Smart and Sustainable Buildings for Climate Resilience: Integrating Renewable Energy Systems

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Abstract: The construction industry is responsible for a significant share of the world's energy use and emissions, which can be reduced by using renewable energy and smart-grid technologies. Other methods include the use of recycled materials, green roofs, and 3D printing methods to reduce waste. In this study, a questionnaire survey and interviews were conducted to elicit feedback from construction practitioners and experts on the sources of renewable energy and their use within the UAE construction industry. The results indicated a high level of awareness and familiarity with renewable energy. About 87% of the respondents indicated that solar energy is the most recognized form of renewable energy, followed by wind energy with 74%. The most significant advantage of incorporating renewable energy into buildings is the environmental sustainability and cost savings. However, high initial costs and design complexities are the most significant challenges to the widespread use of such technologies within construction.

Keywords: Climate Resilience; Energy Efficiency; Green Building Materials; Renewable Energy; Smart Buildings; Sustainable Construction.

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1 Introduction

The construction industry is under increasing pressure to reduce its environmental impact as a result of the impact of the changing climate. As an increasing number of people live in urban areas, the impact of construction and the buildings themselves has become of major interest in relation to sustainability. Overall, buildings are responsible for around 34% of global energy use and about 37% of CO2 emissions, [1]. These statistics help to highlight the importance of the reconsideration of many of the strategies that have historically guided the construction and building of structures, and to implement strategies that will help to reduce the release of CO2 into the atmosphere and otherwise promote the construction of sustainable construction sites. The strategies that are being considered for incorporation into construction sites include buildings that are energy efficient, use renewable energy sources, and are constructed in a way that can withstand the changes to the climate. Such technologies as smart buildings, sustainable and recycled construction materials, and systems incorporating renewable energy are all thought to be essential elements of both sustainable and low-carbon construction strategies. Each of these strategies presents potential cost savings, promotes healthy environments, and increases the resilience of such buildings against extreme weather conditions.

This article examines the role of renewable energy, smart grids, and sustainable construction in the building industry. The growth in the planet's population and the increase in the living standards of the people globally are contributing significantly to the increase in the demand for energy. The energy demand is growing at an average rate of 2.2% per annum, [2], [3]. The construction of buildings contributes to approximately 34% of the energy used by humankind, and around 37% of the CO2 emissions threaten the planet's environment, [1]. Thus, if the construction industry continues to grow at the same rate as the world population, the building of structures utilizing conventional construction methods will worsen the greenhouse gases released into the planet's atmosphere and create further environmental instability. Therefore, researching and implementing techniques for building structures that help to reduce the construction industry's threat to the planet's environmental problems is essential.

The International Energy Agency has proposed that the use of green and renewable energies should be deployed in the construction industry to achieve net-zero emissions by the year 2050, [4]. Many countries around the world have committed to utilizing the techniques required to achieve net-zero emissions by 2050. The construction industry, being one of the most energy-intensive industries, has been targeted with significant responsibility to reduce its use of energy and its carbon footprint. There is a lack of guidance and regulations regarding the use of sustainable techniques in the construction of buildings in many countries. However, in more developed countries such as the United States and Europe, there have been significant revisions to the construction regulations to encourage the construction of near-zero energy buildings, [5], [6]. Despite these efforts, there is still a lack of initiatives in other parts of the world to encourage the construction of zero-energy buildings. Furthermore, China has also committed to using 100% of its energy from renewable and sustainable sources by 2060, [7]. According to an article within the Wall Street Journal published on January 31, 2024, the United States is expected to deploy around 17% more renewable energy sources than it had during the previous year, reaching 42 gigawatts (GW) of deployed renewable energy and utilizing 100% of its electricity from such zero-carbon sources, [8]. Furthermore, through the use of provisions of the Inflation Reduction Act and the Infrastructure Investment and Jobs Act that were passed by the US government, the National Renewable Energy Laboratory (NREL) has projected that construction of between 44 GW and 93 GW of both wind and solar power will be constructed within the USA between 2023 and 2030:

Furthermore, the NREL has also projected that the United States will develop 850 GW of renewable energy sources for both solar, wind, and energy storage facilities by the year 2030, [9]. With the construction industry being the major contributor to the United States' energy demands, the construction industry must find a way to utilize renewable energy to construct energy-efficient buildings that use natural materials to minimize the construction's contribution to climate change and energy use, [10].

The use of natural materials in the construction of buildings has been proven to be a good source of renewable energy, as natural materials are green, environmentally friendly, and an alternative to the energy used from traditional energy sources in construction, [10], [11]. The use of renewable energy in construction becomes imminent if the construction of buildings can promote sustainability and reduce the environmental impacts of construction of buildings. As the planet continues to experience an increasing need to reduce the amount of carbon dioxide and other greenhouse gases that are released into the environment during the construction of buildings, the use of renewable energy is an essential part of the construction process, [12]. In building construction, the integration of renewable energy systems utilizes sources such as geothermal, biomass, wind, solar, plants, and water to reduce the need for traditional energy sources that contribute to climate change and the environmental sustainability of the constructed buildings, [13], [14]. With the increasing awareness of the benefits of utilizing renewable energy in the construction of buildings, the application of these energy sources in modern buildings has also gathered further momentum. For example, architects have designed buildings in such a way that they allow for the use of natural sunlight for the heating or ventilating of the buildings, [15], [16]. Furthermore, other engineers have also begun to use these sustainable energy sources for constructing buildings. For example, solar panels could be constructed on the buildings' rooftops to produce energy for the buildings, natural construction materials can be used to replace traditional building materials, and biomass boilers can be constructed as part of the buildings to provide hot water and heating systems for the buildings that contribute to energy efficiency for those buildings and the reduction of their carbon emissions. Despite the various benefits of using renewable energy in the construction of buildings, the application of these energies within buildings still depends on the type of energy that will be used for such a construction purpose.

