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The Role of Architecture in the Sustainable Development of the United Arab Emirates (UAE)

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***Abstract*— The United Arab Emirates (UAE) growth has developed immensely throughout the past few years, and along with its growth several environmental issues have been faced. In response to the climate and environmental inflictions and in support of the United Nation sustainable goals for 2030, the United Arab Emirates has developed several means by which sustainable development can be achieved. The United Arab Emirates has created a widespread vision for future sustainability goals that govern the country's role towards accomplishing successful path towards green economy. According to the Brundtland Report 1987, Sustainability developments are defined as those that "meet the needs of the present, without compromising the ability of future generations to meet their own needs" Sustainable development regulatory bodies such as Estidama categorize sustainable development under 4 major categories; environmental, economic, social and cultural which are relevant in achieving a sustainable future. Through these initiatives, the UAE aims to meet the goal of achieving 50% target for clean energy by the year 2050.**

This research discusses the UAE initiatives, measures and goals in the field of sustainable development and their effect in the UAE and the Middle East. The research also analyzes different aspects by which sustainable architecture in the UAE aids in providing a sustainable future for the country on its path of development. Most important, the write-up aims to relate sustainable architecture and sustainability goals roles in the process of sustainable development. In a nutshell the write-up discusses the solutions, responsibilities, challenges and initiatives that helps in meeting sustainability goals and maintains a better future for the upcoming generations.

Keywords—Sustainable development, Environment, Sustainability, sustainable architecture, clean energy, ecological footprint, Awareness, Carbon Emission, Vernacular, Traditional, Cooling loads, EUI, Passive, Active

I. INTRODUCTION

Through utilizing innovative sustainable architectural design solutions, a sustainable city can be established that as a result leads to achieving a country's sustainable development. In the light of this, The UAE aims to achieve strong sustainable development to match with its expansion and growth over the years in order to preserve a bright future for its inhabitants by creating sustainable cities and communities that are based upon innovative sustainable architecture design. Consequently the UAE is a resilient supporter in the creation of agenda 2030 that was founded in 2017. Agenda 2030 consists of the 17 sustainable development goals, based on the united nation's millennium development goals, which aim to achieve better life and future to all. According to the United nations the agenda is" a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom." The agenda focuses on a multidisciplinary work plan highlighting sustainable development centered around 4 pillars, 6 national priorities and 52 federal-level key performance indicators. The agenda is therefore a guideline to sustainable development through the creation of sustainable cities. By embracing vernacular architecture solutions in relevance to climatic, environmental, social, cultural and economic problems and modern innovative trends and solutions,

sustainable architecture can help achieve a sustainable future for the UAE.

II. Sustainable development

The UAE aims to achieve 17 sustainable development goals by 2030. The sustainable development goals cover three main areas that are classified under the 17 goals: social, economic, and environmental. The goals include zero poverty and hunger, good health and wellbeing, quality education, gender equality, sustainable cities and communities

According to the Dubai Electricity and Water Authority (DEWA), the average Dubai resident consumes 20,000 kilowatt-hours of energy per year .Due to the inflictions on the environment by insatiable consumption of electricity and Carbon dioxide emission, the UAE, sustainable solutions with a lower ecological footprint must take action. Sustainable architecture aids in creating sustainable cities. In order to fulfill the sustainable development goal relevant to sustainable cities and communities, cities and human settlements need to be safe, inclusive, strong and sustainable. The UAE has created a set of efforts in order to fulfill cities and communities sustainable needs including: Promoting sustainable infrastructure, UAEpedia, sustainable cities and communities, and sustainability in the environment.

A. Sustainable Infrastructure

UAE vision 2021 agenda contains improving the quality of air, preserving water resources, increasing the contribution of clean energy and implementing green growth plans which is achieved through sustainable infrastructure initiatives. The UAE aims to create efficient and sustainable airports, ports, road infrastructure, and electricity sources that utilize smart systems and technologies. The UAE is investing $163 billion into renewable, clean fossil and nuclear energy technologies for achieving a better future. Examples of sustainable infrastructure initiatives include Masdar city infrastructure studies and IRENA (International Renewable Energy Agency).

