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Review

Decarbonization Strategies in the UAE Built Environment: An Evidence-Based Analysis Using COP26 and COP27 Recommendations

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Abstract: The urgency of addressing climate change is increasingly evident through the rise in devastating natural disasters and significant shifts in global temperatures. With the urbanization of rural landscapes to accommodate population growth, the built environment has emerged as a major contributor to climate change, accounting for approximately 40% of natural resource consumption and carbon emissions. In pursuit of tackling climate challenges, countries have united under the United Nations Framework Convention on Climate Change (UNFCCC) to develop strategies for climate action and adaptation, through the Conference of the Parties (COP). The UAE has been an active member of the COP and has been at the forefront of implementing decarbonization strategies. This paper aims to provide a comprehensive analysis of the decarbonization recommendations presented during COP26 and COP27, specifically focusing on the built environment sector. The primary objective is to highlight how recommendations were effectively incorporated into the UAE's built environment sector, employing a case study approach further highlighting the specific implementation strategies adopted in the G+2 SEE Institute building while demonstrating how COP26, COP27, and the UAE's National Climate Change Plan 2017–2050 recommendations were translated into practical measures. The study places particular emphasis on the areas of energy, water and waste management, investigating how these strategies were integrated to promote decarbonization efforts. By examining the G+2 SEE Institute building case, this research attempts to provide valuable insights on aligning built environment practices with climate change mitigation objectives. The planning of the building structure employed a systems thinking approach, while assessments were conducted to identify materials and designs that would enable the building to achieve net-zero status. Real-time data analysis was employed for comprehensive analysis. The findings of this study will contribute to the body of knowledge on sustainable construction practices and serve as a guide for stakeholders, including developers, policymakers, and practitioners, in adopting effective strategies in reducing carbon emissions and fostering environmental sustainability in line with the Paris Agreement.

Keywords: decarbonization; COP26; COP27; UAE Climate Change Plan; built environment; embodied; operational carbon

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1. Introduction

Over centuries, environmental issues have crippled the planet due to global warming, climate crisis, and the depletion of resources. As per the United Nations, climate change refers to long-term shifts in temperatures and weather patterns. The increase in greenhouse gas (GHG) emissions, primarily caused by human activities and excessive utilization of natural resources, has driven this transformation, particularly since the 1800s [1]. According to [2], carbon emissions have been causing a definite and continued increase in global temperatures. The evidence is that the world has already seen four major disasters in Turkey, Syria, Sao Paulo, New Zealand, and the United States in 2023. According to the Centre for Research on the Epidemiology of Disasters (CRED), the world encountered

187 cases of natural disasters in 79 countries in 2022, mainly related to climate issues. The number of people affected by natural disasters was 50 million, in terms of economic losses, total damage exceeding 40 billion dollars has been estimated while the most affected countries were Asian countries such as India, Pakistan, Bangladesh, and the Philippines [3]. Such events highlight the aftermath of human behavior on the planet and if the world continues to be ignorant, then the future generation will face more challenges.

The built environment is a broad sector covering physical buildings and infrastructure-related industries such as the construction sector. It is basically a surrounding created by humans offering several settings to make human life comfortable, however, how they are built has an influence on both humans and the environment [4]. Apart from being a necessity, humans also expect to have their built environment to be aesthetically pleasing as well as convenient, which means there is a need for a well-developed infrastructure and good roads, leading to higher carbon emissions if not developed in a sustainable manner. For example, buildings are responsible for at least 40% of energy use in most countries due to the natural resources utilized during the construction of the infrastructure, schools, homes, and office buildings. The built environment in total contributes to around 40% of GHG emissions and this has been a major concern [5,6]. Therefore, carbon mitigation or decarbonization has become an urgent issue that needs to be solved and is permeating into all fields, for example, politics, economy, lifestyle, ecology, and others [7].

The Paris Climate Agreement signed in 2015 has urged governments to implement urgent strategies that will reduce the amount of carbon being released into the atmosphere to avoid the devastating consequences of global warming. It has been outlined by multiple parties, including scientists, the Intergovernmental Panel on Climate Change (IPCC), and other global governing bodies, that in order to combat the severe consequences of climate change, society must maintain a 1.5-degree warming limit similar to pre-industrial levels. This means that the world must mitigate these changes by taking strict action, now. For these actions to be successful and impactful, GHG emissions will need to be cut in half by 2030 and carbon dioxide emissions will need to reach net zero by around 2050, which is an enormous but achievable challenge [8]. Therefore, the objective of this paper is to highlight the decarbonization recommendations presented during COP26 and COP27 meetings and to emphasize solutions incorporated into the UAE built environment sector using a case study approach. The research further highlights how the project team of the G+2 SEE Institute building utilized the COP26 and COP27 recommendations and the UAE's National Climate Change Plan 2017–2050 to implement specific decarbonization strategies through energy, water, and waste management of the building.

2. Literature Review

2.1. The Climate Agreement

Climate change is one of the biggest ecological and social challenges humankind is facing during the twenty-first century. Anthropogenic activity such as industrial practices and urbanization have significantly contributed to climate change through greenhouse gas (GHG) emissions. The consequences include extreme weather, forest fires, melting polar ice caps, and increased seismic and volcanic activity [1]. The urgency of addressing global warming is evident, emphasizing the international responsibility to take action.

The United Nations Framework Convention on Climate Change (UNFCCC), established in 1994, aims to stabilize greenhouse gas (GHG) emissions and prevent "dangerous anthropogenic interference with the climate system" [9,10]. Notably, the Kyoto Protocol, adopted in 1997, set binding emission reduction targets for developed countries. The Paris Agreement, adopted in 2015, established a more inclusive framework, with commitments from both developed and developing nations to limit global warming to well below 2 °C and 1.5 °C [11].

The Conference of the Parties (COP), held annually (except in 2020 due to the COVID-19 pandemic), brings together countries to assess progress and advance climate action and push toward decarbonization. COP26, held in 2021, prioritized the role of the built environment in decarbonization, focusing on areas such as clean energy, sustainable transportation, and resilient infrastructure. COP27, held in 2022, continued efforts to strengthen climate commitments and emphasized international collaboration, technology, and financing for effective climate solutions. These recent COP meetings emphasize the recognition that the built environment plays a significant role in implementing decarbonization strategies to achieve the targets set by the Paris Agreement.