As reported by [11], [12], the various forms of renewable energy (such as solar, geothermal, wind, hydro, and biomass energy) have the potential to meet the energy needs of buildings in a sustainable manner. Solar energy, in particular, is known for its environmentally friendly attributes and unlimited source of energy, which makes it one of the leading forms of renewable energy that is used around the world, [15]. For example, [16], have reported that the use of renewable energy systems within buildings reduces the environmental impact of those buildings. Additionally, another study published in [17], reports that the use of solar technology can lead to a 48%

reduction in the energy needs of buildings and can lead to the buildings' contribution of renewable energy to the power grid to reach 83%. Furthermore, biomass energy is considered to be the oldest form of carbon-neutral energy to be used by humankind, [18]. Studies have been performed regarding the potential of using biomass energy within buildings. For instance, [19], performed a study on the feasibility of utilizing biomass as the primary power source for residential buildings. Additionally, authors such as [12], [20], have reported that biomass energy is being utilized to heat buildings and to generate electricity within those structures. The efficiency of utilizing biomass energy can be improved by utilizing biomass as fuel for the creation of compressed wood pellets. Compressed wood pellets are created through the processing of biomass under high temperatures and pressures, [21]. Furthermore, biomass can also be utilized within a building as construction materials for building components, such as thermal insulation or the structural components of a building. The use of biomass in construction materials reduces the environmental effects of buildings by reducing their dependence upon fossil fuels to construct those buildings, [22], [23]. Geothermal energy systems are also utilized as one of the renewable energy forms that is applied to reduce the energy needs of buildings. Geothermal systems can be combined with other forms of renewable energy systems, such as solar energy systems, to increase the performance of the buildings' systems. Geothermal systems are known to reduce the cost to operate a building and reduce the emissions that are released by the structures. For instance, one study by [24], indicated that geothermal energy was significantly associated with the reduction in the energy, cost, and CO2 emissions associated with buildings, as compared to the use of conventional gas boilers to heat those structures. Wind energy is another form of renewable energy that is applied to buildings. Wind energy is often recognized as one of the most widely used forms of renewable energy within building projects, [25]. For instance, the study by [26], reported that wind energy can supply approximately 15% of the energy needs of buildings. Additionally, architects often design buildings to utilize natural ventilation methods to allow for air to circulate within the buildings using the natural power of wind. This eliminates the need for air conditioning systems for those buildings. Finally, the energy that can be generated from water resources can be used to provide low-cost electricity to those buildings, as well as to control floods, irrigate agricultural lands in those areas, and provide drinking water for human populations. Hydro energy systems provide low-cost electricity to buildings while maintaining their durability over time in comparison to other forms of energy, [27]. Finally, hybrid energy systems combine various forms of energy to reduce the cost of those energy systems, the emissions that are released by those systems, and to improve the capabilities, values, energy efficiency, or environmental performance of buildings in comparison to the case where individual renewable energy systems are applied to those structures.

In addition to the above natural sources of renewable energy that are already being used in buildings, it is also possible to generate energy by combining those natural energy sources with traditional electricity sources. Examples of such systems include the use of solar and wind energy, solar and hydrogen energy, wind and hydrogen energy, geothermal and hydrogen energy, and more. Energy from hydrogen energy systems can be used to heat houses, heat water for use in the homes, cook meals, and power electrical devices in those structures. Additionally, solar and hydrogen energy systems are the most efficient method of producing renewable energy. Furthermore, such systems are becoming increasingly common in residential, commercial, and industrial construction efforts as a means of reducing the energy expenses for those constructed buildings. The aims of this study are to:

1. Identify the different types of renewable energy sources that can be utilized in construction projects, their applications, and their contribution to sustainable construction practices.
2. Investigate the role of smart-grid technologies in constructing sustainable buildings.
3. Investigate the benefits of incorporating renewable energy systems throughout the life cycle of projects, including the use of natural materials that help to reduce the need for energy sources that contribute to the carbon footprint.
4. Investigate the awareness of construction practitioners of renewable energy systems.
5. Explore the benefits, limitations, and environmental considerations of each of the types of renewable energy that can be incorporated into construction projects.
6. Highlight relevant standards, guidelines, or regulations related to the adaptation of renewable energy systems in construction projects.

2 Methodology

This paper focuses on the main forms of renewable energy that can be incorporated into building projects to minimize their environmental impact. The types of renewable energy that can be used include solar, biomass, geothermal, wind, hydropower, and various forms of hybrid power systems (Figure 1). In order to understand how these types of renewable energy are used in construction projects, the paper reviews the use of renewable energy in construction in general, and within construction projects in particular. These reviews discuss the various forms of renewable energy that are utilized in construction projects, such as those relating to the development of sustainable buildings, the integration of smart-grid technologies, energy efficiency, and sustainable construction materials. Other topics that are covered in the review include the use of renewable energy for climate-resilient buildings, the advantages and disadvantages of each form of renewable energy, the environmental impact of each type of energy, and the regulations that relate to each type of renewable energy within the construction industry.

