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RESEARCH ARTICLE

Environmental Considerations for Sustainable and Green Architecture: a Study for Saudi Arabia.

Dr. Mona A. Omar, FHEA
Assistant Professor and Fellow of the UK Higher Education Academy, Department of Architecture, College of Engineering, Prince SultanUniversity, KSA.

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Abstract

The rapid population growth, associated urbanization, and infrastructure development resulted in adverse impact on the environment, which is becoming increasingly alarming and creating many challenges.
These circumstances have made the concept of "Green Buildings and Sustainable Built Environment" a necessity rather than an option.
This research studies and introduces the environmental considerations for green and sustainable architecture, it aims to identify the factors that affect green building design and sustainable urban development. It also defines various elements and procedures required to achieve a successful green design. Furthermore, the study classifies the main factors that drive the urban development in the Gulf region that can improve the energy efficiency and the quality of the built environment in hot countries, such as Saudi Arabia and similar climatic zones. The research methodology is based on case study approach to analyze and evaluate concerning environmental considerations. It combines observation and qualitative research methods. This research attempts to fill a gap in the literature concerning green built environment considerations in Saudi Arabia in particular and the Gulf region in general.

Introduction:-

The rapid population growth, associated urbanization, and infrastructure development resulted in adverse impact on the environment, which is becoming increasingly alarming. Symptoms relating to this adverse impact include global warming, noise, excessive energy consumption, climatic changes and ecology imbalance.

These challenges have made the concept of "Green Buildings and Sustainable Built Environment" a necessity rather than an option, especially in Saudi Arabia and the Gulf region, where construction activities are still peaking.

This research studies and introduces the environmental considerations for green and sustainable architecture, it aims to identify the essential factors that affect green building design and sustainable urban development. The study defines various elements and procedures required to achieve a successful green architectural design. This research hypothesizes that understanding the various environmental considerations for sustainable and green architecture, in

Corresponding Author:-Dr. Mona A. Omar, FHEA
Address:-Assistant Professor and Fellow of the UK Higher Education Academy, Department of Architecture, College of Engineering, Prince SultanUniversity, KSA.

addition to identifying the main factors that drive the urban development in the Gulf region can improve buildings energy efficiency and generally enhance the quality of the built environment in hot countries, such as Saudi Arabia. The research methodology is based on case study approach to analyze and evaluate existing environmental considerations. It combines observation and qualitative research methods. This research fills a gap in the literature concerning green built environment considerations in the Gulf region, focusing on Saudi Arabia.

In this regard, the building industry has a key role to play in achieving sustainable development in any country and improving the quality of the built environment(Alrashed and Asif, 2014). Therefore, reversing the current trends of degradation in the environment requires strong promotion of the green design concept and ongoing education of the stake holders. For instance, raising the awareness of the community is important, as there is currently a lack of public awareness concerning sustainability in Saudi Arabia (Al Surf, 2014), and in the Gulf region, in general. Furthermore, the enforcement of sustainable building design and construction regulations is significantly needed at council, ministerial and state levels.

Research Approach and Methods:-

The research reviews the literature concerning the fundamentals of green buildings concepts. It introduces the essential environmental factors for sustainable architecture. The research paper highlights the various elements and procedures required to achieve efficient green design.
This research also hypothesizes that identifying environmental considerations for sustainable architecture of a region can improve green building design performance, advance the architectural education and refine the professional practice. Moreover, knowledge of environmental considerations can enhance the community awareness regarding sustainability and climate responsive design.

The study aims to answer the research question, which is "What are the main environmental considerations for sustainable and green architecture in hot regions, focusing on Saudi Arabia?"
To fulfil the research objective and answer its question, the research methodology adopts a case study approach to analyze and evaluate current situations. It combines observation, description and analytical methods in assessing the factors that influence sustainable and green building design. To formulate the study, the researchalso employsqualitativemethods (Cameron 2015).This methodological combination represents an appropriate approach to the study that can be formulated to examine and identify environmental considerations for sustainable and green architecture that can fulfil professional practice requirements and expectations, taking Saudi Arabia as an example. The research outcomes meet the research objective and answers the research question.

