of the solar photovoltaic contribution for the domestic hot water production with heat pumps in dwellings. *Appl. Therm. Eng.* **2016**, *101*, 379–389. [CrossRef]
57. Quesada, G.; Rousse, D.; Dutil, Y.; Badache, M.; Hallé, S. A comprehensive review of solar facades. Opaque solar facades. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2820–2832. [CrossRef]
58. Charles, R.G.; Davies, M.L.; Douglas, P. Third generation photovoltaics—Early intervention for circular economy and a sustainable future. In *2016 Electronics Goes Green 2016+ (EGG)*; IEEE: Piscatway, NJ, USA, 2016; pp. 1–8. [CrossRef]
59. Khatri, S.; Ip, K.; Picco, M.; Hashemi, A. Potential and impact of incorporating roof photovoltaic to enhance environmental sustainability of historic English churches in the United Kingdom. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *290*, 12154. [CrossRef]
60. Ceranic, B.; Latham, D.; Dean, A. Sustainable design and building information modelling: Case study of energy plus house, hieron's wood, derbyshire UK. *Energy Procedia* **2015**, *83*, 434–443. [CrossRef]
61. Negroponte, N. The architecture machine. *Comput. Aided Des.* **1970**, *7*, 190–195. [CrossRef]
62. Shi, X. Performance-based and performance-driven architectural design and optimization. *Front. Archit. Civ. Eng. China* **2010**, *4*, 512–518. [CrossRef]
63. Hamdy, M.; Hasan, A.; Siren, K. A multi-stage optimization method for cost-optimal and nearly-zero-energy building solutions in line with the EPBD-recast 2010. *Energy Build.* **2013**, *56*, 189–203. [CrossRef]

64. Bre, F.; Silva, A.S.; Ghisi, E.; Fachinotti, V.D. Residential building design optimisation using sensitivity analysis and genetic algorithm. *Energy Build.* **2016**, *133*, 853–866. [CrossRef]
65. Lützkendorf, T.; Balouktsi, M. Assessing a sustainable urban development: Typology of indicators and sources of information. *Procedia Environ. Sci.* **2017**, *38*, 546–553. [CrossRef]
66. Ascione, F.; Bianco, N.; Mauro, G.M.; Vanoli, G.P. A new comprehensive framework for the multi-objective optimization of building energy design: Harlequin. *Appl. Energy* **2019**, *241*, 331–361. [CrossRef]
67. Azari, R.; Garshasbi, S.; Amini, P.; Rashed-Ali, H.; Mohammadi, Y. Multi-objective optimization of building envelope design for life cycle environmental performance. *Energy Build.* **2016**, *126*, 524–534. [CrossRef]
68. Gossard, D.; Lartigue, B.; Thellier, F. Multi-objective optimization of a building envelope for thermal performance using genetic algorithms and artificial neural network. *Energy Build.* **2013**, *67*, 253–260. [CrossRef]
69. Ferrara, M.; Fabrizio, E.; Virgone, J.; Filippi, M. A simulation-based optimization method for cost-optimal analysis of nearly zero energy buildings. *Energy Build.* **2014**, *84*, 442–457. [CrossRef]
70. Abdallah, M.; El-Rayes, K.; Clevenger, C. Minimizing energy consumption and carbon emissions of aging buildings. *Procedia Eng.* **2015**, *118*, 886–893. [CrossRef]
71. Mostavi, E.; Asadi, S.; Boussaa, D. Development of a new methodology to optimize building life cycle cost, environmental impacts, and occupant satisfaction. *Energy* **2017**, *121*, 606–615. [CrossRef]
72. Schito, E.; Conti, P.; Testi, D. Multi-objective optimization of microclimate in museums for concurrent reduction of energy needs, visitors' discomfort and artwork preservation risks. *Appl. Energy* **2018**, *224*, 147–159. [CrossRef]
73. Wu, J.Y.; Cervera, M. Strain localization of elastic-damaging frictional-cohesive materials: Analytical results and numerical verification. *Materials* **2017**, *10*, 434. [CrossRef] [PubMed]
74. Hay, R.; Ostertag, C.P. Life cycle assessment (LCA) of double-skin façade (DSF) system with fiber-reinforced concrete for sustainable and energy-efficient buildings in the tropics. *Build. Environ.* **2018**, *142*, 327–341. [CrossRef]
75. Najjar, M.; Figueiredo, K.; Hammad, A.W.A.; Haddad, A. Integrated optimization with building information modeling and life cycle assessment for generating energy efficient buildings. *Appl. Energy* **2019**, *250*, 1366–1382. [CrossRef]
76. Ceranic, B. Sustainable design analysis and BIM integration. *Archit. Technol. Res. Pract.* **2013**, 89–120. [CrossRef]
77. Krygiel, E.; Nies, B. *Green BIM: Successful Sustainable Design with Building Information Modeling*; John Wiley & Sons: Hoboken, NJ, USA, 2008; Volume 4.
78. Gou, S.; Nik, V.M.; Scartezzini, J.L.; Zhao, Q.; Li, Z. Passive design optimization of newly-built residential buildings in Shanghai for improving indoor thermal comfort while reducing building energy demand. *Energy Build.* **2018**, *169*, 484–506. [CrossRef]
79. EnergyPlus. Available online: https://energyplus.net (accessed on 9 December 2019).
80. MATLAB®. Available online: https://www.mathworks.com (accessed on 9 December 2019).
81. SIMLAB. Available online: https://www.simlab-soft.com (accessed on 9 December 2019).
82. Bamdad, K.; Cholette, M.E.; Guan, L.; Bell, J. Building energy optimisation under uncertainty using ACOMV algorithm. *Energy Build.* **2018**, *167*, 322–333. [CrossRef]
83. Smarra, F.; Jain, A.; de Rubeis, T.; Ambrosini, D.; D'Innocenzo, A.; Mangharam, R. Data-driven model predictive control using random forests for building energy optimization and climate control. *Appl. Energy* **2018**, *226*, 1252–1272. [CrossRef]
84. Li, X.; Wen, J. Net-zero energy building clusters emulator for energy planning and operation evaluation. *Comput. Environ. Urban. Syst.* **2017**, *62*, 168–181. [CrossRef]
85. Kerdan, I.G.; Raslan, R.; Ruyssevelt, P.; Gálvez, D.M. ExRET-Opt: An automated exergy/exergoeconomic simulation framework for building energy retrofit analysis and design optimization. *Appl. Energy* **2017**, *192*, 33–58. [CrossRef]
86. Delgarm, N.; Sajadi, B.; Delgarm, S. Multi-objective optimization of building energy performance and indoor thermal comfort: A new method using artificial bee colony (ABC). *Energy Build.* **2016**, *131*, 42–53. [CrossRef]