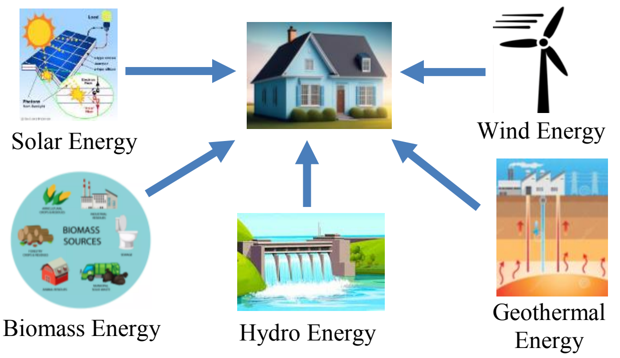

Figure 1: Renewable Energy Sources Used in Construction.

Source: created by the authors.

A questionnaire survey was conducted to gather the views of construction practitioners on their experiences and perceptions toward renewable energy sources and their use in the United Arab Emirates (UAE) construction sector. The survey was distributed to construction practitioners working in municipalities, contractors, and design firms across the UAE, and responses were collected accordingly. Interviews were also conducted with construction project managers, engineers, and others in the construction industry to obtain their insights into the advantages and challenges of the use of renewable energy in construction projects. The responses from the questionnaire survey and interviews were examined using both qualitative and quantitative methods to determine a general picture of the use of different types of renewable energy within the construction and construction industry, and their benefits and environmental effects.

In this analysis, renewable energy options currently applied in the UAE construction sector were ranked using a relative-importance index, based on their level of adoption and potential for use in building projects. The study further considers how renewable energy contributes to climate-resilient building design and highlights the advantages and challenges raised by practitioners, including expected environmental impacts and the effect on long-term sustainability. In addition, standards and regulations that guide the use of renewable energy in construction, and how these regulations align with the needs of the UAE construction industry.

3 Renewable Energy and the Construction Industry

The following subsections discuss the use of renewable energy systems within the construction industry to create a more sustainable and green construction. Within these subsections, discussions include the use of renewable energy to support the concept of sustainable buildings, including in reducing their environmental impacts, and how the construction of such green buildings contributes to the efficiency of the buildings in relation to energy. Substantive discussions also occur about the types of sustainable and low-carbon construction materials that can be utilized within the construction of green buildings, as well as the strategies for improving the buildings' ability to withstand climate-related stresses. Additionally, each of these subsections also reviews the benefits and challenges of using such technologies and their implications for the environment. Finally, an overview of the policies related to renewable energy, as well as its incorporation into construction projects.

3.1 The Role of Renewable Energy in Sustainable Buildings

The integration of renewable energy into the construction of buildings has been an essential component of climate-mitigation strategies of the nations around the world. Solar energy from photovoltaic panels can be harvested by buildings to help meet their own electrical requirements. Solar thermal units can provide low-carbon heating to buildings. While wind energy is typically generated from large rural installations, the use of vertical-axis turbines allows for the use of renewable energy within urban environments. Geothermal systems provide an alternative means of heating and cooling buildings by utilizing the stable temperatures beneath the Earth's surface.

Each of these technologies can help to reduce the dependence of buildings on fossil fuels. Furthermore, many buildings can be constructed with methods that maximize energy efficiency, use sustainable building materials, and are constructed as “net-zero” energy buildings, meaning that they can meet the energy demands of the buildings themselves, and often export any remaining power to the electrical grid. Smart-grid technologies allow buildings that utilize renewable energy technologies to further increase these benefits. Buildings that incorporate smart meters are able to adjust the way in which they use energy according to energy pricing schedules or the availability of renewable energy on the grid. Energy storage technologies, such as batteries, allow buildings to store any excess energy generated by their renewable energy technologies for later use, such as during periods of peak energy demands or extreme weather conditions that may impact the power supply from the grid. Furthermore, building management systems that use artificial intelligence are able to automatically adjust the lighting, heating, ventilation, and air conditioning (HVAC) systems of a building to provide comfort to the individuals within the building while minimizing the use of energy. Statistics on the number of efforts made by construction projects to incorporate each of these technologies are presented in Section 3.5.

3.2 Sustainable Building Construction Materials

Beyond the use of renewable energy in buildings, another aspect of sustainability relates to the materials used in the construction of these buildings. Many of the traditional building materials contain high carbon footprints due to the energy required to produce those materials. Traditional materials like bamboo, cork, rammed earth, and straw bales are biodegradable and require less energy to produce and leave less impact upon the environment overall. Additionally, the use of recycled building products contributes to these goals of sustainability, as well. Furthermore, the use of bio-based materials is another way to reduce the environmental impact of building construction. Finally, the development of methods that create less waste during construction, such as prefabrication techniques or 3D printing technologies, helps to reduce the environmental impacts of such construction, [27].

In addition to construction methods, another aspect of sustainability relates to the way that buildings are designed. For instance, buildings can be designed in a way that minimizes the amount of energy that is required to heat and cool the buildings through the use of green roofs. Also, buildings can be designed in a way that allows those buildings to remain functional despite extreme weather conditions. Such designs could include elevating the buildings away from the ground and using flood-resistant materials. Buildings located within areas that often experience hurricanes could be constructed with building techniques that can withstand such types of weather conditions.