Background:-

To further understand local traditional built environment in Saudi Arabia and the Gulf region, scholars have studied and analyzed Muslim-Arab architecture and buildings. They found that such buildings were formed by a conceptual framework, which developed an understanding of conscious responses to environmental, urban and socio-cultural conditions of existence.
Traditional buildingsare the true expression of the architecture that provides comfortable living conditions in all different climates. In hot regions particularly, the forms of these traditional buildings were designed according to the available natural resources of energy, which help reduce humidity and create natural ventilation (El-Shorbagy, 2001).
There are a number of architectural elements that help provide cooling in internal spaces, including an inner courtyard, wind-catchers, and using local building materials (Figures 1 & 2).

Figure 1. Example of historic and modern climate responding buildings in Saudi Arabia (Source: El-Shorbagy, 2001)

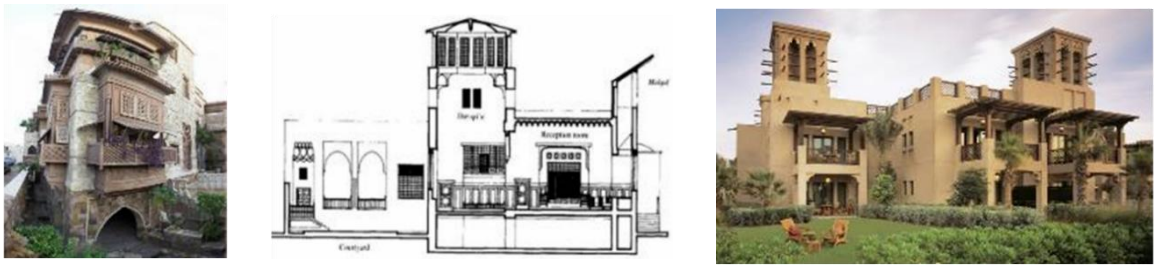


Figure 2. Elements of environmental design in Islamic architecture (Source: El-Shorbagy, 2001)

Identifying Environmental Considerations:-

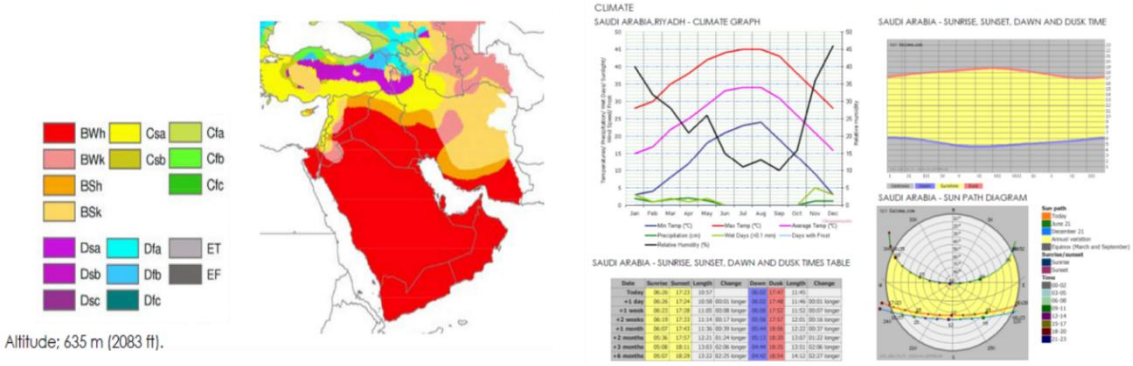
a) Climate:-

Understanding the climate is a precursor to establish guidelines and criteria for a successful green design, therefore this section introduces briefly the climate of Saudi Arabia (Figure 3).

The warmest average max/high temperature is 45 °C in July and August. The coolest average min/low temperature is 3 °C in January and December. The average temperature in Saudi Arabia is 25.3 °C.