2.2. COP26 to COP27: What Have We Achieved?

COP26 was originally scheduled for 2020 in Glasgow but was moved to 2021 due to the COVID-19 pandemic and was a highly significant conference. It featured the release of a report from the Intergovernmental Panel on Climate Change (IPCC), which signaled the rapidly impending dangers of global warming [12]. The report revealed that projected temperature increases are more severe than previously believed, exceeding the 1.5 °C safety threshold. It demonstrated how the current global warming trends contribute to rainfall pattern shifts, glacier melting, and extreme weather events. While carbon emissions briefly reduced during the pandemic due to lockdown measures, they rebounded sharply by the third quarter of 2021 [13]. The main objective of COP26 was to solidify countries' commitments to significant GHG emissions reductions by 2030. The conference also focused on discussing adaptation measures to address the changing climate and increasing funding for climate-related actions, with a particular emphasis on supporting less developed nations.

The outcome of the COP26 gathering was disappointing, as significant advancements were lacking. The failure of wealthy nations, who bear the primary responsibility for the high emissions, to take decisive climate action posed a major obstacle. This setback made it even more challenging to achieve the target of limiting global warming to 1.5 °C by 2030. Additionally, funding provisions for less developed countries affected by climate impacts received insufficient attention [14,15]. Though there was a multitude of discussions and recommendations during COP26, their details are beyond the scope of this paper.

Experts believed that COP26 was significant for the built environment due to dedicated discussions on its role in achieving net-zero targets [16]. Important announcements during COP26 emphasized the crucial role of the built environment in reducing carbon emissions by 2030 and limiting global warming to 1.5 °C. According to the World Green Building Council, 26 climate action initiatives in cities, regions and built environments urged governments to take concrete actions and design pathways for change through appropriate regulatory frameworks and access to finance. Cross-sectoral collaborations were considered accelerators for transforming towards net-zero targets and creating a resilient built environment. Remarkable elements included $1.2 trillion in real estate assets under management participating in the Race to Zero. Similarly, 1049 cities representing 722 million people joined Race to Zero, indicating the potential for collective action to reduce 1.4 gigatons of global emissions by 2030 [17].

The UN Framework Convention on Climate Change COP27 built upon the outcomes of COP26 to take action on critical issues in addressing the climate emergency. Held in Sherm-El-Sheikh, Egypt, between 7 and 18 November 2022, emphasizing the need for industrialized nations to lead by example and take bold and immediate actions. Key discussions revolved around nature, food, water, decarbonization, and climate adaptation [18]. Member countries were urged to urgently reduce GHG emissions, build resilience, and adapt to the inevitable impacts of climate change while fulfilling their commitments to finance climate action in developing countries. It was reiterated that eliminating carbon emissions from various sectors, including electricity generation, transportation, industry, and agriculture, by 2050 is crucial to avoid disastrous climate impacts.

Numerous initiatives and commitments were announced during COP27, including the development of decarbonization and resilience roadmaps at national and sub-national levels to address energy performance and lifecycle emissions for new and existing buildings. A significant discussion focused on integrating whole-life carbon considerations into decarbonization strategies and decision-making processes. The Race to Zero commitment, introduced at COP26, saw a substantial increase in the number of construction companies committed to halving emissions by 2030, across all scopes [19]. This highlighted the importance of the built environment sector in actively reducing emissions through proactive measures.

Although operational emissions from the built environment showed a 5% increase compared to 2020 levels, showcasing a concerning trend deviating from the Paris Agreement objectives, actions and initiatives announced at COP27 indicate the sector's readiness and capability to scale up with climate-based solutions [19]. Table 1 below highlights some of the recommendations provided regarding the built environment during COP26 and COP27.

Table 1. Recommendations provided during COP26 and COP27 regarding the built environment.

Main Areas	Recommendations—COP26	Recommendations—COP27
Net-Zero Buildings	Governments and stakeholders were urged to commit to achieving net-zero carbon emissions in the construction and operation of buildings. This involved adopting energy-efficient building designs, integrating renewable energy sources, and implementing sustainable construction practices using both active and passive designs.	The event highlighted the importance of moving towards a net-zero, resilient, and circular built environment to achieve climate targets and protect the communities vulnerable to the effects of climate change. To achieve this, multi-level action and public–private partnerships in cities to unlock the urgent challenge of transformation and adaptation that are needed at pace and at scale were initiated.
	The adoption and implementation of green building standards and codes were recommended to ensure that new buildings meet high energy efficiency and sustainability criteria. This includes promoting energy-efficient materials, efficient heating, ventilation, and air conditioning (HVAC) systems, and sustainable water management practices.	Under the Breakthrough Agenda first launched at COP26, countries representing more than 70% of global GDP, with the support of multi-stakeholder partners, produced a package of 25 new collaborative actions to be delivered by COP28 to speed up decarbonization under five key breakthroughs: power, road transport, steel, hydrogen, and agriculture, with the building and cement sectors to be added to the Breakthrough Agenda next year.
	Governments and urban planners were advised to prioritize compact and sustainable urban development, promoting mixed land-use patterns, access to green spaces, and efficient public transportation systems. This helps reduce energy consumption, enhance resilience to climate impacts, and create livable and sustainable cities.	The event highlighted the importance of robust risk assessments and evidence-based climate risk assessments for integrating resilience-building actions into urban planning. It emphasized the need for clear resilience priorities, collaboration with non-Party stakeholders, and the incorporation of nature-based solutions. Success stories on climate-proofing existing plans and private sector engagement were shared, along with the need for innovative funding mechanisms to support adaptation and resilience-building activities.

Table 1. *Cont.*

Main Areas	Recommendations—COP26	Recommendations—COP27
Renewable Energy	Promoting the use of sustainable and low-carbon materials in construction, considering their lifecycle environmental impacts. Integrating green infrastructure elements, such as green roofs, vertical gardens, and rain water harvesting systems, into building designs to enhance biodiversity, improve air quality, and manage stromwater.	Launched by LeadIt and the Global Cement and Concrete Association (GGCA), the Green Cement Technology Tracker was published in order to ensure more transparency and accountability. The aim is to transparently track public announcements of low-carbon investments in the cement industry.
	Encouraging the construction of net-zero energy buildings that produce as much renewable energy as they consume, thereby reducing carbon emissions. Further, the members were encouraged to promote energy-efficient building designs and technologies to minimize energy consumption and reduce greenhouse gas emissions.	The Planning for Climate Commission was launched, a new global initiative focused on speeding up planning and approvals for the massive deployment of renewables and green hydrogen needed to address climate change and energy security. Organizations representing wind, solar, hydropower, green hydrogen, long-duration energy storage, and geothermal energy industries joined forces in an unprecedented alliance to launch the Global Renewables Alliance. It brings together, for the first time, all the technologies required for the energy transition in order to ensure an accelerated energy transition.
Circular Economy Principles	The adoption of circular economy principles in the built environment was emphasized, which involves reducing waste, reusing materials, and promoting recycling and sustainable construction practices.	There was a focus on addressing the circular economy for waste issues inclusively as well as on scaling up finance. Landfills and waste burning are not sustainable practices. Instead, there is a growing demand for a new green economy that is net-positive, focusing on rethinking decisions at all levels to transform waste into income and contribute to climate action, health, and the attainment of Sustainable Development Goals (SDGs).