3.3 Advantages, Challenges, and Environmental Impact of Using Renewable Energy in Construction

The use of renewable energy within construction presents various advantages to the construction and building industry. The use of such technologies inherently helps to reduce the environmental impact of construction activities and buildings. Construction companies can significantly reduce their costs with such implementations of renewable energy technologies. Furthermore, such technologies help to support the efforts of the country regarding sustainable construction and development practices.

The following subsections discuss the various benefits of incorporating renewable energy technologies into construction practices. Additionally, the challenges and environmental considerations that come with using such technologies are also discussed in these subsections.

3.3.1 Environmental sustainability

Due to the relation between greenhouse gases and the operation of buildings, it is important to incorporate renewable energy into these buildings. The use of a combination of these technologies will help to reduce the footprint of the buildings in relation to their emissions of carbon dioxide. Research into these technologies indicates that incorporating renewable energy into buildings can lead to a 30-70% reduction in the emissions of carbon dioxide from those buildings, [28]. Furthermore, technologies like biomass and geothermal systems are particularly effective in reducing the carbon footprint of buildings; they can help to replace common heating methods within buildings that rely upon fossil fuels.

3.3.2 Long-term cost savings

Despite the high costs of renewable energy systems, there are significant savings over the life of the building. A decline in solar technology costs of more than 80% over the last decade has made these systems more attractive to building owners, [28]. By reducing a building’s dependence on grid-supplied electricity, buildings will have lower costs each month for energy. Additionally, energy-efficient buildings have higher rental prices and resale values. Thus, there are benefits to using renewable energy systems in the construction of buildings.

3.3.3 Enhanced energy efficiency and performance

Beyond the significant long-term cost savings that can be generated through integrating renewable energy systems into commercial buildings are the positive effects that such integrations can have upon the energy efficiency of those buildings. For instance, buildings that implement solar thermal installation systems will reduce their dependency upon conventional methods of heating their water, while geothermal systems will allow for more efficient regulation of the temperature within the buildings. Additionally, buildings that incorporate wind turbines or even hybrid renewable energy systems will have some source of supplementary power to provide to the buildings as needed. Finally, the implementation of smart-grid and building management systems will allow for further improvements in the way that renewable energy systems are managed and their impacts on the energy efficiency of buildings. For instance, smart meters have proven to lead to around 15% improvements in the energy efficiency of buildings, [29].

3.3.4 Increased energy independence and resilience

The ability of renewable energy to be produced at the construction sites of buildings can reduce the reliance of those buildings upon the central power grid, especially during extreme weather conditions. The use of battery storage with these renewable energy systems will ensure that each building can still maintain its essential services in the case of the failure of the main power grid. Furthermore, the use of hybrid systems that utilize different forms of energy within each system, such as solar and wind energy systems, or solar energy and hydrogen systems, can provide additional security to the buildings. Such additional security is especially important within regions threatened by increased threats related to the climate, such as heatwaves, hurricanes, and flooding.

3.3.5 Social and health benefits

Given the numerous benefits of incorporating renewable energy into construction, the buildings that feature such systems offer healthier and more comfortable conditions within their structures. These properties include better ventilation systems, more daylight access, and better temperature control within the interiors. Additionally, these properties feature healthier indoor air for the occupants of these buildings. Finally, the growing emphasis on sustainable construction has created new forms of employment for those involved in the construction and certification of green buildings.

Despite the numerous benefits that renewable energy offers to the construction industry, there are also some obstacles to the widespread use of these technologies in buildings. High initial costs, technical limitations, the challenges associated with constructing buildings to incorporate these technologies, the regulatory issues, the shortage of labor, and the costs of maintaining these structures present some challenges to the development and construction of buildings with renewable energy systems. These challenges are discussed in more detail in subsections 3.3.6 to 3.3.9.

3.3.6 High initial cost

Another of the main obstacles to the incorporation of renewable energy systems into building construction projects is their high initial investment, which is required to install such systems. The installation of systems like solar panel arrays, geothermal systems, and biomass boilers requires specialized equipment and skills to install, and often requires additional work to be performed at the buildings to install such systems. Each of these systems can be 15-25% more expensive to install than conventional building systems and become even more expensive relative to conventional systems with the complexity of deep geothermal wells or battery storage systems, [30]. Finally, building owners and developers often encounter difficulties in the early stages of construction in that budgets are typically established for the project, and the decision of the investors to spend money on a construction project is typically based upon the short-term expenditures that will be required of the construction project and company, rather than the long-term cost savings that can be provided by the implementation of a system like a renewable energy system.

Despite the cost savings that can be provided to buildings by implementing such systems, the high initial cost of those systems can lead developers to be hesitant to implement those systems altogether. The uncertainty of variables like the cost of implementing such systems, the regulations that may apply to those systems, and the performance of those systems creates hesitations among those stakeholders regarding their implementation. Thus, such a high initial cost of implementing renewable energy systems into construction projects is one of the main factors that limit their widespread adoption in the construction industry, despite their environmental and economic benefits to the buildings that incorporate those systems.