Masdar city initiatives are emphasized on development of technologies in renewable energy, carbon management and monetization, energy efficiency, water usage and desalination coinciding with agenda 2030.

IRENA is an intergovernmental organization in the Middle East that promotes sustainable and renewable energy. It is an organization that aims to solve problems relevant to regional and national renewable energy initiatives.

One of the main culprits of greenhouse gas emission is transportation. The establishment of sustainable transport system and redesign of transportation contributes significantly to sustainable development in modern cities. One of the main transportation initiatives towards sustainable transportation in the field of sustainable infrastructure is The Smart Dubai initiative. The initiative includes strategies such as self-driving smart transportation and RTA smart vehicle that can deliver up to ten passengers driverless. Dubai also aims at expanding and developing public transportation systems in cities such as taxis, buses, Dubai metro and tram by using electrical vehicles and eco-friendly transportation.

B. UAEpedia

UAEPedia is an online encyclopedia of the UAE documenting its culture, history and heritage while giving knowledge and information about aspects of the land. It helps in raising awareness about the diversity and identity in the UAE.

C. Sustainable cities

One of the major sustainable development goals that have an enormous impact on the ecosystem and carbon emissions is sustainable cities. Sustainability is achieved in cities through maintain the three main pillars of sustainability: Environmental, Economic and Social sustainability. A sustainable city has to be sustainable socially, economically and environmentally. It is often a challenge to achieve sustainability through a holistic approach. The basic idea of a holistic approach to sustainable development is to provide a whole solution which addresses all the three main factors of sustainability, rather than just dealing with one part solely. Ultimately, the main goal of any sustainable city should be to provide its users with the best quality of life possible together with the lowest environmental footprint.

In order to create a sustainable city, a set of guidance rules and regulations should be followed and maintained. Abu Dhabi introduced Estidama, a sustainable building initiative in 2010 that utilizes the Pearl Rating system for the design, construction and operation of buildings, dwellings and communities. All new buildings are required to obtain at least a one-pearl rating out of five, whereas all government buildings and dwellings must obtain a minimum of a two-pearl rating. Dubai also introduced Al Sa'fat green building evaluation system in 2016.

The UAE has established several sustainable cities in compliance with the sustainable development goal and in response to climate change. These cities include Masdar city, Dubai sustainable city, Desert Rose city and Sheikh Mohammed bin Rashid al Maktoum solar park.

D. Sustainable environment

In order to maintain a sustainable city and to protect the environment, the government has passed several laws and launched several policies that protect and conserve the environment. These laws include federal laws such as laws concerning Protection and development of environment and its related issues, Delamination of maritime zones, on the

protection of new plants and laws concerning the exploitation, protection and development of living aquatic resources. Furthermore, the laws also contained cabinet decrees such as the decree on banning importation, exportation and use of asbestos sheets, decree on the use of ships and offshore units as floating warehouses transporting or sorting oil substance of any derivatives and the decree on the protection of ports and coast of the country and its territorial sea against marine oil pollution. In addition to this the UAE has also participated in several agreements and conventions that aim at recognizing and solving various environmental problems by signing and ratifying environmental agreement including the Vienna convention for the protection of the ozone layer, United nations convention to combat desertification, Stockholm convention on persistent of organic compounds and the Kyoto Protocol for the UN convention on climate change.

Moreover the UAE has established several efforts in aims of focusing on sustainability on the environment and ways to improve it. The UAE has established Air Quality Monitoring stations to study the quality of air and ensure its safety as well as to record and document carbon emissions. One of the efforts includes the engagement in the implementation of projects that aim in reducing the emission of greenhouse gas. These projects may include sustainable and eco-friendly infrastructure, services and the study and creation of sustainable cities. Moreover, the UAE aims to eliminate the consumption of numerous Chlorofluorocarbons (CFCs), Halons and methyl bromide and completely eliminating the consumption of Hydro-chlorofluorocarbons (HCFCs) by 2040 .The UAE aims to construct 130 dams and levees with a total storage capacity of about 120 cubic meters of water and set up 33 desalination plants to provide water requirements.

