Identifying Retrofit Technology to Improve Building Energy Performance: A Review

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ABSTRACT

Retrofitting an existing building is one of the environmentally friendly solutions to reduce the dependency on constructing new buildings. There are huge numbers of existing building stocks that are suitable to be retrofitted such as historical buildings, offices, residential, warehouse, factories, vacant buildings and other historical buildings. However the retrofit process is still confronted by technical and social challenges. So we need to know how to make the best use of the public buildings in Egypt in sustainable way. In light of the anticipated relocation of the ministerial authorities to the New Capital city, more than 40 public administrative buildings in Cairo will be vacated and subjected to adaptive re-use plans. However, the available literature does not effectively help in terms of selecting the best retrofit techniques because energy efficient retrofitting is neither required nor widely practiced in Egypt. This paper presents a systematic approach to selecting and identifying the best retrofit alternatives for existing buildings. The generic building retrofitting problem and key issues involved in building retrofit investment decisions are outlined. There is also an overview of the research and development, as well as technologies of retrofit in existing buildings. This paper provides building practitioners and researchers a better understanding of how to undertake an efficient building retrofit to enhance energy conservation and sustainability. Furthermore, it highlights the significance of Building Information Modeling as a part of the retrofitting process.

Keywords: energy efficiency; energy retrofits; building information modeling; existing public building

INTRODUCTION

Worldwide, the building sector is responsible for consuming more than 36% of the final global energy and produces 39% of carbon dioxide emissions. [12] Accordingly, sustainable retrofit is an important method to achieve energy reduction and sustainable development. [22] Furthermore, by comparing the global CO2 emissions from different sectors, buildings are forming the highest portion (about 5.5 GtCO2-eq). Electricity consumption in public buildings, including administrative, educational and health buildings (9 percent) is the 2nd largest type after residential buildings. [40]Buildings currently consume 40% of the total primary energy in the United States (U.S.) and in the European Union (E.U.) and are responsible for 55% of the greenhouse gas (GHG) emissions. [04] Green retrofitting is the sustainable refurbishment of an existing building to make it more efficient, as well as better for the environment and long-term sustainability Reducing energy consumption through retrofitting building is considered a low-cost method to increase the efficiency of existing buildings. Green building measures can reduce the costs of energy consumption by 30 %, carbon emissions by 35%, water use by 30% to 50%, and reduce waste costs by 50% to 90% (Birk, 2007). Attention to existing buildings is also important because these buildings contribute the most to energy inefficiencies. Thus, the drive to address global warming has opened a huge market for retrofitting projects, especially for public buildings. [9] Retrofitting existing buildings improve sustainable development, decrease energy consumption, reduce maintenance costs, and mitigate climate change. For that, Green retrofit is the sustainable refurbishment of an existing building to make it more efficient also better for the environment and sustainable for the future. The traditional method of computer-aided design uses two-dimensional viewing planning does not have the capability to perform energy simulation during the initial phase of design [6]. Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of the facility, which constitutes a shared and accurate knowledge platform for conducting sustainability measures and the analysis of energy performance at an early stage of design [7]. BIM is an innovative technology that uses several methods that can accurately measure energy efficiency in buildings [8]. In practice, however, it is hard to realize a mass retrofitting due to the complexity of the decision making process, the high number of stakeholders involved and the absence of sufficient information about the existing buildings stock .[35]The use of Building Information Modeling (BIM) in conjunction with dynamic energy simulation can help overcome these challenges, As BIM “offers the best solution for data management and flow throughout a retrofit project from the survey to the building site” [6]. To make the retrofit process easer BIM’s potentials in existing buildings embrace quality control of retrofit measures and services, retrofitting planning, operation and maintenance, energy analysis, cost calculation and life cycle assessment (Elaheh Gholami, 2015).BIM can offer a solution to achieve a sustainable approach by making the possible options comprehensive for stakeholders and assure them about the quality of retrofit measures. (Elaheh Gholami, 2015). In addition, adoption of BIM to retrofit existing buildings is a trending research issue and has been stressed by researchers as the new direction towards energy retrofitting studies [21].

Sustainable Retrofitting in Egypt

Egypt is a developing country and throughout its journey to be a developed country in 2050, the rate of development in Egypt is very rapid with the contribution of construction industry. This rate of development comes with environmental, social and economic consequences.by integrating sustainable construction aims to aid future and current generations to achieve better quality of life (Hill & Bowen, 1997). In light of the anticipated relocation of the ministerial authorities to the New Capital city, more than 40 public administrative buildings in Cairo will be vacated and subjected to adaptive re-use plans. [27] While only a considerable amount of energy is consumed during building construction, the building sector in Egypt, including services, accounts for 38% of the total energy consumption, while with respect to energy sources used, it accounts for more than 52% of the country’s electricity consumption and more than 17% of the fuel oil consumption. [07] And in another study the building sector is responsible for 62% of the total electricity consumption, 26% of the total energy consumption and 70% of CO_2 emissions. [43] Public buildings energy consumption; in turn; has a great effect on total energy consumption. In Egypt public buildings represent 40% of the Egyptian building sector. They can give a large potential in reducing total national energy demand and solve a part of energy problem in Egypt. [41] Nevertheless, retrofitting actions in Egypt, especially from the energy saving and energy efficiency is new concept and gained momentum in mid-2014. The Egyptian government is currently constructing a new governmental quarter in the New Administrative Capital City, located east of Cairo. A planned relocation for all ministerial authorities to the New Capital City will leave a vacant governmental estate in Cairo. The study of the energy retrofit options provides a unique opportunity to reduce energy use and maximize the benefit from the anticipated investment in the re-use to be implemented within this stock. [27] And According to the New & Renewable Energy Authority [10], Egypt is targeting to renewably produce 40% of its total energy production by 2035. [42]According to the latest census report in Egypt, there were approximately 16.2 million buildings in Egypt (2017), of which about 0.8 Million buildings are office buildings. [42] Therefore, this research aims to explore the potential of achieving sustainability through retrofitting existing public buildings in Egypt. And will focus on the following research questions:

1. What are the challenges in sustainable retrofitting of public buildings in Egypt?
2. Which retrofit technology has the most significant impact in satisfying what the owner or tenant expects to achieve as a result of the retrofit process?
3. What benefit can building information modeling (BIM) bring to sustainable retrofitting of public buildings in Egypt?