3.3.7 Technological challenges, design complexities, and lack of skilled labor

Due to the differences in the technology requirements of most renewable energy systems relative to conventional building energy systems, there are challenges in integrating these systems into buildings. For instance, solar installations require a suitable amount of roof area for the installation of solar panels. Wind turbines require open spaces with suitable wind conditions for installation. Finally, geothermal systems require geological formations with suitable properties for the installation of geothermal energy systems. Furthermore, the challenges of fitting these systems into existing buildings or architectural designs can prove to be difficult.

Finding ways to incorporate renewable energy systems into buildings requires the coordination of architects, engineers, and renewable energy specialists, all of whom are adding to the complexity of the incorporation process. A shortage of individuals with the necessary skills and knowledge for the installation and maintenance of most renewable energy systems creates another challenge to the incorporation of these technologies into buildings. Errors in installation or failure to properly maintain such systems can lead to reduced performance and a decrease in the lifespan of components of those systems. Thus, the lack of available labour for the implementation and maintenance of such systems presents a challenge to their widespread adoption in the construction of buildings.

3.3.8 Regulatory barriers

Local regulations can also create a barrier to the adoption of renewable energy systems. Building codes, local regulations, and permitting processes all vary from region to region. Understanding and adopting such local regulations can eat into the resources and time necessary to complete a building project. Many forms of renewable technologies, such as wind turbines, geothermal wells, or solar systems, involve approvals that add to building construction costs and efforts. In some countries, local regulations regarding renewable energy sources actually limit the amount of energy that may be exported from the electrical grid, reducing the incentive to adopt such technologies within those countries. Such uncertainties regarding local regulations create hesitation regarding the use of these types of energy systems for buildings.

3.3.9 Operational and maintenance issues

While most forms of renewable energy require less routine attention than conventional technologies, they are far from completely maintenance-free. Technologies like biomass boilers or geothermal heat pumps all require various forms of maintenance to ensure that they remain functional. Even for those technologies that often require low maintenance efforts, issues can still arise relating to the performance of that technology if the panels are covered in dust, the turbines of wind turbines wear down over time, or biomass boilers have issues with their biomass feed mechanisms. Regular maintenance of such technologies will ensure that they remain efficient over time.

The challenges discussed within the sub-sections 3.3.6 to 3.3.9 must all be considered before the integration of renewable energy into building projects. Through interviewing professionals within the construction industry, it is clear that careful planning is required for such integrations. The various parties involved in constructing a building will have to work together to overcome these challenges. Furthermore, innovative approaches will need to be taken in constructing buildings to include such technologies. Despite the challenges to be overcome in the construction of buildings with smart and sustainable technologies, there are some benefits to their construction. The ability of buildings with these technologies to reduce their use of energy and to become power generators for the buildings will reduce the cost of those buildings' energy expenses. These cost savings will work to offset the higher cost of constructing the buildings. In addition to these cost savings, the rising demand for environmentally friendly buildings will continue to create higher values of buildings that use these technologies. Finally, the buildings that use these technologies will have various benefits in their operation and for their occupants. They will produce better air quality within the buildings, they will maintain more consistent indoor temperatures, and their occupants will have better access to natural daylight. Overall, each of these buildings will enjoy the long-term benefits of its constructed design elements.

3.4 Policies Supporting the Use of Renewable Energy in Buildings

Government regulations play an important role in encouraging sustainable construction. Building codes and policies require that renewable energy systems be included within buildings. Several countries have standards and policies that support renewable energy use in construction. Germany, for example, mandates that its Energy-Plus program requires new constructions to create more energy than they use.

The Green Mark scheme of Singapore promotes sustainable construction practices from construction to demolition. The Estidama program in the UAE encourages buildings to conserve water and energy, especially in arid environments, [31]. The European Union's Energy Performance of Buildings Directive (EPBD) requires all new constructions within the continent to have a nearly zero-energy performance standard, [32]. The United States uses the LEED (Leadership in Energy and Environmental Design) system to construct buildings that incorporate energy-efficient and renewable energy systems, [33]. Additionally, Canada's National Energy Code for Buildings (NECB) and Australia's National Construction Code (NCC) both promote the use of buildings that achieve a net-zero energy use standard over the long term. Several cities around the world have implemented these policies and regulations. Cities like Masdar City in the UAE, Songdo in South Korea, and Freiburg in Germany have become models for the use of sustainable construction practices and renewable energy systems to construct communities that efficiently utilize their resources and infrastructure.

3.5 Statistics Supporting Renewable Energy and Sustainable Construction

Table 1 (Appendix) presents the statistics on the use of renewable energy systems in construction from various global organizations, such as the IEA, the United Nations, the World Green Building Council, and also from the findings of other research articles on the topic. The table presents statistics regarding energy use, emissions contributions, efficiency, and the benefits of utilizing renewable energy systems within the construction of buildings. The table also brings to light the environmental impact of the construction sector and the importance of renewable means of improving building sustainability. The data shows that buildings are indeed major contributors to both energy use and CO_2 emissions, but renewables like solar PV systems, wind systems, geothermal, biomass, and smart grids deliver significant reductions in these concerns. Sustainable construction methods like 3D printing and low-carbon materials provide further support for waste and efficiency goals.

The research efforts given in Table 1 (Appendix) highlight that buildings contribute to a good percentage of the global CO_2 emissions and energy use. These efforts also highlight the benefits of using renewable energy and sustainable construction methods such as prefabrication and 3D printing. However, the main barrier is cost, but smart grids and distributed systems can improve efficiency, reduce power interruptions, and boost resilience.