III. Sustainability through sustainable architecture

Sustainability goals can be meet through sustainable initiatives and targets that should be developed by the client and consultant team to help guide the design towards a sustainable path. The goals can be divided into categories such as water, health, energy, materials, ecology and waste. For instance sustainability goals in the field of water can be met by recycling and reuse of water, rainwater harvesting and efficient water systems.

In order to approach sustainability and sustainable architecture, environmental, cultural, social and economic aspects should be taken into consideration.

A. Environment

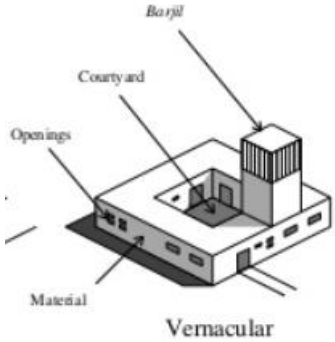

Figure 1: shows the traditional housing layout of the UAE including, courtyard, openings, and materials, from "Sustainable architecture in the United Arab Emirates past and present by Yasser Mahgoub

Several vernacular and modern technologies can solve issues relevant to the climate of the UAE and ensure comfort conditions without inflicting harm upon the environment. The climate in the region is often hot and humid and Vernacular architecture has developed several solutions for this issue including courtyard, coral blocks, wind towers, small openings, and the Arish. Traditional houses were courtyard styled, which provided cooler outdoor environment and enabled cross ventilation which is essential for maintaining comfort conditions. Coral blocks created from corals and shells of nearby shores were used as building blocks. Due to its porosity, the blocks allowed for air to easily enter the building whilst providing a cooling interior effect. Wind towers are tall structures that collect prevailing wind and distribute it inside the building. This mechanism along with small windows use cross ventilation to cool down buildings during the summer season. The Arish is a type of Mashrabiya (façade shading element) that is constructed from palm leaves used to provide shading on building elements and on outdoor spaces. Modern architecture tries to utilize some of the vernacular typologies along with high thermal mass which insulates the building and prevents cool air from leaving and hot air from entering, efficient mechanical ventilation system that saves energy while providing comfort for the inhabitants, passive and active cooling systems and louvers that reduce heat gain through shading. Vernacular architecture of the region utilized local building materials such as coral stone, mountain stones and palm leaves and thus helps in conserving resources. Modern architecture aims to use recycled materials and low u-value materials that prevent solar heat gain. In some cases, Sustainable architecture is reverting back or mimicking vernacular architecture building design of the region through creating introverted buildings with small openings.

B. Social and cultural

There are three vital aspects to consider in UAE's cultural and social sustainability that root back to the country's tradition: privacy, identity and religion. Privacy is often achieved through 3 levels(Exterior, in house, public and private spaces).The typical house is divided into 3 levels, the exterior often contains tall a fence which blocks people on the outside from seeing the residents on the outside. Secondly, traditional houses often include Majlis, which is a separate structure intended to be reception space for guests and as a result it prevents guests from entering the main house and invading the residents privacy. The courtyard is often used as a private outdoor area for the house which could either be private or semi-private. Identity is often preserved through utilizing elements from vernacular architecture and symbolic elements that emphasizes and respects the local culture. The main religion of the country is Islam and therefore, mosques are usually often placed within walking distances from settlements and communities, to allow ease of access.

C. Economic

Economic sustainability can be achieved through three levels: building resources, consumption and operation. In relevance to building materials, renewable, recyclable local and non-toxic materials are preferred to protect the environment and ensure availability and material conservation. Recycling and reuse of waste materials is considered in order to reduce the consumption cost. Efficient low consumption systems are used in order to maintain low operational cost. In terms of cost, sustainable options are often believed to be more costly which a turn off is for stake holders because it increases the building cost. However in the long run it is more suitable and costs less to utilize sustainable options.