This paper is based on a review of 40 articles considered relevant, which were published in the years 2002–2022. The following concepts were found in the research and were used as search terms: energy efficiency in building retrofits, active and passive energy efficiency systems, life cycle assessment in building retrofits, and implementation BIM on retrofit process, taking an architectural perspective into account.

Research Methodology

Retrofitting of existing buildings faces enormous challenges. One of which is uncertainties such as climate change, government policy variations. These may affect the retrofitting technologies. The research starts with a literature review to introduce the concept of green retrofitting and highlight its benefits and the obstacles facing its promotion. A systematic literature review was conducted for articles published from 2012 to 2022. The review procedure is divided into five major steps:

- Identifying research database (SCOPUS database).Where the SCOPUS database is the widest and most comprehensive base in covering research papers
- Finding keywords.
- Setting criteria to select collect and exclude papers that are out of the criteria.
- Analyzing and discussing results.
- Finding research gaps

Boolean Operators were added to the search to find relevant papers. These Boolean Operators were based on keywords identified in the title as shown in (Table 1). Using the SCOPUS database provided by Elsevier the Scopus database initially returned 170 results. This search is then refined based on defined criteria. With this further filtering, the number of articles is reduced to 37. Fig. 1

Filter Category	Criteria
Keyword	"sustainable retrofitting "AND "BIM" "sustainable retrofitting "AND "BIM" AND "Egypt"
Language	English
Document Type	Article and review
Subject Area	‘‘Engineering” and ‘‘environmental Sciences” and ‘‘Energy”
Date range	Article published between 2012 and 2022
Content	Full articles, Clarity of abstract, Articles that are a relevant topic

Table 1 shows the selection criteria. Source: Authors.

The distribution of article records in the SCOPUS database shows current studies of BIM integration in sustainable retrofitting.

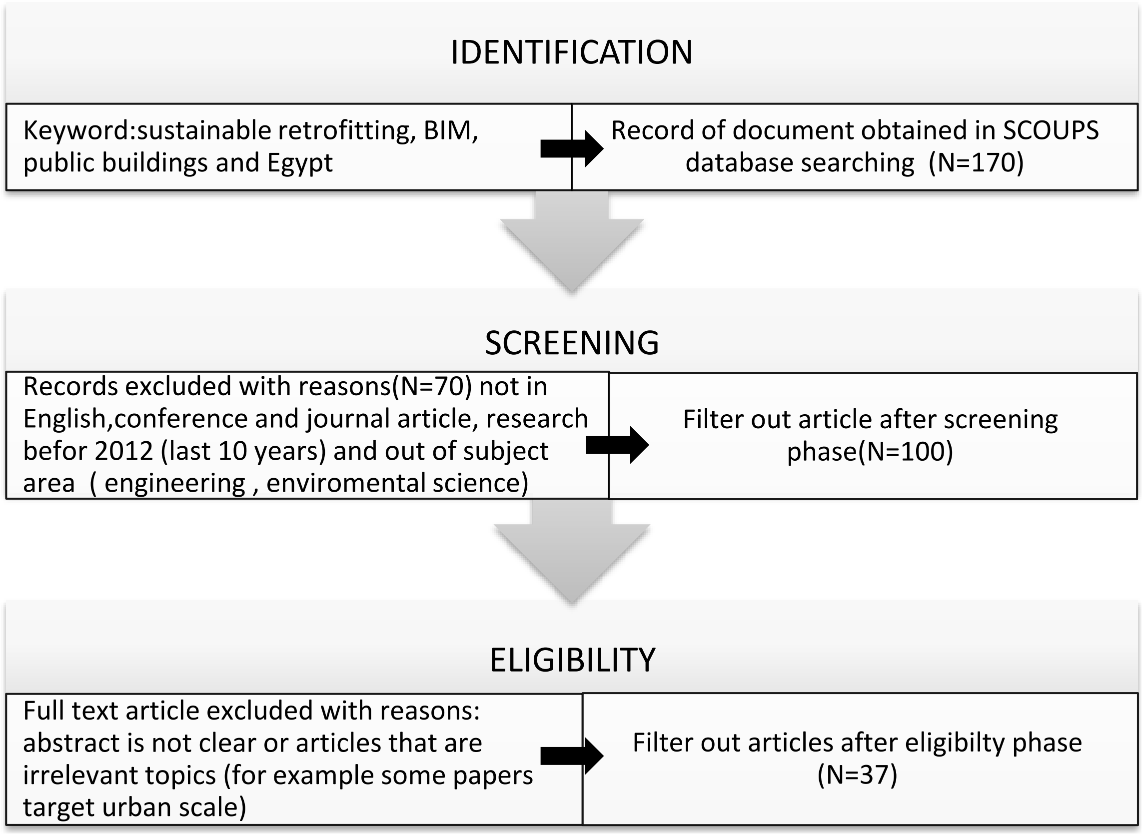

Figure 1 articles collection. Source: Authors.

Building Retrofit Barriers and Challenges

The real challenge of greening the existing buildings is to reach the desired achievement while still respect budgets, in addition to handling occupant resistance to the change. [46] the most common main barriers dedicated from reviewing 16 papers showed in the following table and A schematic overview of the five main types of barriers they defined as following : financial barriers, lake of awareness, lake of information, Institutional and administrative barriers and Technical barriers(complexity of the retrofitting action). The identified barriers can be used to guide how construction stakeholders can be influenced to make improvements in sustainable retrofitting projects.

MAIN BARRIERS	Financial barriers	Expensive and inconvenient[1] [22] [17] [10]
		complicate financial sharing[22]
		The most significant barriers to sustainable construction were first cost premium of the project, long payback periods from sustainable practices[3]
		The European Commission identified a number of obstacles preventing increased building energy efficiency, including: such as

		capital[10]
		There are frequently gaps in the documentation of the infrastructure and existing structures. It can be very costly to analyze a structure and it can lead to just-in-case reinforcements or even demolition. [17]
	Lake of awareness	The main barriers are identified as a lack of awareness, even among professionals, consultants, and clients. Education and information about the advantages of building green buildings have frequently been cited as the main reason for the slow progress and reluctance to get involved in green initiatives[3]
		many studies show that owners and tenants have a lack of knowledge about how, when, and why a building should be sustainably retrofitted (Bernstein et al. n.d.; Lapinski, Horman, and Riley 2006; Menassa and Baer 2014) [22]
		Further research is needed especially on insulation mechanism on walls and the effect on retrofit on buildings fabrics[1]
		The only concern, the selection of buildings that represent the best potential is another concern that needs to be considered [2]. In this regard, cooperation between architects, energy experts, environmentalists, economists, building owners, managers and contractors is essential [24]. [32]
		Sustainable retrofit projects involve complex processes usually unfamiliar to stakeholders. [22]
	Lake of information	lack of information about the process and implications of sustainable retrofitting is one of the main obstacles to consider sustainable retrofit[22]
		The records of the existing structure and the infrastructure are often missing. The cases show that even for rather recent buildings, from the 1970s, drawings cannot always be found and not structural data. [17]