Source: Summary of Global Climate Action at COP27; Alayza, N.; Bhandari, P.; Burns, D.; Cogswell, N.; Kiyomi de Zoysa; Finch, M.; Fransen, T.; Maria Lemos González; Krishnan, N.; Langer, P.; et al. COP27: Key Takeaways and What's Next, available online: https://www.wri.org/insights/cop27-key-outcomes-un-climate-talks-sharm-el-sheikh (accessed on 8 July 2023) [20].

2.3. The Built Environment and Climate Change

The built environment refers to the human-created surroundings that provide the backdrop for human activity. It encompasses buildings and parks or green spaces and communities and cities, often accompanied by supporting infrastructure, such as water supply, energy networks and leisure activities [21]. The built environment has an influence on both human and environmental health, and therefore, it is crucial to develop a built environment that is safe and provides longevity to both. However, the buildings and the infrastructure humans are surrounded with consume limitless levels of natural resources during all the phases which negatively impacts the environment. The major contributors to these emissions are the materials used during the construction of the infrastructure as well as the heating, cooling, and lighting of buildings. Therefore, over the years the world has been facing increased temperatures, adverse climatic conditions, and various other adversities [21]. Ongoing anthropogenic climate change is mainly triggered by the increased levels of greenhouse gases (GHG), especially carbon dioxide (CO_2) in the environment. According to [22], the responsibility is shared by multi-stakeholders such as developers, architects and engineers, material suppliers, building managers, and operation and maintenance personnel in the case of the built environment sector. Therefore, there was a major discussion during COP26 and 27 that the stakeholders should take responsibility for reducing their carbon emissions during the construction and the operational phase as well as looking at waste management strategies throughout and at the end of the life of the building [8].

The world requires cost-effective building solutions that support the drive for decarbonization throughout the construction industry's entire value chain. According to a report by Deloitte, actions should be taken to lower the carbon intensity of building materials by implementing climate-smart, low, and clean energy consumption during the construction phase. Similar solutions should also be implemented to reduce the operational carbon of real estate and infrastructure development as well as the circularity of the building [23].

Key decisions regarding low-carbon building materials will remain significantly important. However, building design is another crucial element for reducing operational carbon. Bioclimatic building design is an excellent example of building architecture that is often used in the design of new buildings. Several bioclimatic (passive) design measures, such as building shape, orientation, and window distribution, can effectively reduce a building's energy use at little or no additional cost [24,25]. Researchers have compared traditional and modern designs and concluded that traditional passive designs hold superiority in improving thermal conditions both indoors and outdoors. Passive design can enhance internal thermal conditions by reducing indoor temperatures with minimal maintenance, and it can be implemented using locally accessible resources. These solutions contribute to climate-responsive strategies for regulating indoor thermal conditions while reducing energy consumption and GHG emissions [26,27].

Buildings consume a significant amount of energy, and energy consumption in buildings has been rising in recent decades. Therefore, energy-conserving measures (ECM) are needed for achieving green building development and urban sustainability [28]. Several research studies have identified building insulation, equipment systems, conserving behavior, control and management systems, and renewable energy sources as effective in enhancing the active design parameters of buildings based on local climate features [29]. Considering that climate characteristics and the need for climate-responsive buildings differ across regions, it is reasonable to assert that energy-efficient design strategies should take into account the specific meteorological and climatic conditions of each region [30].

The built environment plays a vital role in combating climate change and adapting to its effects, as it encompasses various climate-related factors such as energy, water, materials, human welfare, biodiversity, and transportation. Water scarcity is a pressing issue due to rising populations, adverse climatic conditions, and extensive industrialization, which put immense pressure on safe and sufficient water resources. Traditional sources of water, both liquid and solid, have been depleted, leading researchers to explore alternative methods of water generation using the gaseous state [31]. Constructing and maintaining alternative solutions such as active dew collection (electrically powered condensers), water transfer infrastructure (such as dams, reservoirs and pipelines), and seawater desalination plants can be costly due to their high operational expenses. Atmospheric water harvesting (AWH) is gaining popularity as a passive water production solution that utilizes millions of droplets and vapor in the atmosphere. This alternative could prove vital in addressing water-related challenges in landlocked countries facing dry and arid climates [32,33]. AWH technology has received favorable responses from different stakeholders since it does not require additional energy, unlike other alternatives. These technologies are cost-effective, easy to install and maintain, energy efficient, and have high harvesting performances compared to conventional methods [34].

A collaborative approach to waste disposal is crucial to building sustainable cities that can meet the needs of future generations. Waste management, particularly organic waste, is a critical challenge faced to date. According to The World Bank 2022 report, 53%

and 57% of food and green waste, respectively, are generated by middle- and low-income countries. These percentages are expected to increase with the rising population and poor waste management solutions. Landfilling is the most common waste management solution, but the world is running out of space, leading some countries to export waste to others [35]. One notable solution is applying anaerobic digestion (AD) to convert large amounts of food waste into biogas, which yields significant energy (367 m^3 of biogas per dry tonne at about 65% methane with an energy content of 6.25 kWh/m^3 of biogas yielding 894 TWh), annually representing almost 5% of the total global electrical energy utilization. AD reduces the need for landfill space, saves transportation costs, and reduces greenhouse gas emissions. Although biogas plants have been utilized since the 19th century, their widespread adoption in urban environments is hindered by cost and maintenance issues.

2.4. UAE's Climate Adaptation in the Built Environment Sector

The UAE is an emerging economy that has experienced impressive growth over the past decades; however, due to this rapid growth, development needs took priority over environmental considerations. The main reason for the rapid growth was that the UAE was initially focused on oil-based trade revenue; however, regulations have been put in place that address sustainability and energy consumption in different sectors, including buildings [36,37]. UAE has been an active advocate of climate action since 1989 when the Vienna Convention for the Protection of the Ozone layer was organized alongside the creation of the Montreal Protocol and further joined as a member of the UNFCCC in 1995. Climate change is a serious issue for UAE since it is based in an arid climate, and it is expected that it will face a harsher climate in the future. Therefore, to mitigate the issues, the UAE listed climate change as one of the main priorities to maintain the country's sustainability and growth [38].

The first initiative was to appoint a ministry dedicated to focusing on climate-related issues and, therefore, the Ministry of Climate Change and Environment was formed. The UAE government formed the UAE Council for Climate Change and Environment to develop partnerships with the private sector to conduct climate-specific research and support policy and framework development. Through its Energy Strategy 2050, the UAE affirmed its plan to generate around 50% of its electricity from clean energy sources such as solar energy by 2050 and reduce its carbon footprint by 70% by 2050 [39].