IV. SUSTAINABLE REGULATORY BODIES

Estidama, means 'sustainability' in Arabic, is the initiative which aims to transform and guide Abu Dhabi into a model of sustainable urbanization. It aims to create more sustainable communities, through the four pillars of sustainability; Environmental, economic, social and cultural. Estidama plays a huge role in guiding the UAE through the 2030 Agenda through its pearl rating system. The Pearl Rating System for Estidama addresses the lifecycle of projects from construction to operation. The pearl rating system is organized into seven categories: integrated development process, natural systems, livable buildings, precious water, resourceful energy, stewarding materials and innovating practice. Integrated Development Process aims to encouraging multidisciplinary teamwork to deliver environmental and quality management throughout the life of the project. Natural Systems focuses on conserving, preserving and restoring the region's critical natural environments and its habitat. Livable Buildings aspires to improve the quality and connectivity of outdoor and indoor spaces. Precious water focuses on methods of conserving and preserving water as well as reducing water demand and encouraging efficient distribution and alternative water sources. Resourceful Energy targets energy conservation through passive and active means in order to reduce energy consumption and demand. Stewarding Materials considers the life-cycle of materials during construction and specifications. Innovating Practice encourages innovation in sustainable building design and construction to facilitate market and industry transformation. Pearl rating is achieved through collecting mandatory points and extra points according to the building typology. Points are acquired in relevance to the pearl rating categories and the building performance in each category. For instance, in order to obtain 4 pearls, it is required to fulfill all mandatory credits with an extra 115 credit points.

There are three types of rating in Estidama: Pearl design rating, Pearl construction rating and Pearl operational rating. Pearl design rating takes place during the design development stage of the project. The project undergoes a series of reviews then a Design submission is issued which would be reviewed by an assessor and the design rating would be achieved. Pearl construction rating ensures the commitments made during design stage are achieved. The project undergoes the same process as in design rating; the project goes through a series of reviews then a Construction submission is issued which would be reviewed by an assessor and the design rating would be achieved. Pearl operational rating is achieved after two years of building usage and reaching 80% occupancy.

V. CASE EXAMPLES

A. Masdar city

Masdar city, located in Abu Dhabi, incorporates modern building technologies while preserving the cultural aesthetic of traditional Arabic architecture. Masdar city was initiated in 2008 and was set to be the world's most sustainable eco-city. Masdar city sets an example of how cities can reduce their ecological footprint, accommodate rapid urbanization and reduce energy, water, and waste.

The city combines traditional architecture of the region along with modern technologies. It features prevailing wind capturing technologies to reach comfort temperatures, harnessing sun energy through rooftop solar technologies that produce 17500MWH annually. Streets maximize shading throughout the day, capturing cooling breezes and reducing the need for air-conditioning. The city's core contains Masdar Institute of Science and Technology, a

research university dedicated to studying innovative solutions in the fields of energy and sustainability. It also houses IRENA headquarters in the UAE. Companies can connect with the university and invest in several of its innovative projects to increase the economic sustainability and accelerate breakthrough technologies to market. The mixture of educational and recreational, housing, retail, manufacturing, and office spaces provide the citizens with all their necessities while reducing transportation requirements. Buildings are densely populated, allowing residents to live and work in the same location which subsequently reduces heating, cooling and internal transportation needs. Water conservation and preservation is established by the utilization of high-efficiency appliances, low-flow showers, a water tariff, smart water meters and grey water technologies such as treated wastewater, which is later recycled for plant irrigation.