		It is difficult because of the requirements of data collection in its different formats. [32]
		The European Commission pointed out the several difficulties that are hindering the improvement of buildings' energy efficiency: information about the process and possible benefits. [10]
		Information gaps about green structural materials and systems of green options for the opportunity to identify and evaluate alternatives. [3]
	Institutional and administrative barriers	Policies and regulations are energy efficiency standards, which set minimum energy efficiency requirements for retrofitting of existing buildings. [11]
		Regulatory and planning gaps have not allowed the public sector to be the driver for improved energy efficiency in buildings. The average age of the building stock is increasing because of a low demolition rate. . [3]
		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, not only by providing information to stakeholders but also incentive-based regulations[10]
	Technical barriers(complexity of the retrofitting action)	An energy-efficient retrofit project is more complex and riskier than a general retrofit project because of the lack of information about the existing building[22]
		The optimal identification of retrofitting scenarios, which allow the best economic and environmental benefits, is another challenge [32]
		Energy retrofitting in existing buildings stills seem broad and ambiguous; it is a vague process, which is described as a complicated task because several criteria have to be met and assembled, such as building typology, owners' lifestyles, construction characteristics, the country's regulatory arsenal and the local energy market situation .[32]

Table 2: review on the main sustainable retrofitting barriers. Source: the author

A summary of the main barriers and challenges from previous studies and papers analyzed could be summarized as follows in five basic points:

1- Financial Barriers: The most significant barriers to sustainable construction were first cost premium of the project, long payback periods from sustainable practices **[3]** One of the most frequently mentioned hurdles to energy saving measures is a lack of financial resources. Prioritize perceived core investments in personnel and equipment over energy costs. Although greater tendency to invest in energy retrofits provided the financial advantages associated with them are suitably enough.

2- Lake of awareness: The main barriers are identified as a lack of awareness, even among professionals, consultants, and clients. [3] Many studies show that owners and tenants have a lack of knowledge about how, when, and why a building should be sustainably retrofitted (Bernstein et al. n.d.; Lapinski, Horman, and Riley 2006; Menassa and Baer 2014). [22] As that Sustainable retrofitting projects involve complex processes usually unfamiliar to stakeholders. [22]

3- Lake of information: lack of information about the process and implications of sustainable retrofitting is one of the main obstacles to consider sustainable retrofitting**.** [22] AS the records of the existing structure and the infrastructure are often missing. The cases show that even for rather recent buildings, drawings cannot always be found and not structural data. [17]

4- Institutional and administrative barriers: Regulatory and planning gaps have not allowed the public sector to be the driver for improved energy efficiency in buildings. [3]although multi stakeholders made it very difficult to agree on energy saving investments in multi-owner buildings if many different property owners have to either approve a decision or make a financial contribution.

5- Technical barriers (complexity of the retrofitting action):Energy retrofitting in existing buildings stills seem broad and ambiguous; it is a vague process, which is described as a complicated task because several criteria have to be met and assembled, such as building typology, owners' lifestyles, construction characteristics, the country's regulatory arsenal and the local energy market situation .[32]

Building Retrofit Barriers and Challenges in Egypt

Retrofitting of existing buildings in Egypt faces enormous challenges. One of which is uncertainties such as climate change, government policy variations.[40] Unfortunately, retrofitting of existing buildings in the third world countries focuses on structural or aesthetic measures and mainly on historical buildings for conservation. [45] Retrofitting still faces many obstacles, especially in developing countries. Some of these barriers include high initial costs, lack of end user's awareness, and the lack of financial institutions awareness. [44] Egypt has a vast energy production capacity, but as local consumption has increased and investment in the energy sector has decreased, Egypt has become dependent on hydrocarbon imports. This issue had a negative influence on the country's economic trade balance and budget. As a result, the Egyptian government encourages energy-saving research.

Financial Barriers: The construction developers in Egypt use the minimum expenses to construct a building without paying attention to energy performance measures. [43] This is especially evident in the difficulty of allocating appropriate funds related to the implementation of energy saving strategies and the costs that this entails. [44]

Policies and Regulations: There is still unawareness of the importance of activating building codes to enhance building performance. In return, a building consumes more energy consumption and provides an uncomfortable indoor thermal comfort for the occupants. [5] Therefore, any solutions towards improving the energy efficiency in building sector plays an important role in reversing the negative impact on environmental and energy demand. [43] In developing countries like Egypt, no firm policies target the promotion of energy savings in buildings and their effect on climate change. [44]

Building specific information: For many, it is the complexity of retrofit and financing that present a barrier to intervention and uptake. Based on the correct retrofitting strategy improvement of the building envelope energy performance is provided. To understand thermal performance of retrofit the properties of the existing buildings must first be understood. [45]

Sustainable Retrofitting Measures

The purpose of retrofitting existing buildings is to decrease their energy consumption, but other factors that must be taken into consideration include the building owner's finances, the characteristics of the building, the energy expended by the facility, and many more. Therefore, the best way to address these problems is to suggest simple retrofitting measures that also lead to increased energy savings. The main retrofit options that green consultants recommend, considering financial issues as the main barrier, are heating and cooling reduction through implementation of passive design solution. [28] And 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. [10] Main retrofit measures can be identified into three main categories passive design, active design and renewable energy.