4 Questionnaire Survey and Interviews with Construction Experts

A questionnaire survey is conducted to elicit feedback from construction practitioners regarding the various forms of renewable energy and their use in the UAE construction industry. The survey includes five main sections: 1) information regarding the demographics and experience of the participants, 2) information regarding the various forms of renewable energy that are recognized by construction professionals, 3) information regarding the implementation of the forms of renewable energy within the construction industry practices, 4) the benefits that they have observed from using renewable energy within their projects, and 5) the challenges and future of the use of renewable energy within the UAE construction industry. In addition to the questionnaire survey, semi-structured interviews are conducted with experts within the construction industry regarding their experience with implementing renewable energy technologies within construction industry practices. The interviews aim to explore previous experience, key challenges, and practical considerations associated with such implementation.

The questionnaire survey was distributed to 83 construction industry professionals from various emirates within the UAE. Responses were received from 62 of these professionals, giving the survey a response rate of 74.7%. The construction professionals represent a wide range of positions within the industry, including project managers, resident engineers, architects, designers, developers, site engineers, and academics.

5 Data Analysis and Results

Table 1 presents the affiliations of the individuals who completed the survey. The largest group represented was contracting firms at 37.1%. This answer is not surprising, as these individuals will have the most insight into how to incorporate these technologies into construction projects. Following them are municipal engineers at 30.6%. These individuals were able to provide insight into how the UAE municipalities oversee green buildings and the policies that are put into place for the construction industry. Their answers will provide insight into how the UAE's regulations support or do not support the use of renewable energy technologies in construction. From these answers, it will also be possible to adjust policies to improve the use of these technologies in construction projects.

Table 1: Affiliations and Diversity of Survey Participants.

Organization	Number of Responses	% of Responses
Contractors	23	37.1%
Municipalities	19	30.6%
Design Firms	10	16.1%
Academics	7	11.3%
Developers	3	4.9%

Source: created by the authors.

On the other hand, the percentage of respondents who were from design offices accounted for 16.1%. These individuals include architects, designers, and engineering consultants who incorporate renewable energy systems into construction designs during the building construction phase. They know the various design-related matters regarding the integration of these systems into construction projects. Furthermore, their response to the survey helps to shed light on the innovations in the design phase of constructing buildings with renewable energy system integrations. The remaining respondents included those from academic institutions (11.3%) and developers (4.9%). The academics contributed to the survey responses with information regarding current scientific trends related to the integration of renewable energy systems into construction projects. These representatives from the construction industry reflect a wide range of individuals from the construction sector within the UAE, providing a well-balanced overview of the associated challenges and opportunities for integrating such systems into construction projects. The majority of those who responded to the survey were from Abu Dhabi (29%) and Dubai (27.4%). Sharjah contributed to around 14.5% of responses from the UAE construction sector, while Ras Al-Khaimah saw only 4.8% of total responses.

The abundance of respondents from Abu Dhabi and Dubai reflects the role that these Emirates play as major construction hubs within the UAE. These cities have a large number of construction developments that are occurring within the nation. However, the construction of Sharjah indicates its growing involvement with the construction sector and the related sustainability of construction developments in the area. No responses were received from Umm Al-Quwain Emirate, which may be due to the limited scale of construction activities there or lower engagement in renewable energy–related efforts. Participants also varied in terms of educational background. Around 79% of the participants hold a bachelor's degree, while about 13% have a master's degree. Four participants hold a doctorate, and one participant has a diploma. In terms of professional experience, the largest group (40.3%) had more than ten years of construction experience, followed by those with five to ten years of experience (37%). The remaining 22.7% had fewer than five years of experience. When asked about the types of projects upon which they typically work, the majority of respondents indicated that their area of focus is r

esidential projects (40.3%), followed by commercial projects (22.6%). The next most popular type of project within this group of construction professionals is infrastructure projects (17.7%), followed by industrial projects (14.5%). Finally, the least common project type within this group is road and highway projects at 4.9%. The second section of the survey posed questions regarding feedback about the level of familiarity with renewable energy technologies.

Approximately 46.8% of the participants indicated that they are very familiar with these types of technologies, while 33.9% of the participants indicated that they are only somewhat familiar with renewable energy technologies. Around 11.3% of the participants are neutral, and only 8% indicated that they are not familiar with these technologies. Participants were also asked to provide feedback on which sources of renewable energy they are aware of. The majority of the survey participants (54) indicated that they are aware of the "solar" source of renewable energy, while 46 participants indicated that they are aware of the "wind" renewable energy source. A summary of the survey responses for this question is given in Figure 2.

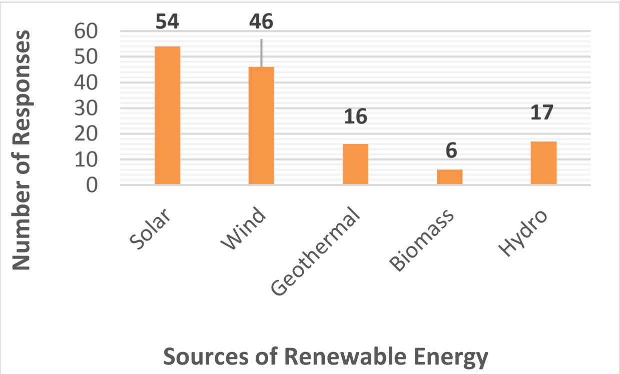

Figure 2: Awareness of Participants on the Various Sources of Renewable Energy.