Masdar city is also specialized in clean energy development, consultancy services and real-estate. It contains the Masdar free zone as well. Masdar Clean Energy division is a high quality developer and operator of utility-scale, grid-tied projects such as small-scale projects that gives energy access to communities without the use of the electricity grid or any use of carbon related projects. Masdar's renewable energy projects span the UAE, Jordan, Mauritania, Egypt, Morocco, the UK, Serbia and Spain with an electrical generating capacity reaching up to 2.7 gigawatts. Masdar offers two distinct consultancy services: project management in renewable energy and clean technology, and sustainability integration services. The project management consultancy focuses on developing project delivery aided by business and application development through managing the process from the client and the idea generation until the completion and delivery stage. Masdar's sustainability team works on a wide variety of external projects, including consultancy work with other Abu Dhabi government entities such as the Ministry of Foreign Affairs and the Emirates Identity Authority. The sustainability consultancy includes: Sustainability strategy action plans, Sustainability committee establishment plans, Sustainability policy development, Operational energy & water analysis, Operational carbon management plans, Sustainability awareness campaigns, Waste management strategy plans, Sustainable procurement strategy, Green ICT strategy development, Sustainability reporting roadmaps. Masdar city aims to attract companies to commercialize and use clean energy technologies in the Middle East through its real estate opportunities. Its achievements include energy and water demand reduction by 40%, housing 400 companies in its quarters, and establishment of Siemens regional headquarters. Socio-economic sustainability is promoted in Masdar city through its free zone development. It offers to clients 100% foreign ownership, 100% exemption from corporate and personal income taxes, easily accessible and quick solutions for registration and government relation, freedom of repatriation of capital and profits, Research & Development hub partnering with Masdar Institute and highly cost effective licensing and office space.

Masdar city has developed and built an eco-villa module under the patronage of His Highness Sheikh Dhiyab bin Mohamed bin Zayed Al Nahyan. The eco-villa has an area of 405 square-meters and is set to achieve a 4 pearl rating in Estidama Pearl Building rating system. It is set to use around 72% less energy and 35% less water than a conventional villa in Abu Dhabi. The villa also reduces about 63 tons of carbon dioxide annually.

The cost of construction is similar to that of a conventional villa of the same size; its energy and water efficiency will also reduce running costs on the long run. The four-bedroom property is expected to consume just 97 kilowatt hours (kWh) of electricity per square meter. The villa features 87 rooftop solar panels which are capable of providing 40,000 kWh of electricity to the national grid. Once a family moves into the property, Masdar's sustainability team will monitor the villa's energy, water and waste management performance. The data collected will help in obtaining important insights the design of the Eco-Villa to be further refined, supporting the eventual commercialization of the building concept.

B. Dubai Sustainable city

In reference to the "sustainable city villas use less energy, water" article published by the gulf news in 2018, the sustainable city in Dubai is a sustainable ecological mixed-use community that runs on clean energy such as solar energy. The villas located in the Dubai sustainable city have been monitored and studied. The monitored results showed that the villas use 42 per cent less electricity and 31 per cent less water per capita than a conventional villa in Dubai. The villas utilized sustainable architecture features and innovative technologies to achieve such milestones. These features include an improved eco-efficient design, rooftop solar panels, solar charged electrical vehicles, and organic waste composting.

The initiative of the sustainable city villas helps in reducing the greenhouse gases emitted. The city has been effectively proven that the greenhouse gas (GHG) intensity at the sustainable city villas is 50 percent less than the traditional villas of the United Arab Emirates. The villas were measured by the developed greenhouse gas inventory, which is capable of measuring the sustainable city community carbon emissions and its effects on the environment.

The sustainable city in Dubai aims to meet the sustainable development goals and comply with the Paris

agreement of 2015 through its attempts to reduce climate change and the carbon emissions. According to Farid Saeed, the CEO of the creator company of the sustainable city, Diamond Developers, stated that the city plans to reduce carbon emissions and reduce the ecological footprint through the addition of 55741.824 square meters of 3.6MW of solar photovoltaic panels, the utilization of biodiesel for building construction activities as well as awareness campaigns spread out in the city for its current residents.

The sustainable city also promotes social sustainability through its facilities and amenities. It contains a variety of sport and leisure facilities such as Community Centre and the Equestrian Club, biking and shaded jogging trails across the city and convenient essential facilities such as clinics, bank, Juma'ah mosque and a traditional souk. Moreover, it promotes economic and cultural sustainability through tourist attractions spots such as a Planetarium and a grass Amphitheatre for hosting events. It also contains ecofriendly features such as Natural 'bio dome' greenhouses, organic farm and individual garden farms for local food production. Awareness is raised among the residents through and a nature inspired 'Green School' from Kindergarten to Grade six. Further research is conducted at Sustainable Engineering and Research Institute and Training Centre for sustainable practices located in the city.