Passive Systems:

the five most essential retrofit technologies which can contribute to the success of energy efficiency and satisfy the owners at the same time are: (1) application of an external thermal insulation system, (2) replacing the existing windows and doors, (3) roof renovation, (4) replacement of the heating system and air conditioning system and (5) replacement of the water heating system. [22] It can be responsible for reducing an energy demand up to 90%. [10]

Active Systems:
Active energy-saving strategies, such as the use of upgraded HVAC systems and the replacement of high-energy appliances, can effectively reduce energy use to a certain extent. [50] Declared that there is a potential of 75%–90% reduction in lighting energy consumption compared to conventional patterns with a combination of daylight sensors, energy-efficient lighting, and lighting control. [50] Also active systems include Use of window shading to reduce solar heat gain in summer, Night ventilation, Use of thermal storage materials (e.g., phase change materials) and Energy efficient equipment and appliances, etc. [100]
Renewable Energy:
Comprehend efficient and renewable energy generation techniques, both in the form of heat and electricity, Sustainable technologies can include solar systems, wind turbines, biomass boilers and combined heat and power systems, which have lower GHG emissions than conventional energy supply systems. [28]

Main Effective Retrofitting Technologies

Green retrofit measures can include, building envelope improvement, window enhancement to minimize heat gains, efficient lighting and lighting technologies.[3] A significant amount of research has been conducted to develop and investigate various Green retrofit measures in order to improve the energy performance of existing buildings. The Green retrofit measures of buildings can be classified into the four categories shown in the following table. [100] The building retrofitting measurements were a combination of thermal performance improvement for external walls and a solar photovoltaic generation system for the rooftop. [50] Building envelope is the physical separator between interior and exterior of a building. A well-designed envelope should be using suitable materials and must suit local climate so that the heat transfer within the building can be minimized. In hot tropical climate, the heat transfer between indoor environment and outdoor climate is significant through the fenestration of building envelope which means a good approach of building envelope is needed not only to provide adequate natural ventilation and lighting but at the same time keeping the building cool.[28]
To summarizing the all sustainable retrofitting technologies that we can use retrofit public building we can find in the following: [40] a general description of sustainable retrofit and refurbishment in the context of carbon reduction, retrofit and refurbishment is about making buildings more thermally efficient and sustainable. It principally concerns improving the insulation of the building envelope

Building Envelope	• Walls: insulation of cavities or on external/ internal surfaces. • Roofs: usually loft insulation (virgin and top-up). • Doors: usually draught-proofing, but can include additional/replacement doors. • Windows: very often includes replacement of old windows with double or triple glazed units, but can include draught-proofing existing windows and/or the installation of secondary glazing.

	• Floors: insulation.
Buildings Systems	• Lighting: new controls, occupancy sensors, LED, fiber optic and other low-energy technologies. • Controls and Building-Management Systems: installation of a building-management system, upgrade to include digital controls and greater number of sensors, which all relate to non-dwellings. • Air conditioning: upgrade and provide passive replacement in areas of building where possible, which all usually relate to non-dwellings.
Renewable Energy Systems	• Photovoltaic, solar thermal hot water, solar ventilation pre-heating, passive solar heating, wind energy, retrieved-methane powered plant installations, wood and organic-waste power-sourced heating or power plant, replacing traditional air conditioning with air-source (ASHP) or ground-source heat pumps (GSHPs), micro-hydro power. This array of options will usually be applicable to non-dwellings. • Water conservation: low-flow water fittings and shower heads, low flow plumbing equipment, water-efficient irrigation, grey water systems and rainwater harvesting.

Table 3: review on the main sustainable retrofitting technology. Source: the author

Research Studies on Different Types of Buildings

The following table investigates the principal retrofit methods used in different building types and the main results for using those technologies based on a review of papers.

Ref. no.	Building type	Major retrofit technologies used	Savings determination method	Major results
1	Kuala Lumpur Performance Art Centre	▪ Heat recovery; Day-lighting and natural ventilation were used ▪ the usage of large UV-coated swing windows	comparison between retrofitting existing building and constructing new building that has same function and capacity Analysis of measurement data from the	There is a significant cost saving of MYR 14 Million on retrofitting the existing building based on the 2 buildings. KLPac project also managed to significantly saves construction time by 29 months earlier as compared to construct a new building.

			database	
22	Romania Residential sector	▪ Mechanical System: Replacement of Heating system and air conditioning system, Replacement of Water heating system ▪ Electrical system: Lighting fixtures ,Replacement of Electrical system ▪ Plumbing system: Replacement of Domestic hot and cold-water system, Recycling methods of residual water ▪ Building envelope: Application of an external thermal insulation system ,Replacement of windows and doors ,Roof renovation	Simple energy calculation through developing a Technical Targets relationship matrix	the five most essential retrofit technologies which can contribute to the success of energy efficiency and satisfy the owners at the same time are: (1)application of an external thermal insulation system, (2) replacing the existing windows and doors, (3) roof renovation, (4) replacement of the heating system and air conditioning system and (5) replacement of the water heating system.
17	Office block for mixed use including residential, offices, retail and a café. in England	Providing a noise screen that will enable the building to be naturally ventilated. A new façade will be set up with super-insulated panels and floor to ceiling full height glazing. The whole block is heated with a biomass boiler and there will be solar heaters for domestic hot water.	Analysis of measurement data from the database	The project would add public value in terms of environmental quality, mixed use living, the attractive atrium space and a public garden.

	head quarter building in England	Use geothermal heating combined with a biomass boiler, local waste water management. Solar collectors and wind turbines and the lake have been decontaminated.		Initially Urban Splash aimed at an excellent level of BREAM rating Eco Homes (now Sustainable Homes). They are actually on level 4 (of 6) due to changes in the assessment model.
28	Prime Minister Office	Viable integration of green technology equipment and fittings. Building envelope improvement; Using passive systems and techniques; Installation of energy saving lighting systems and use of daylight; Improvement of heating, cooling, ventilation systems and renewable energy		Energy saving program resulted in significant saving of more than 30 percent of energy consumption four years after the building had been retrofitted. The result after 4 years of retrofitting measures shows that the carbon emission reduction is more than 50 percent.
32	high-rise building in Algiers	envelope materials, energy consumption, domestic hot water, heating and cooling systems Solar collectors and PV cells	3D modeling, meteorological regeneration data, energy simulation of buildings, estimation of renewable energy production and statistical analysis	The reduction in heating ranges from 51% to 75%, while the reduction in cooling ranges from 32% to 5%. Electricity need was met by 97%, while thermal need was met by 80% for heating and domestic hot water. Excess energy generated by the RES is estimated at 27% for electricity and 12% for thermal production. Investment cost resulting from the retrofitting operation of an energy