UAE has been quite ambitious in spearheading several initiatives to alleviate the impacts of climate change [40]. One of the major implementations of the UAE-built environment is the Estidama Pearl Rating System (PRS), which was established in 2009. Estidama in Arabic means sustainability. This rating system is an initiative by the Abu Dhabi government (an Emirate in the UAE) to create sustainability frameworks where new developments receive a certain number of pearls if specific sustainability measures are followed. Another very important initiative was the reformation of the Dubai Green Building Regulations and Specifications as Al Sa'fat initiative in 2020, which provides a comprehensive set of requirements for all new developments to secure a more sustainable built environment [41]. There have been several other landmark initiatives undertaken in different parts of the UAE, such as Masdar City in Abu Dhabi built in 2006, and several sustainable initiatives have been implemented. The Sustainable City in Dubai, Sharjah, and in the future in Abu Dhabi, focuses on three pillars of sustainability i.e., social, economic, and environmental. EXPO2020 was yet another remarkable undertaking for the world stage, as it was built with sustainability parameters at the forefront and is currently operating in an energy-efficient environment [42]. According to Asif (2016) [43], among all the GCC countries, the UAE has been at the forefront of having the biggest share of green buildings in the Middle East and North Africa (MENA) region.

Recently, the UAE submitted a new NDC to the UNFCCC that highlights the inclusion of an economy-wide emission reduction target and therefore intends to reduce its GHG emissions from 23.5% to 31% by 2030 which is consistent with the approach adopted under article 4.7 of the Paris agreement [44].

The UAE National Climate Change Plan 2017–2050 and UAE Energy Strategy 2050 both recognize the critical role of the built environment in achieving sustainability and preventing climate change; below are some of the plans discussed in both strategies:

1. Energy-efficient buildings—the plans emphasize the importance of promoting energy-efficient buildings through improved design, construction techniques, and the use of advanced technologies. The goal is to reduce energy consumption in buildings and minimize GHG emissions.
2. Green building standards: The plans encourage the adoption of green building standards and certifications, such as Leadership in Energy and Environmental Design (LEED) and Estidama's Pearl Rating System. The standards promote sustainable building practices, including energy and water efficiency, use of renewable energy, and sustainable materials.
3. Renewable energy integration: The plans promote the integration of renewable energy sources, such as solar and wind power, into the built environment. This includes installing solar panels on buildings, implementing net-zero energy building designs, and encouraging the use of renewable energy in construction projects.
4. Research and development: The plans emphasize the need for research and development in the built environment sector to foster innovation and develop sustainable building technologies and materials. This includes supporting research institutions, collaborating with industry stakeholders, and promoting knowledge exchange.

The above discussion will be reflected in the analysis section to highlight the elements incorporated during the construction of the SEE Institute building used as a case study in this research.

The 28th session of the Conference of the Parties (COP28) will be held in November 2023 at the EXPO City in Dubai, which reflects the UAE government's efforts to transform the economy from oil-based to clean and renewable energy sources along with technological advancements and climate-smart solutions. Overall, the UAE has been persistent in encompassing all the Sustainable Development Goals (SDGs) and the recommendations provided during COP26 and COP27 gatherings, across all initiatives and sectors to progressively adopt economic diversification, which is a resilient co-benefit for climate mitigation and adaptation.

The literature review chapter is a crucial part of the paper since it provides a comprehensive outlook on COP26 and COP27 developments and recommendations provided particularly for the built environment sector. The latter part of the discussion in the literature review focuses on the UAE's contribution to swiftly acting on climate emergencies and creating regulatory measures to control carbon emissions much earlier than the 2050 target.

3. Methodology

This paper focuses on two main objectives: to evaluate the recommendations of COP26 and COP27 in relation to the built environment and to highlight the contributions of the UAE built environment sector in achieving decarbonization strategies using a case study approach. The data collection was carried out in two ways: desk research, and primary data collection. The reports regarding COP26 and COP27 were available on both the UN and UNFCCC website, whereas the details regarding decarbonization strategies in the UAE were found using the UAE official websites, expert discussions on various platforms, and video recordings of COP meetings, and several examples from the peer-reviewed literature between the years 1995 and 2022 were used to achieve the first objective. A total of 60 papers were initially identified as relevant but finally around 46 peer-reviewed journal papers from databases such as MDPI, Renewable and Sustainable Energy Reviews, and other Scopus-based journal papers were used. According to [45], a real-time phenomenon can be explored with its naturally occurring set up which provides a realistic view of how the details were integrated; therefore, a newly constructed G+2 building named the SEE Institute was used as a case study to showcase the decarbonization efforts of the built environment sector in the UAE. This case study is also a valuable contribution to the built environment research since it would be the first net-zero building in the Middle East region. The major areas of focus discussed in this paper were how energy, water, and waste management strategies were implemented throughout the building to follow the decarbonization strategies recommended during COP26 and COP27 as well as the UAE National Climate Change plan 2050 and which will assist in achieving net-zero targets by 2030.

3.1. Application of Decarbonization Strategy to the SEE Institute Building Case Study

The SEE Institute Building is located in the Sustainable City, Dubai, UAE. The Sustainable City is a mixed-use development located in Dubailand, with over 3000 residents from around 60 different nationalities living in 500 3- and 4-bedroom villas and 89 apartments. This inclusive community has retail outlets, offices, restaurants, a school, an equestrian center, an autism support center, and facilities such as a sports area, an art center, a hospital, and a mosque. The only element missing was a space for a research and training center. Therefore, in 2019 the foundation was laid for the construction of the SEE Institute building; however, the process was delayed due to the COVID-19 pandemic. The acronym SEE stands for the three pillars of sustainability: social, environmental, and economic [46].

The project team collected data related to the materials used during the construction phase, and appliances and automation installed in and around the building using the systems thinking approach. Therefore, it is necessary to note that all data used in this case are from a first-hand source. Secondly, the data featured in the analysis section on energy usage are based on the energy modelling software, Integrated Environmental Solutions (IES), which is a software that assists in designing and operating efficient buildings. The data discussed under the water section are provided by the suppliers of the water harvester which is installed in the building. During the installation of fixtures, guidelines provided by the Dubai Electricity and Water Authority (DEWA) and other international guidelines were followed carefully to ensure optimal water pressure and usage were adhered to in order to maintain green building practices. These guidelines are crucial since they provide an opportunity to benchmark and analyze usage accordingly. The waste management strategies in the study were not limited to the construction of the SEE Institute building alone. They were implemented throughout the construction of The Sustainable City. There, the data discussed in the waste management section were collected from both the biogas suppliers and engineers involved in the development of The Sustainable City from the very beginning.