Source: created by the authors.

When asked about the importance of using renewable energy technologies in construction projects, around 46.8% of the participants believe that it is very important, while 40.3% believe that it is important. Around 6.5% were neutral, while 4.8% believe that the use of renewable energy technologies in construction projects is slightly important. Only 1.6% of the participants believe that it is not important. Section 3 of the survey requested participants to provide information about their involvement and implementation of renewable energy in construction projects. Around 53% of the participants were involved in construction projects utilizing renewable energy technologies. Those who indicated that they had utilized renewable energy within some of their construction projects were asked the type of renewable energy used. They were also requested to select all renewable energy technologies that apply. In response to this question, 29 participants indicated that they have used “solar panels” in some of their projects, while 11 indicated that they have used “wind turbines” technology. Only 5 participants used “hydroelectric energy”, and 4 participants used other types of renewable energy. Figure 3 depicts the various forms of renewable energy technologies that are used in construction projects according to the responses provided by the project managers.

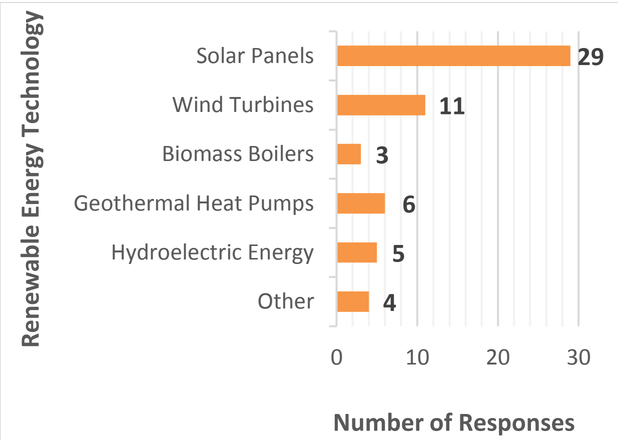

Figure 3: Renewable Energy Systems Used in UAE Construction Projects.
Source: created by the authors.

The results illustrate that there is an increasing acceptance of incorporating renewable energy into construction projects. Furthermore, many of the construction managers are aware of the importance of technologies such as solar technologies, which are prevalent in the UAE’s construction site projects. However, there is a lack of interest in technologies like hydroelectric systems due to the geographical features of the UAE. While the importance of incorporating renewable energy elements into construction projects is evident in comparison with the number of such projects employing these technologies, this indicates potential challenges to wider use. It is essential for those within the construction industry to recognize such challenges and encourage the use of these technologies within construction projects of the future.

Section 4 of the survey requested that the participants provide their feedback regarding the advantages and benefits of the use of renewable energy within the construction of building projects. The question asked the participants to note which advantages (if any) applied to the construction of buildings with the use of such renewable energy and the importance of each such advantage. Of the total number of participants who responded to the questionnaire, 53 participants (85.5%) indicated that one of the important advantages regarding the use of renewable energy in the construction of buildings is its environmental sustainability. Additionally, 43 participants (69.4%) indicated that the use of renewable energy results in cost savings for the construction of those buildings. One participant indicated that the use of renewable energy in the construction of buildings is a waste of money. The responses to this question are provided in Table 2.

Table 2: Advantages of Using Renewable Energy Technologies in Construction Projects.

Advantages of Using Renewable Energy in Construction	% of Responses
Environmental sustainability	85.5%
Cost savings	69.4%
Energy efficiency	62.9%
Alignment with the UAE’s strategic goals for green buildings	45.2%
Improved building performance	
Waste of money	30.6%
	1.6%

Source: created by the authors.

Section 5 of the survey asked the participants to indicate the challenges that exist in the implementation of renewable energy in construction projects, and they were specifically asked to select all the challenges that they believe exist. The responses indicated that 41 of the 61 respondents (66.1%) believe that the main barrier to the implementation of renewable energy technology in construction is its high initial costs. Additionally, 26 of the 61 participants (41.9%) believe that the main challenge to the implementation of these technologies is the complexities associated with their design. Furthermore, 23 of the 61 participants (37.1%)

believe that the reason renewable energy is not commonly used in construction is due to technological limitations of those technologies. Additionally, 21 of the 61 participants (33.9%) believed that regulatory difficulties are one of the main challenges to the use of renewable energy in construction. These results are presented in Table 3.

Table 3. Challenges in Implementing Renewable Energy Technologies in Construction Projects.

Challenges in Implementing Renewable Energy in Construction	% of Responses
High initial cost	66.1%
Design complexities	41.9%
Technological limitations	37.1%
Regulatory difficulties	33.9%
Lack of skilled workforce	27.4%
Maintenance and operational issues	30.6%
Material supply	3.2%

Source: created by the authors.

Feedback from the survey and interview responses provided several suggestions regarding how the challenges related to the use of renewable energy in construction projects can be addressed. One of the suggestions from the interview responses was the implementation of incentives to encourage the use of renewable technologies within construction projects, as well as the implementation of regulations regarding their use. Additionally, many respondents noted that providing training to construction industry professionals regarding the use of renewable technologies would help to reduce the skills gap within the industry. Other suggestions included the development of improved collaboration among various groups involved in construction projects, which would allow for construction managers and others involved in building projects to make better decisions regarding the use of those renewable technologies. Additionally, many participants suggested the need to invest in research and development regarding the use of renewable energy technologies and their applications in construction projects. Finally, many individuals also noted the importance of implementing smart grid systems in construction project management, which is likely to become increasingly important to the construction industry in the near future.