				transition system shows that the payback period is 10 years. GHG emissions of the entire building can be reduced by up to 91%.
10	Amman building stock	optimizing the building envelope by the external walls and roof	Analysis of measurement data from the database	Save 72% of the energy spent on the heating and cooling loads
	Office building in Carbonia, Sardinia	package of retrofit actions to reduce the payback time installation of a PV system		
11	five office building types	Building envelope, HVAC, artificial lighting systems, and the integration of passive components for heating and cooling.	Simulation model developed	For enclosed/light/skin dependent/cellular office buildings, the combination of all retrofit options resulted in a reduction of total energy use ranging from 48% in the North Coastal to 56% in the North European climatic regions.
	Canadian office building	Heat recovery; Day-lighting; Boiler efficiency economizer; Preheat upgrade; Lighting load reduction.	Simulation program, Energy Plus	The use of five retrofit options could achieve 20% reduction in electricity consumption for Edmonton, Ottawa and Vancouver, and 30%, 32% and 19% reduction in natural gas for each of the respective cities
	Empire State building	Windows upgrading; Insulated reflective barriers; Tenant day-lighting, lighting and plugs; Chiller plant retrofit; Using a new air handling layout unit; Demand	Energy and financial modeling	Can achieve a 38% reduction in energy use, save 105,000 metric tons of CO_2 over the next 15 years, and has an incremental net present value of approximately $22 million

		control ventilation; Balance of direct digital controls; Tenant energy management		
14	high-rise residential buildings	wall insulation, window upgrading, shading devices, energy-efficient heating or cooling systems, renewable energy (RE) systems	energy simulation was performed to evaluate the building thermal performance	The warm zone requires a higher investment in retrofit to achieve a 40% reduction in energy consumption. This higher retrofit cost means that it is more difficult to improve building energy efficiency in cooling dominant zones; and warm zones have to employ more complicated energy-efficient measures to reduce the energy consumption the most effective and common way to improve the thermal performance of a building envelope is to improve the wall insulation, and the coefficient of heat transfer of external walls, or the U-value, is used to evaluate the thermal performance of a wall
26	typical large office building in Beijing	Insulate the exterior wall and roof, Replace the outer window, Retrofit the central air conditioning system and Reinstall the circuit and use energy efficient appliances	using simulation software, the software Design Builder	▪ Lighting and air conditioning systems have the potential to reduce the energy consumption greatly via all kinds of energy-efficiency technologies. Combined retrofit works on both lighting

				and air conditioning systems have a mutual influence. Improvements to these can reduce the total energy consumption of the large office building by around 8–13%. ▪ Installing an LED lighting system and the frequency conversion device for the water chiller cannot only sufficiently reduce the building's energy consumption but also make it more economical. ▪ The optimal technical schemes can reduce the total energy consumption by around 13% and their payback periods are around 7–8 years.
31	Three heritage residential buildings in Cairo	The proposed scenarios are based on hybrid strategies of mixed-mode ventilation, solar and thermal control. Replacement of Lighting, Replacement of Air Conditioning units, Building Integrated Photovoltaic (BIPV)	using simulation software, Design Builder software	Package of passive scenarios greatly improved electricity use throughout the year compared with the base case. The application of this package reduced the electricity consumption of the base case in reference building 7 from 84 to 43.5 kWh/m2/year
40	The building which houses the Architectur al	External wall thermal insulation, a double glazing low-E glazing and re simulation was done, Green roof (GR) was applied and	A BIM model was created for the whole building in REVIT then the generated	It indicates that most of the saving was found from application the green roof. Such saving was about 29 percent. The saving in the

	Department, Faculty of Engineering at Cairo University	Day lighting assessment	model was exported to “Design Builder” software	electric energy consumption the maximum saving of about 890 kWh, which is about 15 percent
27	the Central Agency for Public Mobilization and Statistics	External wall insulation, Roof insulation, External shading, HVAC unit type and Change of glazing system and decrease of window area	energy model, Design Builder	The study of the payback period showed that all tested retrofit solutions managed to achieve the payback in full in less than 20 years. The use of LED tube lights, internal blinds, UPVC double glazing and keeping the existing external shading most frequently appeared in the optimal retrofit solutions obtained. Reductions in the energy use intensity of up to 50% (off the adjusted baseline office building re-use scenario) could be achieved as a result of the application of the retrofit measures.
41	office building prototype	Building envelop energy reduction alternatives, Shadings elements added , natural Ventilation system designed and Installation of energy saving lighting Green roof is also tried.	Energy model by Revit Autodesk program, then integrated directly into Design Builder program.	Insulating the building envelop can save up to 5.75% from the total energy consumption, adding shadings on the building openings can save up to 8.87% from the total energy consumption, integrating energy reduction strategies together can reduce the energy consumption by 28.52%. In this case study, energy consumption reduction techniques

				result in a 28% base-case reduction. The remainder of the energy need is then met by the integration of solar panels and wind turbines, which will produce 44% and 56.7% of the required energy, respectively.
42	office buildings constructed between 1970–1980	Insulating external walls and roofs, changing glazing, and using overhangs in West and South facades. Lighting fixtures will be replaced with LED, A mixed-mode HVAC system based on the same VAV system will be incorporated, allowing natural ventilation combined with mechanical ventilation.	energy model, Design Builder	The proposed retrofitted strategy succeeded in decreasing annual energy consumption by 46%–65% and CO_2 emissions by 59%–72% for all the retrofitted cases.
04	Green E-Park, Yangpu District	Improve natural ventilation, roof garden and vertical plants, runoff control measures, movable envelope, rainwater collection system, installation of wastewater membrane treatment system and intelligent management system, solar water heater and PV-system	Multiple simulations using BIM models	Annual CO_2 emission savings: 5716.3 kg, 140.2 kg of dust reduction, runoff coefficient was reduced to 0.62 from 0.78. Indoor environmental quality (IEQ) was within 90% acceptability range of ASHRAE 55-2010 comfort standard.
	Two office buildings (26 and 36-storey with	Insulations (walls, roof and floors, upgrade in windows and shading, upgrade	Energy Plus Simulation tool, support vector	Best simulation of practical cases is obtainable with physics-based