3.2. The SEE Institute Building Description

The SEE (which stands for social, environmental and economic) Institute's (SI) building is located in the Sustainable City in Dubai and was built to achieve net zero by 2030. The SI building is a hub for sustainability education, research, innovation, and incubation. It was designed and constructed to function efficiently and in a sustainable manner. The SI building used Al Sa'fat requirements as its metrics and worked towards reducing its embodied carbon as much as possible throughout the entire process. Further to this, the building is registered under the ILFI Zero Carbon certification program. This certification program addresses both embodied and operational carbon and calls for reducing and offsetting emissions associated with materials, construction, and energy consumption, respectively. The image below (Figure 1) showcases how the building worked towards reducing embodied carbon to become net zero by using the reduce, report, and offset methods. The second phase of the project is the operational phase which will tackle the downstream emissions by using several passive and active design strategies.

Figure 1. Visual representation of the SEE Institute Building with different materials and design strategies.

Each building is a complex system—a system that comprises interdependent and interacting parts. Prior to constructing the SI building, the team conducted an assessment to evaluate the building materials. The objective of such assessment was to make proactive decisions on designing and selecting building materials with reduced embodied carbon and higher utility. This step proved beneficial since the team was able to use systems thinking to select materials such as green concrete due to its higher strength and durability as well as its harmonization with the natural environment, further reducing waste and GHG emissions. Another example of proactive design decision making was the use of recycled steel rather than virgin steel. There were several strategies implemented during the construction phase to reduce embodied carbon compared to a conventional method of design and construction. It is also necessary to mention that all the construction materials were sourced locally to minimize transportation emissions. Key decisions during the construction phase assisted in reducing 26% of the project's embodied carbon, which significantly contributes to reducing GHG emissions.

The built-up area of the building is spread over 5955 square meters and incorporates several important sustainability elements. This case study is an important link in this study since it incorporates the recommendations offered during COP26 and COP27 for the built environment sector. The case also follows the guidelines provided in the UAE National Climate Change Plan 2017–2050 and UAE Energy Strategy 2050. The SI building is an example of sustainable construction promoting energy neutrality, and low embodied carbon and was designed and constructed to function simply and efficiently, covering all its energy needs with onsite renewables, such as producing potable water from non-conventional sources and diverting organic waste from going to landfill. The next section will provide greater details regarding the energy, water, and waste strategies.

4. Results and Discussion

4.1. Energy

It is necessary to understand that tackling operational emissions is not just about design, but requires a holistic approach where all aspects—design, facilities management, and occupants' behavior—are equally addressed. One of the key aspects was to gain a deeper understanding of how the building operates and performs in the operational phase. As discussed in the methods section, energy modeling was used to estimate the annual energy consumption of the Institute, which is informed by factors such as climate, orientation, the geometry of the building, construction materials, mechanical infrastructure, and electrical systems [47].

Through a design lens, every measure taken should be directed at maximizing energy efficiency. Passive and active design techniques were applied in all ways possible; such strategies are simple in theory yet prove to be extraordinarily efficient. Passive design implies responding to local climate and site conditions to prioritize energy use. Typically, this design combines elements such as building location and orientation on the site, layout, window design, insulation (including windows), and green roofs and vertical gardens [48]. Active designs are those that utilize some form of energy (including electricity from the grid and natural gas) to keep buildings comfortable, and the components included could be mechanical systems such as air-conditioning, electric lighting and heating, heat pumps, radiant heating, and heat recovery ventilators.

Keeping in mind that the SI building was constructed to make it a hub for sustainability and adhere to the recommendations provided during COP26 and COP27, it was natural that reducing energy consumption was a priority and efforts were made to implement feasible standards into action. The challenge was that until recently, less attention was paid to the impacts of the construction industry on the climate, particularly in the UAE; therefore it is the mission of the project team to make the SI building net zero by 2030. The SI building was designed with embodied carbon reduction in mind, however, there were trade-off moments where the project team was guided by conducting a whole life cycle and systems thinking approach.

Up until recent years, the procurement strategy for building materials would typically involve selecting material suppliers based on a range of traditional criteria that are likely to include delivery timeliness, cost, quality, specific project requirements, and financing. However, the importance of sustainability when purchasing goods and services has seen growth in recent years [49]. This might assume accounting of lifecycle, environmental, and social impacts. Such external considerations are factored into decisions for the SI building besides the conventional procurement criteria. The energy discussion will be further divided into two parts: passive design and active design strategies.

4.1.1. Passive Design Strategies Implemented at the SEE Institute Building

Façade and Thermal Insulation

Façade considerations and thermal insulation reduce unwanted heat gain (in the hot climate) through the creation of a smart building envelope. The design of the envelope is the key factor that determines the quality and controls the indoor conditions regardless of outdoor conditions and temperatures. The building envelope assists in reducing the energy demand necessary to cool a building [50], further mitigating the overall GHG emissions. In the context of the SI building, it was essential to select an arrangement that ensures both—high thermal insulation properties, that when combined with other building elements meet the required energy demand, yet do not compromise the embodied carbon of the whole building.

The project team reviewed several external wall/façade components from various suppliers and based their final product selection on achieving the required operational performance including insulation and acoustic values, a reduction in material use, and cost. A three-pronged approach aimed at lowering the embodied as well as the operational carbon of the building while maintaining its cost-effectiveness was used.

Table 2 below highlights the external wall/façade components along with their properties such as embodied carbon per square meter of surface, thermal transmittance, sound isolation, and weight. All these aspects impact the embodied or operational carbon of the building.

Table 2. Materials used during the construction of the SEE Institute Building.

Option	* GWP, $kgCO_2e/m^2$	* GWP Difference	U-Value, $W/m^2 \cdot K$	Acoustic Insulation	Weight, kg/m^2
Thermal insulated block	54.1	0%	0.27	n/a	410.0
External Insulated Finishing System (EIFS)	49.2	−9.1%	0.33	n/a	500.0
Precast insulated panel	62.6	+15.7%	0.22	n/a	600.0
SG Lightweight Façade	53.4	−1.3%	0.22	STC 69 dB	77.7
Thermal AAC	64.5	+19.2%	0.57	n/a	180.0
Easy Wall Panel	47.16	−12.8%	0.50	n/a	156.0

* GWP (Global Warming Potential).

It is necessary that a given building element is broken down into its components for which embodied carbon factors need to be sourced in order to perform the calculation. Factors that quantify the embodied carbon of construction materials are typically presented in the format of $kgCO_2e$/functional unit. Internal partitions were supplied by Saint Gobain and comprised four layers of plasterboard 12.5 mm each, an acoustic partition wall—these are major components—and sealant and studs to bind the whole thing together. The overall carbon footprint of 1 sqm of the wall surface is a summary of embodied emissions of all the items that make up each wall. It is always better to use construction materials that have EPDs because carbon factors obtained from generic databases may be less accurate as the data are sourced from a variety of global sources and may not precisely reflect the specifications of a particular project.