4 Concluding Remarks

These days, with such an increase in the impact of the effects of climate change, it is again important to consider the use of renewable energy systems, smart grid technologies, and sustainable materials in city construction. The survey of construction practitioners and interviews with experts working on construction projects helped identify both the technologies used in these projects and the difficulties encountered during construction. The results of such a survey reveal a high level of awareness of renewable energy technologies among those participating in construction. The majority of participants were familiar with different types of renewable energy systems. Solar energy was the most recognized (87%), followed by wind energy (74%). Around 53% of those responding have experience working on construction projects that make use of such renewable energy technologies, the most common being solar panels and wind turbines. The most common reasons for integrating such technologies relate to both environmental benefits (named by 86% of respondents) and cost savings potential (also named by the majority of respondents). Issues contributing to the lack of increased use of such technologies include cost, design and technological aspects, regulatory issues, maintenance issues, and labor shortages. An area of importance for both survey respondents and interviewees included smart grid technologies, which were cited as having beneficial features like increasing the efficiency of the construction projects. Suggestions for encouraging the increased use of renewable energy technologies in construction projects included incentives, regulations, coordination between participants in construction projects, and providing training to develop a skilled workforce. Additionally, many individuals suggested the performance of research and development efforts to create cost-effective technologies that suit the conditions of the region in which the construction projects are to be built.

Through this research, it becomes evident that the integration of renewable energy systems, smart grids, and sustainable construction materials is essential for the construction of cities that meet the net-zero objectives for energy use and sustainability in construction. The viewpoints presented by those working in the construction industry provide valuable insight into methods of addressing the challenges that face the construction of sustainable cities. Future studies can build upon this information to propose additional strategies for increasing the use of renewable energy within construction and to support the sustainability of the construction of cities. Also, collaboration among the different construction stakeholders will be critical to translating these strategies into practical solutions.

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Contribution:
Essam Zaneldin contributed to the conception and design of the study, design of the questionnaire survey, data interpretation and analysis, drafting of the manuscript, and supervision. Ziad Ismail, Mohamed Salloumi, Obaid Alshamsi, and Rashed Mohammed contributed to the literature review, data collection, and data analysis. Waleed Ahmed contributed to data interpretation and critical revision of the manuscript. All authors reviewed and approved the final version of the manuscript.

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The authors declare that they have no conflicts of interest relevant to this article.

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Appendix

Table 1: Statistics Supporting Renewable Energy and Sustainable Construction.

Topic	Statistic	Source/Reference
Global building energy demand	Buildings account for 37% of global CO_2 emissions and 34% of energy use	UN Environment Programme (UNEP) Global Status Report, 2024, [1].
Population & construction demand	Urban population projected to increase by 2.5 billion people by 2050, intensifying demand for sustainable buildings	United Nations Department of Economic and Social Affairs (United Nations DESA), 2018, [34].
Solar PV cost reduction	Solar photovoltaic costs decreased by 82% between 2010–2023	IRENA Renewable Power Generation Costs Report, 2023, [30].
Solar impact on buildings	Building-integrated PV (BIPV) can reduce electricity consumption by 20–60%	Renewable Energy, 2020, [17].
Wind contribution	Small urban wind turbines generate 1000–5,000 kWh/year, covering up to 15% of building energy needs	Wind Engineering and Industrial Aerodynamics, 2023, [26]; Buildings, 2025, [35]
Geothermal performance	Ground-source heat pumps operate at 300–600% higher efficiency than resistance heating and reduce energy use by up to 70%	Energy, 2022, [24]
Biomass benefits	Biomass systems can reduce CO_2 emissions by up to 90% vs. fossil systems	Fuel, 2022, [18]
Prefabrication & 3D printing	Prefabrication reduces construction waste by up to 52% and project duration by 20–30%; 3D printing reduces material use by 30–60%	IJMS, 2023, [27]; Heliyon, 2024, [36].
Smart grids – peak reduction	Smart grids reduce peak demand by 15–20%	U.S. DOE Smart Grid Report, 2016, [37]
Smart meters & automation	Real-time monitoring and smart meters improve building energy efficiency by 8–18%.	ACEEE Report, 2017, [38]
Outage reduction	Automated smart-grid fault detection reduces outages by 10–30%	Power and Energy Systems, 2022, [39]
Concrete emissions	Cement manufacturing accounts for 7% of global CO_2 emissions	GCCA, Cement and Concrete Industry Net Zero Action and Progress Report, 2025, [40]
Steel emissions	Global steel production contributes 8% of global emissions	IEA, Iron and Steel Technology Roadmap, 2020, [41]
Bamboo sustainability	Bamboo sequesters 200–400% more CO_2 than timber and has compressive strength of 40–80 MPa	Science of the Total Environment, 2022, [42]
Renewable system costs	Renewable energy integration adds 15–25% higher initial costs compared with conventional systems	UN Environment Programme (UNEP) Global Status Report, 2024, [1]
Smart grid resilience	Distributed renewable–smart-grid systems improve climate resilience by 20–40% during outages	NREL Grid Modernization Studies, 2021, [43]

Source: The sources for the information presented in the table are provided in the last column.