	a total floor area of 49,650 and 87,765 m2 respectively)	of chiller units, HVAC, lightings, use of gas-fired boilers and centrifugal chillers for heating and cooling respectively	regression (SVR) and actual measurement tools	simulation, supported by sensitivity analysis, optimization algorithm and non-linear regression tools.
	Multipurpose Commercial building, Shanghai	Upgrade HVAC, lighting systems, oil boiler to natural gas boilers, installation of sub-metering and control systems, roof and wall insulation, window upgrade (shadow, films and double-layer glass) and solar power installation	Cost–benefit analysis and Monte-Carlo simulation	Energy savings: 1949 GJ with energy-saving investment; 895,000 USD depending on ERMs. Net present value (NPV) changed by 97% with the discount rate changing from 0–8%.
	Two hotels, Shanghai	Upgrade: Building envelope (insulating walls, roofs and windows; replacement of single glass windows to low-E ones); lighting systems (LEDs); domestic hot water system (with heat recovery and card operated) efficient cookers, HVAC upgrade (replacement of heat pumps, motors and exhaust fans), water-saving cooling towers and solar water heater.	Energy Plus Simulation tool and actual measurement tools	Energy savings: 26% and 38%, respectively, with energy user intensity (EUI) savings of 66.68 and 54.06 kWh/m2 respectively. Actual measurement was 10.4% more than simulated benefits.
06	Library building , Malaysia	green envelope variances are selected is determined, namely wall insulation, double glazed window, green roof	Building simulation using Autodesk Revit BIM software.	Green roof as green envelope reduced the energy consumption from 207,693 kWh to 77,738 kWh, a tremendous reduction of

	and application of sun-shading device	62.6% from the control. Next, double-glazed windows are applied, which recorded more than double the energy consumption of green roof at 163,368 kWh

A summary of the reviewed retrofit studies shows a mix of suitable retrofit technologies for each building type. The classification of these technologies is based on the general retrofit technologies defined presented in previous Table. The significance of each retrofit technology was computed from the normalized average impact of each retrofit technology on the building energy performance using collated data from the reviewed papers. a general description of sustainable retrofit in the context of carbon reduction is about making buildings more thermally efficient and sustainable. It principally concerns improving the insulation of the building envelope. Green retrofit measures can include, building envelope improvement, and window enhancement to minimize heat gains, efficient lighting and lighting technologies. [3]A significant amount of research has been conducted to develop and investigate various Green retrofit measures in order to improve the energy performance of existing buildings. The Green retrofit measures of buildings can be classified into the four categories: Building Envelope which include Improvement of fabric insulation level, Weather stripping windows and doors/ Increase air tightness and Use energy efficient window glazing. Passive technologies and energy efficient equipment which include Use of window shading to reduce solar heat gain in summer, Use of thermal storage materials (e.g., phase change materials) and Energy efficient equipment and appliances. Lighting Upgrade which includes: Use of high efficiency lamps and Use of time scheduled control Improvement of luminaries and installation of reflectors. Renewable Energy which includes: Install Solar PV/PVT systems, wind power systems, geothermal systems, biomass systems. This research has concluded that different types of sustainable retrofitting contribute positively by optimizing the energy consumption of the building thus improving the building energy efficiency.

Techniques Used in Retrofit Projects

In construction, the 3D Digital Mock up is a relatively recent technology and is therefore very rarely available for an already existing building. If it is absolutely needed, the first step of the work might be to create it. This "as-built" model is expected to accurately represent the building as it was constructed. It must be noted, however, that besides the necessity of acquiring licenses and skill in mastering complex 3D software, these reengineering solutions with very challenging management of increasingly heavy files and 3D point clouds processing is feasible only with major direct or indirect investments (workforce training, for example), and is difficult for companies with an average of 2.5 employees to consider. A recent 502 French Small and Medium Businesses (SMB) construction manager survey from the CSTB (2016) confirms this assumption. 90% admit they do not really know what BIM means. For 80%, the impediments to the development of a digital model in their enterprise are the cost, their lack of competence and the fact that they do not consider BIM to be a strategic priority. A large number of ongoing research programs are looking into the implementation of Building Information Modeling (BIM) platforms to optimize design and construction processes. [5] Nonetheless, the application of BIM to retrofit existing buildings faces challenges which could be due to the multi-disciplinary nature of information exchange, the timeliness of the exchange, and the wide array of technological components that are needed to ensure an optimal exchange.

Integration of Building Information Modeling

More than 2,500 publications containing the word BIM (or Building Information Modeling/Modeling) can be found in databases like Google Scholar (GS) and about 250 via Science Direct (SD). Adding renovation, refurbishment, rehabilitation or retrofit in the search keywords reduces the hit number to 42. [24] BIM is an innovative technology that uses several methods that can accurately measure energy efficiency in buildings. [37] BIM Technology has many tools for performance analysis (Insight 360, Autodesk Green Building Studio (GBS), and Design Builder. BIM technology can create a virtual environment similar to the actual work site environment which helps in the early stages of the project to identify and solve safety problems. [37]
BIM could be used as a strategy to facilitate the analysis of the energy performance of existing buildings; energy audits can be utilized for the refurbishment of existing buildings to identify the energy usage and the associated costs of retrofitting. [5] Several improvements are possible for BIM’s implementation in the life cycle of a construction project especially in the operation and maintenance stage. There is a need for mature BIM tools to help modelers deal with uncertainties more effectively. In particular, properties of time and money, source properties, and products properties should be programmed into BIM. Properties of time and money are related to the costs of material, idle times, and project overhead associated with every refurbishment option. Source properties clarify the energy consumption as well as the treatment and maintenance that each option requires. Integrating all three property types in BIM provides a solid decision platform for an energy-driven retrofit project. The decision should be based on a detailed cost-benefit analysis that includes environmental considerations (energy savings) as well as economic factors such as return on investment or payback period. [5]In recent years, much research has used BIM technology in various aspects of construction; for example, BIM technology can be applied to retrofitting buildings to minimize energy demand, identifying and assessing sustainable design parameters based on the tools provided by Building Information Modeling to improve sustainability in the building sector.[37]

In practice, however, it is hard to realize a mass retrofitting due to the complexity of the decision making process, the high number of stakeholders involved and the absence of sufficient information about the existing buildings stock. The use of Building Information Modeling (BIM) in conjunction with dynamic energy simulation can help overcome these challenges; As BIM "offers the best solution for data management and flow throughout a retrofit project from the survey to the building site". [35] The widespread use of BIM models in future would facilitate the having a more accurate representation of the buildings and can therefore accelerate their retrofitting rate. [35] Building Information Modeling (BIM) can offer a comprehensive and integrated platform for construction projects, as has been demonstrated in many large-scale projects, mostly in new buildings but sometimes also in retrofit projects. [36]

BIM's potentials in existing buildings embrace quality control of retrofit measures and services, retrofitting planning, operation and maintenance, energy analysis, cost calculation and life cycle assessment. [36]

Although capturing sufficient and accurate data can at the moment be time consuming, the technologies are developing fast and considerable improvements in automated capturing are expected in the near future and, in general, BIM applications will improve the predictability and reduce the time of construction in retrofit schemes (Rebekka et al., 2014).