The sustainable city plays an important role in setting a model example for the for the future of sustainable mixed-use communities, through its innovative plans to reduce Greenhouse Gas emissions, combat climate change and promote renewable energy while promoting a high-performance model for the city. Moreover, it is also vital to implement measuring tools to recognize achievement and progress and raise awareness to the residents and the community as well. To sum up sustainable housing consumes less energy and water than a conventional housing which is therefore better for providing a more viable future for the forthcoming generations.

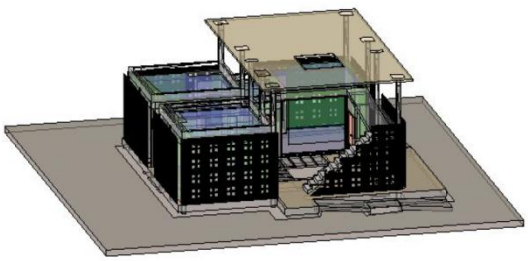

Figure 2: Solar decathlon Middle East American university of Rasalkhaimah net zero energy house 3D schematic (Autodesk Revit)

C. Sheikh Mohammed bin Rashid Solar Park

Part of the sustainable cities initiatives is Sheikh Mohammed bin Rashid solar park in Dubai, which is dedicated to the study of solar powered mechanisms and their capabilities in order to achieve maximum efficiency. The solar park has a planned capacity of 1,000MW by 2020 and a 45, and 5,000MW by 2030, with a total investment of AED 50 billion. The vision of the location is to enhance the sustainable development of the UAE and support the clean energy strategy of 2050 to make Dubai a global center for green economy. The solar park contains a wide variety of photovoltaic (PV) and Concentrated (CPV) solar power technologies to provide clean energy to the residents of Dubai. It also includes an innovation center, a research development center that tests facilities and a solar powered desalination plant.

The energy production Projects are direct on four phases. The first phase is 13MW photovoltaic commissioned on 22 October 2013. Second phase is 200MW photovoltaic commissioned 20 march 2017 and third phase includes 800MW photovoltaic will be implemented in stages as well as the fourth which includes 700MW CSP (concentrated solar power) which will be implemented by 2020.

The solar park will house the solar decathlon Middle East competition under the patronage of His Highness Sheikh Hamdan bin Mohammed bin Rashid Al Maktoum, Crown Prince of Dubai and Chairman of Dubai Executive Council which is a collegiate competition of 10 contests that challenges university students to design and build solar-powered houses. The competition is a collaboration of the Dubai Supreme Council of Energy, Dubai Electricity and Water Authority, and the U.S. Department of Energy which will integrate unique local and regional architectural characteristics. The competition is set to adapt to the climate and the environment of the Middle East including the heat, dust and high humidity while producing a sustainable, socio-economic and eco-friendly approach to housing design through the utilization of modern technologies that benefits the inhabitants of the Middle East region. The projects should also respond to the UAE's our cultural, climatic and social contexts while solving issues relevant to sustainable lifestyle in the middle east.

Along with 20 other university teams from around the world, The American University of Rasalkhaimah is participating in the Solar Decathlon Middle East in building a net zero energy house through utilizing elements of sustainable architecture, traditional housing of the UAE, and new innovative technologies as shown in figure 2.

The concept of the house compromises of a modular grid that consist of 4 large modules (bedroom, Kitchen, Living room and courtyard) and two support spaces (mechanical room and bathroom). This concept tackles

socio-economical sustainability factors such as house modification. The house is set to support the growing family needs, as the family grows the house grows with them, more modules can be easily added around the courtyard to expand the house. The house embraces the local traditional housing architectural style of the UAE through the use of the courtyard plan, roof terrace, and mashrabiya (façade shading elements).These elements tackle both cultural and environmental sustainability.