Thermal-insulated blocks served as a benchmark as one of the most popular options for external wall construction, specifically when considering embodied carbon of regular blocks. For this purpose, the team conducted a life cycle assessment of the listed building assemblies for walls and façades, excluding installation. As highlighted in Table 1, the lightweight façade was the preferred choice, despite its insignificant embodied carbon reduction compared to the thermal insulated block, since it has the lowest U-value which indicates better insulating performance, as well as higher sound isolation.

One example of how standards were followed while selecting materials is the U-value for external walls recommended by Al Sa'fat, the Dubai Green Building System, 0.57 W/m^2K and 0.42 W/m^2K for Silver and Gold and Platinum certifications, respectively. The chosen lightweight façade has a U-Value of 0.22 W/m^2K which means it is 50–70% lower compared to the prescribed parameters by Al Sa'fat. This lightweight façade guarantees better performance during the operational phase of the building [51]. A similar study was conducted in Greece and Hong Kong, where thermal insulation and low infiltration strategies reduced energy consumption by 20–40% and 35–47%, respectively, during peak seasons [48,52].

External glazing is part of the building fabric and has just as large of an impact as external walls. It is important to note that the better the glazing insulates the interior from the exterior, the less energy is required to maintain a constant temperature difference between the inside and the outside. The glazing's light transmittance affects total solar heat gain, which is the amount of heat generated by the sun on the interior of a building. This factor also adds the necessary consideration of the knock-on effect on how much visible light can pass through the glazing. In a building located in a hot climate, reducing the solar heat gain is crucial while allowing daylight to pass through, and therefore in this case, special coatings for the glazing panes can provide high daylight income, with no compromise on performance and comfort perception.

With these specifics in mind, a new generation of window glazing was selected for the SI building. A highly selective coated glass ensures solar protection and strong thermal insulation thus minimizing the use of air-conditioning systems. This glazing has a U-value of 1.5 W/m^{2}K, which is 20% lower than the values proposed by Al Sa'fat, the Dubai Green Building Regulations—1.9 W/m^{2}K [53,54]. In terms of the comfort and healthy environment for building occupants, the light transmittance of the selected glazing is 75%, which means it provides sufficient daylight and a clear unaltered view and is also a perfect use case for educational and mixed-use facilities. Table 3 summarizes the properties of several building components such as the external wall and glazing which play a key role in the successful passive design implementation.

Table 3. Properties of Building.

	For Silver Al Sa'fat	**For Golden and Platinum Al Sa'fat**	**The SEE Institute Design**
External Wall U-value (W/m^{2}K)	0.57	0.3	0.22
Glazing U-value (W/m^{2}K)	1.9	1.9	1.5
Glazing Light Transmittance	0.1 (min)	0.1 (min)	0.75

Source: Building Component guidelines.

4.1.2. Active Design Strategies Implemented at the SEE Institute Building

Intelligent LED Lighting System

An energy efficiency initiative in the form of an intelligent LED lighting system was another strategy implemented in the building. Sensors placed in the fixtures assisted in detecting the available daylight or the lack of presence or motion in a certain area of the facility, and automatically reduce the amount of light needed. This function supports high energy conservation which adds further to the building's overall efficiency.

The Building Management System (BMS)

The Building Management System (BMS) is often referred to as a building's brain and is crucial for large-sized facilities such as data centers, hotels, educational and commercial establishments, offices, and hospitals. BMS is a part of the facilities management of the building which helps to understand how a building is functioning and allows the control and adjustment of systems to enhance their performance. In addition, BMS can compile and visualize performance data, generate reports, and send alerts when parameters are outstripped; in other words, it makes the building management "smart." When failures occur or when failures are likely to occur, the BMS can send notifications and alerts as part of preventative maintenance. In case of failures, it intelligently identifies the source of the problem and saves time as it eliminates the need to inspect the whole system. BMS was implemented in the SI building to control and operate systems efficiently, such as chillers, fresh air handling units and power consumption units, water leakage detection, lighting, air quality, solar PV and EV charging points, lifts, and fire alarms. Further to this, voice evacuation is continuously monitored, and data are utilized to modify energy usage and storage accordingly.

Solar Energy

Energy is involved in every aspect of human activity and is the main cause of enhanced global warming; it is a critical point of decarbonization. Therefore, after implementing various measures to manage the operational energy demand of a building, the integration of renewable energy is an essential strategy to offset the remaining energy requirements. As per the Dubai Energy Strategy 2050, the UAE intends to produce 25–50% clean energy to satisfy the demands of the UAE population and encourages both private organizations and citizens to support this initiative. This brings us back to the earlier discussion about energy simulation which predicted Energy Use Intensity (EUI) to range from 95 to 115 kWh/m^2/year, depending on the activities taking place within the space. That comes down to an annual demand of up to 508,000 kWh.

To give perspective, the UAE building code prescribes that energy-efficient buildings should have a EUI of anywhere between 160 and 180 kWh/m^2/year. A study conducted by the Emirates Green Building Council in 2019 revealed that median EUI values in schools, hotels, and malls were 134, 249, and 462 kWh/m^2/year. EUI is an important indicator that describes the energy efficiency of a building's design and/or operations, typically expressed as energy per square meter per year [55]. It is calculated by dividing the total energy consumed by the building in one year by the total gross floor area of the building. Doing the reverse exercise allows for determining the annual consumption of the entire building. The above discussion was necessary for a clear perspective on EUI, and it is now clear that a combination of design and different technologies allows for achieving energy efficiency targets.

Nearly 1 MWp (971.95 kWp to be precise) of solar PV panels were installed on the car parks and rooftops of the SI building to meet the energy demand, which is threefold the coverage of what the building might need in a year—about 1.6 million kWh. The reason for such an uptake was to offset operational emissions going beyond just energy use—these imply food, water, purchased goods, employees commuting, and waste generation.

The employed solar panels are bi-facial which, unlike mono-facial solar panels, absorb direct as well as reflected light. The front side of the panels uses direct sunlight, while the reflected light is absorbed from the rear side as demonstrated in Figure 2. Hence, there are multiple benefits of using bi-facial solar PV panels, such as higher efficiency, production being less impacted by bad weather, and angle of installation flexibility, to name a few [56].