BIM Strategy in Sustainable Building Retrofit Projects

BIM could be used as a strategy to facilitate the analysis of the energy performance of existing buildings; energy audits can be utilized for the refurbishment of existing buildings to identify the energy usage and the associated costs of retrofitting**.** [5]To expand the use of BIM technologies in energy-efficient building retrofit projects. The agenda is organized on technological, informational, and organizational needs. At energy modeling stages of refurbishment projects, the research may focus on the calibration of the baseline energy simulation model. For instance, there is a need to create systems in BIM platforms that calibrate the energy simulation using data from actual utility bills. Algorithms are needed to decide on the acceptable margin of difference between the actual results and the baseline models. [5]

As stated earlier, adopting BIM effectively in retrofit projects is a complex task and a proper framework is required for successful adoption. Generally, a BIM-based retrofit framework is categorized into four main sections including data acquisition, modeling, interoperability, and building energy analysis. [30]

Data acquisition: Existing building models must be precise in order for BIM to be used effectively and successfully for energy retrofit. This necessitates the use of various data collection strategies. These approaches can be automated, such as laser scans, which result in the automatic construction of the 3D model, or manual, such as a building audit followed by the creation of the BIM model.

Modeling: The principal applications of BIM models can be divided into two categories: 1) design of EEMs and 2) building specific data. A BIM model can be used to create EEMs and hence visualize the changes caused by the EEMs. Indirect

EEMs, such as envelope features, window shading, and glazing type, can be designed and developed in the BIM model, and the resulting architectural alterations can be presented to customers for approval utilizing BIM's powerful 3D visualization tools.
Interoperability: Following the creation of the geometry in Revit, there are three interoperability approaches that can connect a BIM model and an energy model. These options include using Autodesk's built-in Green Building Studio (GBS), installing external plug-ins from various software vendors, or exporting the building geometry from Autodesk Revit and using external software. Insight 360 is used effectively with BIM technology which is very useful to evaluate retrofitting alternatives and it enables designers and owners to the simulation of the energy efficiency of the building.[37] one of the most practical approaches to implement BIM in projects is defining an aim to collaborate in BIM process. It is not about the three-dimensional model, it is about communication with clients and end users, commissioning and all the information that clients can actually benefit from them.[35]
There are many unexpected events that may challenge the final result of a retrofit project, due to a large number of stakeholders involved, variety of tasks to be completed, timing and budget constraints. Hence, several researchers state that in order to efficiently implement BIM through the building life-cycle, a detailed planning must be performed. [34]

Conclusions

This paper provides a literature analysis on energy-efficiency strategies to consider when retrofitting existing buildings in a holistic manner, from the architect's perspective, taking into consideration their architectonic and structural qualities.
In conclusion, a multi-criteria decision analysis should be undertaken to analyze energy efficiency in building retrofits from a life cycle viewpoint, taking into account location and climate, operational energy, embodied energy, architectonic restrictions, control, and management. Because the architectural elements of a building are often the most demanding criteria, optimization techniques should be used from the design stage to determine which energy-efficiency measures should be implemented. BIM and other software simulation tools can be extremely useful in testing and measuring building design options and energy-efficiency solutions. On a technological level, additional investment should be made in more efficient ways to increase the energy performance of a building envelope and create new active solar energy generating systems, as they were the most commonly used in the various approaches studied. There may be some exciting opportunities in this field for producing unique construction features that combine architectonic integration with the high efficiency criteria of PV technology.

References

[01] Khairi, M. (2017). The application, benefits and challenges of retrofitting the existing buildings. (p. 9). Malaysia: IOP Conf. Series: Materials Science and Engineering.

[02]Morshed.Alam. (2016). Guidelines for Building Energy Efficiency Retrofitting. *Sustainability in Public Works Conference.* research gate.

[03] R. D. Juliardi, M. S. (2019). THE PROBLEMS IN RENOVATION AND RETROFITTING WORKS TO ACHIEVE GREEN BUILDING PERFORMANCE:. *international gradute conference of built inveronment and surveying.*

[04]Yuanda.Hong. (2019). Building Energy Retrofit Measures in Hot-Summer–Cold-Winter Climates: A Case Study in Shanghai. *energies*, 32.

[05]Maggie Khaddaja, I. S. (2016, December). Using BIM to Retrofit Existing Buildings. *International Conference on Sustainable Design, Engineering and Construction*.

[06]Ali.Arif. (2019). Green envelope as an architectural strategy for energy efficiency in a library building. *MATEC Web of Conferences*, 5.

[07]Marco.Caponigro. (2020). Developing a strategy for energy efficiency in the Egyptian building sector. *IOP Conf. Series: Earth and Environmental Science*, (p. 11).

[09]Shanshan.Bu. (2015, September). Literature review of green retrofit design for commercial buildings with BIM implication. *Smart and Sustainable Built Environment*.

[10] Fernandes, J. (2021). Introductory Review of Energy Efficiency in Buildings Retrofits. (p. 18). Portugal: MDPI.

[11]ZhenjunMa. (2012). Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings* (p. 14). Australia: Elsevier.

[12]UN Environment, a. I. (2018). *2018 Global Status Report.* Global Alliance for Buildings and Construction .

[14]Qiong.He. (2021). Identifying practical sustainable retrofit measures for existing high-rise residential buildings in various climate zones through an integrated energy-cost model. *Renewable and Sustainable Energy Reviews* (p. 21). China: Elsevier.

[17]Paula.FEMENÍAS. (2019). POTENTIALS AND CHALLENGES FOR SUSTAINABLE RETROFITTING OF NONDOMESTIC BUILDINGS: A UK PERSPECTIVE. (p. 9). UK: researchgate.