The house utilizes construction and mechanical technologies and passive and active means of green architecture to combat environmental issues including low u-value plaster, green walls, Mashrabiya , solar PV panels, cooling pipes embedded in the ceiling, insulation foam boards ,energy efficient appliances and grey water recycling. Low u-value plaster reduces the amount of heat gain in the house and thus reduces the electricity consumption from mechanical ventilation needed to cool the house and reach comfortable temperature. Green walls also provide a cooling effect as well as contributing to air purification and providing an aesthetically pleasing environment. Mashrabiya gives provides sufficient shading to wall and thus reduces the solar gain on the wall and heat absorption to the house. The house aims to produce more energy than it consumes thus by using solar powered PV panels on the roof directed towards south , east and west, this can be achieved. Pipes embedded in the ceiling can create a cooling effect by running cool water in them, which consequently reduces the electrical consumption of mechanical ventilation. High thermal mass and high thermal insulation reduce heat gains in the house which subsequently keeps temperature at comfort level. The uses of energy efficient appliances such as washing machine, dryer, dish washer, etc. can therefore reduce energy consumption which contributes to environmental sustainability. Grey water recycling from kitchen sinks and reuse in gardening and watering courtyard plants contributes to water conservation and environmental sustainability. Moreover, the construction method of the house is clean and sustainable; it utilizes foam board walls with shotcrete and precast floor slab which reduces the amount of waste materials on site and is therefore environmentally friendly as shown in figure 3.

Thermal analysis and energy analysis have been conducted on the house to obtain cooling loads and estimate the EUI (Energy Use Intensity) to clearly study the energy consumption in the house and areas of improvement. An energy simulation model was built and studied using Autodesk Revit and Green Building studio. The user builds the model using designed plans and other drawings then fills in important the data asked by the program such as the number of users, outdoor air, volume, U-value ,etc. The program then starts the simulation and calculates the energy loads, produces graphs and sometimes adds recommendations on how to improve the situation. The data provided is useful in identifying design problems, improving house performance, testing energy consumption and identifying areas of weakness and how to improve it.

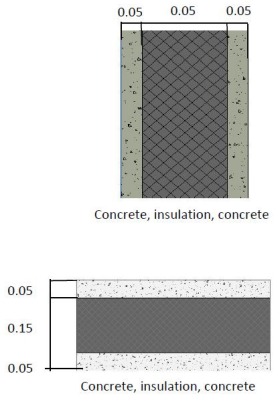

Figure 3: Materials detail section showing the components of walls and floors used in the Solar Decathlon Middle East house respectively (Autodesk Revit)

D. *Analysis*

Building Performance Factors	
Location:	25.2879524230957,55.32373046875
Weather Station:	1303857
Outdoor Temperature:	Max: 40°C/Min: 14°C
Floor Area:	46 m²
Exterior Wall Area:	80 m²
Average Lighting Power:	4.84 W / m²
People:	0 people
Exterior Window Ratio:	0.06
Electrical Cost:	$0.14 / kWh
Fuel Cost:	$0.14 / Therm
Energy Use Intensity	
Electricity EUI:	151 kWh / sm / yr
Fuel EUI:	44 MJ / sm / yr
Total EUI:	587 MJ / sm / yr
Life Cycle Energy Use/Cost	
Life Cycle Electricity Use:	208,956 kWh
Life Cycle Fuel Use:	61,463 MJ
Life Cycle Energy Cost:	$13,073
*30-year life and 6.1% discount rate for costs	
Renewable Energy Potential	
Roof Mounted PV System (Low efficiency):	3,204 kWh / yr
Roof Mounted PV System (Medium efficiency):	6,408 kWh / yr
Roof Mounted PV System (High efficiency):	9,613 kWh / yr
Single 15' Wind Turbine Potential:	1,398 kWh / yr
*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems	

Figure 4: shows the table that is a result of the energy analysis made by Autodesk Revit and Green Building Studio to study the Energy Use Intensity in the Solar Decathlon Middle east house. The highlighted results are the results that need to be carefully studied and analyzed.