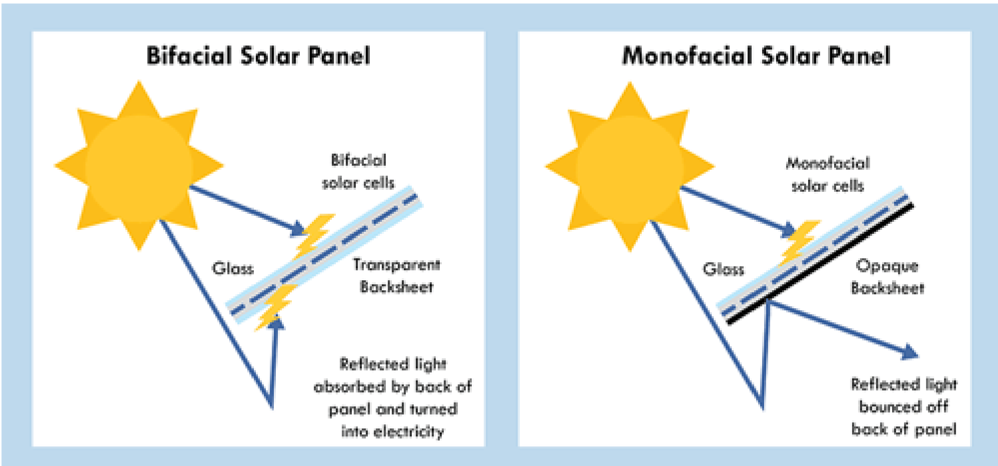

Figure 2. Absorption of Sunlight using Bifacial and Monofacial Solar Panel. Source: https://www.paradisesolarenergy.com/blog/what-are-bifacial-solar-panels [57].

The produced solar energy is fed into the Institute and the adjacent building—short-term accommodation called The Sustainable Homes, consisting of 51 studio apartments. The existing net metering supports any surplus energy to go to the grid, thus contributing to a cleaner energy mix of the national grid and supporting the UAE Energy Strategy 2050.

Smart Cladding

Another innovative solution to further enhance decarbonization was "smart cladding", also known as Building-Integrated Photovoltaics (BIPV). Although it is not a new technology—as PV applications for buildings began appearing in the 1970s—use of this technology has been limited due to a not-so-aesthetically pleasing design and limited choice. However, over a period of time, they have become more esthetically pleasing and available than before [58]. PV panels used on the south-facing wall of the SI building look like normal cladding and have a wide application from design and building perspectives—they are customizable and mimic the color and pattern of the rest of the façade while being efficient in generating clean energy.

4.2. Water

In a country such as the UAE, where the climate is arid with very limited natural water resources, reasonable water consumption is a major concern. The main source of potable water in Dubai is the Jebel Ali power station, which is the largest power and desalination plant in the UAE [59]. The water produced at the Jebel Ali facility is a by-product of electricity generation through multi-stage flash distillation, known to be quite an energy-intensive technology. For this reason, unlike many other countries, water in the UAE has a significant carbon footprint. Beyond the links to climate problems, water desalination disturbs the health of aquatic environments. One more aspect which concerns water conservation is the energy consumed for water pumping and delivery, and, depending on the needs, heat.

During the construction of the SI building, the demand-side management of water was also carefully taken into consideration. The team did not use any groundbreaking technology but rather simple solutions such as water-efficient plumbing fixtures that would save water by having a lower flow rate. For instance, Dyson taps were installed in the washrooms, and have a flow rate of 1.9 L/min compared to the 6 L/min recommended for hand wash basins by Al Sa'fat—Dubai Green Building System. In addition, these taps have a built-in energy-efficient hand dry system, which, according to the brand studies, eliminates single-use paper towels use by 98%.

With water scarcity on the rise, harvesting it from the atmosphere can provide additional supply, and this solution has been receiving considerable attention from researchers worldwide [60]. This system of generating water decentralizes water production, overcoming the challenges of delivering or transporting potable water to long-distance areas, particularly rural. The mechanism for this water machine, named water harvester, has a simple process; once collected from the air, it undergoes heavy metals removal (if any), biological treatment, particle filtration, and mineralization (illustrated in Figure 3). With atmospheric water generation technology installed in the building, we expect to harvest and generate up to 500 L of drinkable water per day. The generated amount is sufficient to operate the SI building requirements.

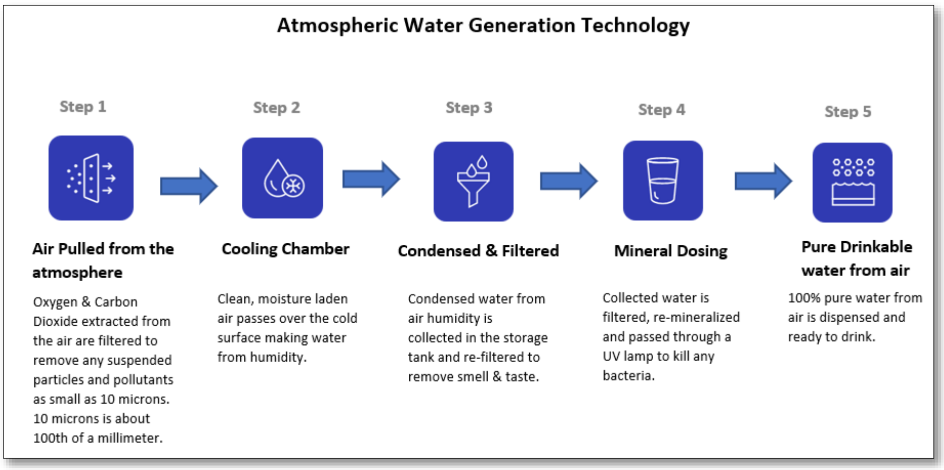

Figure 3. Illustration of the Atmospheric Water Harvester.

4.3. Waste Management

The mixed-use and residential community where the SEE Institute is located, namely The Sustainable City, produces a significant amount of organic waste such as food residues, animal manure, and green waste. Prior to the institute's construction, most of that waste would be collected and transferred to a local waste management company except for some food waste which was challenging to segregate and would be discharged using the garbage disposal unit separately. This was a challenge since some organic waste was still going to landfill, and the team had been looking for solutions to utilize all the organic waste in the best possible manner. An alternative system that could divert the waste (called feedstock) by running a small-scale biogas plant using anaerobic digestion was installed at the building premises. Organic waste is a known cause of methane emissions—the result of decomposition and a potent greenhouse gas. To reduce GHG emissions and displace the use of fossil fuels, organic waste can be removed and used to produce biogas, a renewable source of energy. The plant shown in Figure 4 consumes methane, preventing it from being released into the atmosphere. The energy produced is far more than the energy required to run the plant, and it is therefore self-sufficient.

Figure 4. The Waste Transformers to be installed at the SEE Institute Building.