[19]MennaAllah.Gamal. (2018). Decision Making Approaches and Energy-Saving Retrofit Technologies for Existing Residential Buildings in Egypt. (p. 9). Egypt: Al-Azhar University Civil Engineering Research Magazine (CERM).

[21]Ahmed.Radwan. (2016). Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study:Hospital in Egypt. *Alexandria Engineering Journal* (p. 11). Egypt: Elsevier B.V.

[22]Bianca-Elena.Benzar. (2020). Determining retrofit technologies for building energy performance. (p. 18). South Korea: Journal of Asian Architecture and Building Engineering.

[24] Benzar, B.-E. (2020, Mar 14). Determining retrofit technologies for building energy performance. *Journal of Asian Architecture and Building Engineering*.

[24]L.Joblot. (2017, Mar 14). Literature review of Building Information Modeling (BIM) intended for the purpose of renovation projects. *IFAC (International Federation of Automatic Control)*.

[26]Shiyu.Wan. (2021). Sustainable Buildings' Energy-Efficient Retrofitting: A Study of Large Office Buildings in Beijing. *sustainability* (p. 24). China: MDPI.

[27]A.Hamada. (2021). Cost optimal energy retrofit strategies for public administrative buildings: A Cairo case study. *Journal of Physics: Conference Series* (p. 7). IOP Publishing.

[28]CheHusin. (2019). IMPLEMENTING SUSTAINABILITY IN EXISTING BUILDING THROUGH RETROFITTING MEASURES. *International Journal of Civil Engineering and Technology* (p. 23). Malaysia: Scopus Indexed.
[29]Zhansheng.Liu. (2021). Building Information Modeling Methods for Post-Earthquake Retrofitting Visualization of Buildings Using Augmented Reality. *applied sciences* (p. 19). China: MDPI.
[30]Wahhaj.Ahmed. (2020). BIM-based techno-economic assessment of energy retrofitting residential buildings in hot humid climate. (p. 14). Saudi Arabia: Elsevier.
[31]Hanan.S.Ibrahim. (2021). Towards Nearly-Zero Energy in Heritage Residential Buildings Retrofitting in Hot, Dry Climates. *Sustainability* (p. 36). MDPI.
[32]Khadidja.Rahmani. (2022). Development of a New Residential Energy Management Approach for Retrofit and Transition, Based on Hybrid Energy Sources. (p. 23). Algeria: MDPI.
[35]A.Khoja. (2019). Urban Retrofitting: A Progressive Framework to Model the Existing Building Stock. (p. 11). Germany: IOP Conference Series: Earth and Environmental Science.
[36]Elaheh.Gholami. (2015). EXPLOITING BIM IN ENERGY EFFICIENT DOMESTIC RETROFIT:EVALUATION OF BENEFITS AND BARRIERS. (p. 9). uk: .researchgate.
[37]H.Y.Khudhaire. (2021). Using Building Information Modeling to Retrofit Abandoned Construction Projects in Iraq to Achieve Low-energy. (p. 6). International Journal of Engineering.
[39]Haibo.Feng. (2019). BIM-based life cycle environmental performance assessment of single-family houses: Renovation and reconstruction strategies for aging building stock in British Columbia. *Journal of Cleaner Production* (p. 17). Canada: Elsevier.
[40]Mohsen.Aboulnaga. (2016). Retrofitting approach to improve energy performance and mitigate CO2 emissions in hot climates. (p. 8). Egypt: EDP Sciences.
[41]Rania.Ismail. (2019). AN INTENSIVE METHODOLOGY FOR DESIGNING NEAR ZERO ENERGY PUBLIC BUILDINGS IN EGYPT, OFFICE BUILDING AS A CASE STUDY. (p. 21). Egypt: Journal of Engineering Sciences Assiut University.
[42]M.Hamza. (2022). Exploring the potential of nearly zero energy retrofitting for generic office buildings in Cairo, Egypt. *The 8th International Conference on Energy and Environment Research* (p. 8). elsevier.
[43]Gehad.Abdelsalam. (2020). Effectiveness of High Energy Efficiency to Minimize Energy Consumption for Residential Buildings in Egypt. (p. 16). Engineering Research Journal .
[44]S.SAMEH. (2020). PROMOTING GREEN RETROFITTING TO ENHANCE ENERGY EFFICIENCY OF RESIDENTIAL BUILDINGS IN EGYPT. (p. 20). JOURNAL OF ENGINEERING AND APPLIED SCIENCE.
[45]Ingy.El-Darwish. (2017). Retrofitting strategy for building envelopes to achieve energy efficiency. *Alexandria Engineering Journal* (p. 11). Egypt: Elsevier B.V.
[46]Amr.ElGohary. (2019). The Challenge of Greening the Existing Residential Buildings in the Egyptian Market Base Case. *The Academic Research Community Publication* (p. 17). Egypt: IEREK press.
[50]Xinyi.Hu. (2020). Active–passive combined energy-efficient retrofit of rural residence with non-benchmarked construction: A case study in Shandong province, China. *Energy Reports* (p. 14). China: Elsevier Ltd.
Elaheh Gholami, A. K. (2015). EXPLOITING BIM IN ENERGY EFFICIENT DOMESTIC RETROFIT: EVALUATION OF BENEFITS AND BARRIERS. *researchgate*, (p. 9).
Joblot, L. (2017). Literature review of Building Information Modeling (BIM) intended for the purposeof renovation projects. *IFAC PapersOnLine* (p. 23). ScienceDirect.
Khoukhi, M. (2020). Retrofitting an Existing Office Building in the UAE Towards Achieving Low-Energy Building. *Sustainability*, March .

Moosa, H. M. (2018). Prevailing Value System Based Context, Adaptive Reuse. *Proceedings of Science and Technology*.

Morshed, A. (2016). Guidelines for Building Energy Efficiency Retrofitting. *Sustainability in Public Works Conference.* research gate.

R. Hammond, N. O. (2014). BIM in Sustainable Design: Strategies for Retrofitting/Renovation. *COMPUTING IN CIVIL AND BUILDING ENGINEERING ©ASCE*.

Traykova, M. (2014). SUSTAINABLE RETROFITTING OF EXISTING AND HISTORIC BUILDINGS. research gate.

Zhang, X. (2018, June). Sustainable Retrofitting of Existing Residential Buildings at Community scale in China. *Doctor of Philosophy*. Cardiff University.

Zou, P. X. (2017). Retrofitting public buildings for energy and water efficiency. research gate.