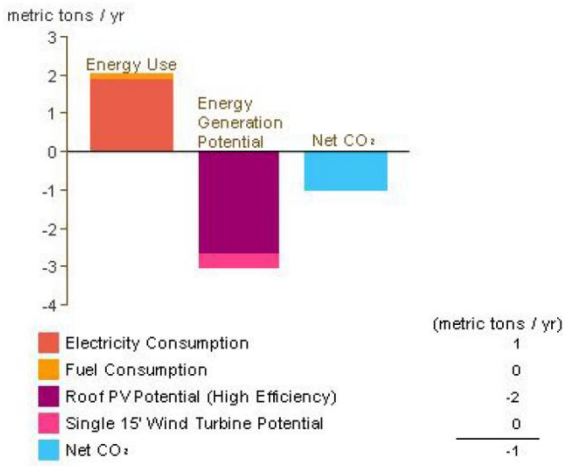

Figure 5: shows the bar graph that is created with the data obtained from figure 4

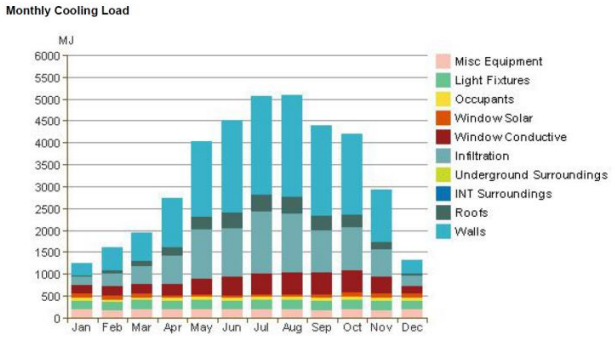

Figure 6: shows the studied cooling loads represented on bar graph with a legend on the right side

Inputs	
Building Type	Single Family
Area (m²)	66
Volume (m³)	256.16
Calculated Results	
Peak Cooling Total Load (kW)	**4.6**
Peak Cooling Month and Hour	August 4:00 PM
Peak Cooling Sensible Load (kW)	4.4
Peak Cooling Latent Load (kW)	0.1
Maximum Cooling Capacity (kW)	4.7
Peak Cooling Airflow (L/s)	292
Peak Heating Load (kW)	**0.9**
Peak Heating Airflow (L/s)	46

Figure 7: shows the result table from the thermal analysis of the Solar Decathlon Middle East house (Autodesk Revit)

E. Results and conclusion

The first set of analysis, the energy analysis, studies the electrical cost, Electricity EUI, and renewable energy potential such as the use of PV panels. The results in figure 4 show that the annual electricity EUI is 151 KWH/sm/yr without using PV panels, while the energy produced from low efficiency PV panels is 3204 KWH /yr. As a result, a net zero energy goal can be reached as the amount of energy produced is greater than the amount of energy consumed. The second diagram, figure 5, clarifies the previous data using graphic presentation in the form of a bar graph. It can be concluded from that diagram that by using energy generation technologies such as PV panels, electricity consumption can be compensated by energy production. Figure 6 graphically represents monthly cooling loads, which is the amount of heat that is needed to be removed from a certain element or space. It can be concluded from the diagram that the walls have the most cooling load and therefore needs an action to be taken to reduce the cooling loads in the house. Such action could be to reduce the exposed surface area of the wall by using façade shading such as Mashrabiya. This therefore shows the importance of using Mashrabiya in the Middle East climate. Further studies can be conducted on which type of Mashrabiya works best and which type openings are more efficient.

The last table, figure 7, calculates the heating and cooling loads. The total cooling loads can be converted into electrical loads to obtain the electrical consumption required by the mechanical system, and attempt to obtain the closest mechanical ventilation unit value to the electrical system in order to save energy and cost.

VI. Conclusion

In conclusion, through preserving each of the three vital factors that influence sustainable development; Environmental, economic and social factors, architecture can help build a sustainable future for the forthcoming generations while maintaining a good life quality for the present generations. Furthermore, it is essential to enhance the field of sustainability and study more about the subject to attempt at solving worldwide solutions regarding cities development and livability without harming the environment.

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