The biogas plant is designed to handle up to 3000 kg of organic waste per day to produce biogas and digestate. There is no combustion—digestion produces approximately 320 m^3/day of biogas (60% methane—40% carbon dioxide) which serves as a direct-fired absorption chiller by firing up the biogas content in an ignition chamber to replace the compressor in a conventional chiller set up to increase the temperature and pressure of the clean refrigerant (water). The biogas is delivered through a well-insulated and concealed pipe. The hybrid cooling system consists of two chillers—the absorption chiller has a refrigerant capacity of 75 tons (TR) and the electrical backup chiller has 185 tons of refrigerant (TR). The absorption chiller contributes around 31% of the cooling load required in the SI building, which leads to a lower electrical use intensity. Furthermore, the digestate is utilized as a soil conditioner/fertilizer for the community landscaping needs around the Sustainable City. Over 79% of the cooling load is served through a highly efficient water-cooled chiller through a two-step compressor that supports operations on part load conditions, as the chiller motor is also equipped with a VFD (variable frequency drive) that helps achieve the highest efficiency rates. It is also worth mentioning that the electricity consumed by the electric chiller is 100% covered by clean energy production from a solar PV source.

A system of this caliber, as noted earlier, further supports demand-side management by cutting the use of electricity, simultaneously diverting organic waste from the landfill, and turning it into clean renewable energy. In addition, the electrical chiller uses water for cooling and has proved to be 35% more energy efficient compared to air-cooled chillers. Finally, it is equipped with a chiller plant manager that acts as a standalone BMS for the chillers alone to ensure its proper functioning.

Clean energy usage was one of the main recommendations during COP26 and COP27 meetings to reduce global warming. Similarly, the UAE Energy strategy and the National Climate Change Plan of the UAE 2017–2050 emphasize that all sectors should utilize clean energy to achieve the mission of increasing the contribution to the use of clean energy by 25–50% by 2050.

Making a building net zero, essentially, has the same roadmap as net zero itself—prioritizing emission reductions (efficient building operations) and compensating for the ones that are hard to eliminate (supplying enough renewables). The above discussions have exemplified only a few of the many actions that took place in the journey of making the building net zero by 2030. Ultimately, it has become apparent that when looking at sustainability in the built environment in pursuit of the acceleration of climate action, the sum of its parts is greater than the whole.

5. Lessons Learned Using the SEE Institute Building Case Study

There were several strategies utilized to make the SEE Institute building energy efficient and integrate systems that supported the reduction in embodied carbon during the construction phase while also using active and passive design techniques. Through this, the future operational carbon will be reduced significantly to achieve the objective of becoming net zero by 2030. Therefore, based on the results of this case, some very important lessons in decarbonization strategy in the built environment can be highlighted:

1. Regarding resource conservation and efficiency, engineers should consider technical solutions, such as new process designs, energy- and water-efficient equipment, and more advanced control systems. Nevertheless, putting the sole responsibility on the physical aspects of the building is not idle—these aspects rather enable the building to be net-zero energy or net-zero carbon, depending on the goal.
2. The single biggest contributing factor to resource conservation potential is the people who work in and use the building. Human behavior has emerged as a significant driver of the challenges our world faces today. As highlighted in various analyses and by researchers, it is imperative to initiate a shift in the human mindset and behavior to effectively mitigate emissions. In this regard, the development of suitable training manuals and guidelines becomes crucial to offer clear directives to the team on day-to-day operations, empowering them to make informed decisions that contribute to reducing their carbon footprint.
3. Integrating energy, water, and waste efficiency into the corporate culture can unlock and multiply positive practices and behavioral changes. The operational team is in the process of introducing policies that may include but are not limited to a single-use plastic ban, a limit on food deliveries and take-outs, and a printing limit.
4. It is necessary to underpin the important role of data collection and analysis to evaluate the building's operation to develop and deploy strategies meant to enhance its performance. The operational team intends to implement site energy audits and other programs that will help in highlighting and enacting efficiency opportunities.
5. As per the case study analysis, it was found that assessment tools such as LCA proved to be beneficial at the very early stages of construction since they clearly provided support while selecting materials that had lower embodied carbon as well as higher efficiency. Other than that, selecting suppliers who provide an Environmental Product Declaration (EPD) will support the process even more positively.
6. Another vital lesson was that, to achieve decarbonization, the construction industry must utilize smart technologies and designs which make the construction and operation of buildings much more efficient.
7. Last but surely not least, an important lesson learned was that all the stakeholders should reflect upon the country-specific climate change agenda and align themselves and their projects for higher visibility and support from the government to achieve net-zero emissions as early as possible.

One of the challenges of this study was that after reviewing the documents on COP26 and 27, it was noticed that there were seldom any decisions made on the built environment sector; therefore, it was hard to quantify the effort towards decarbonization. This means that highlighting the recommendations and incorporating them in the construction and implementation stage was a challenge. Therefore, based on the recommendation for the built environment sector, it is critical to focus on embodied carbon right from the inception of the project. The attention to detail of the project team in the case of the planning and construction of the SI building clearly accentuated the path paved to positively shape the performance and efficiency of the building towards the net-zero targets, as well as aid in contributions towards decarbonization, and reducing the overall carbon footprint spanning throughout the life of a structure.

6. Conclusions

In conclusion, a comprehensive literature review covered the built environment and highlighted how COP26 and COP27 emphasized focusing on this sector due to its resources and technology that can rapidly reduce carbon emissions compared to other sectors. It is important to note that there is no definitive solution or clear roadmap to tackle climate change, but deploying all possible techniques and technologies is necessary. Moreover, it is critical to implement better and faster approaches if we want to meet the targets set by the Paris Agreement. Additionally, the efforts of the UAE in developing decarbonization strategies through the National Climate Change Plan 2017–2050 and the UAE Energy Strategy 2050 were emphasized. These regulatory measures aim to manage greenhouse gas emissions, sustain economic growth, minimize risks, and improve adaptation capacity to climate change. The UAE Energy Strategy 2050 specifically aims to increase the country's contribution to clean energy and reduce the carbon footprint of power generation by 70%. Furthermore, a case study method was used to highlight the decarbonization efforts incorporated into the newly constructed SEE Institute Building in Dubai. The project team used the whole life cycle and systems thinking approach during the construction phase to reduce embodied carbon by 26% and installed smart systems and technologies to be net zero by 2030 in line with the Paris Agreement. The three main areas evaluated in the case study were energy, water, and waste, aligning with the recommendations from COP26, COP27, the UAE National Climate Change plan 2017–2050, and Energy Strategy 2050. It can be concluded that the research was able to achieve the objectives of showcasing the decarbonization recommendations presented during COP26 and COP27 as well as highlighting how the recommendations, as well as the National Climate Change plans of UAE, were incorporated during the construction of the SEE Institute building.

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