Saudi Arabia receives on average 106.5 mm of precipitation annually or 9mm each month. On average, there are 17 days annually during which greater than 0.1 mm of precipitation (rain, sleet, snow or hail) occurs for 1 day on an average month. The months with the driest weather are June, August, September and October when, on average, 0 mm of rainfall (precipitation) occurs. The month with the wettest weather is April when, on balance, 21 mm of rain, sleet, hail or snow falls across 1 day (Al-Ahmadi, 2013). Mean relative humidity for an average year is recorded as 24.5%, and on a monthly basis it ranges from10% in September to 46% in December. On average, there is no measurable frost annually in Saudi Arabia (Yan, 2013).

Figure 3. Saudi climate diagrams (Source: Yan, 2013)



b) Topography and Geography:-

Basically, Saudi Arabia is located on a platform of ancient rocks with the highest part in the mountainous west and dropping from the west to the east. A series of rock fissures forming big trough and valley produces the Red Sea and the Gulf of Aden later. While on the eastern side, the Arabian Gulf coast is flatter. Layers of younger sedimentary rock are deposited which produces vast oil reserves (Metz, 1997).

c) History and Heritage:-

Saudi Arabia has enormous number of buildings that reflect the distinctive architectural heritage of the country which cannot be found anywhere else in the world. The buildings shapes and construction methods differ from one province to the other. The architectural heritage in the central region is distinguished for using the local building materials, namely the mud. The western region is famous for using the stone in building whereas the eastern region uses the mud, stoneand gypsum in the building walls, and palmtree trunks for the ceilings.

The major used materials are simple and local, which typically include clay and mud bricks (Figure 4). The foundation of a building is usually situated on stone blocks (NBHF, 2015).

Figure 4. Saudi vernacular architecture (Source: Sauditourism.sa)

Figure 5. Examples Saudi heritage buildings; a. Masmak fort, and b. Qasr al-Hokm (Yan, 2013)

Saudi vernacular architecture examples include Al-Masmak fort, which has been the most well-known traditional architecture in Riyadh (Determann, 2010); it was built in the mid-17th century (Figure 5a).
Qasr al-Hokm District Development Program was carried out in the 20th Century to revitalize the central core of Riyadh (Figure 5b). The project successfully strikes a balance between old and new architectural elements (ADA, 2008).

d) Socio-cultural Factors:-

The Saudi culture has many unique features driven by exclusive social and historical factors, and conservative religious values therefore, balancing these factors and modernization may form a real challenge.
Given the fact that there is a serious national effort to implement the Saudi energy efficiency program puts more responsibility on the community to improve the utilization of that resource and work to make investing in efficiency as mainstream as investing in oil, gas and renewables.
However, considering the prominence of Saudi Arabia in the global oil market and the region in general, experts and professionals concerned with sustainability should support the success of the national energy efficiency (Fawks, 2014).

e) Economic Factors:-

The decision to include efficiency and low energy design into a project must be understood in its local and regional contexts. In Saudi Arabia, the cost of electricity is quite low (ranging between 2-4 cents/KWh) due to substantial government subsidies. This means that there is little financial incentive for building owners to save energy and that the payback period for many energy saving strategies implemented are too long for them to be economically feasible (Elgendy, 2010). Nevertheless, energy intensity in Saudi Arabia has witnessed significant growth in energy intensity over the past 25 years, particularly since 1985, reflecting remarkable economy growth, the size of its level of economic development and reliance on heavy industry.
The Saudi energy intensity was twice the world average in 2010 and energy consumption is still mounting faster than the economy. The overall objective of the Saudi Energy Efficiency Center (SEEC) is to reduce the electricity intensity by 30% between 2005 and 2030, and halve the peak demand growth rate by 2015 compared to the period 2000-2005 (Fawks, 2014).

f) Legal, Legislative Issues & Saudi Building Codes:-

This section investigates the Saudi government's efforts and initiatives to adopt and implement regulations and other measures concerning sustainable built environment and energy efficient buildings throughout the kingdom (Omar, 2015).The Saudi government has made a national effort in 2003 and launched the National Energy Efficiency

Program (NEEP) to enhance demand side efficiency. Between 2007 and 2010, there was an initiative by the Ministry of Petroleum to transfer the NEEP to a permanent entity, and in October 2010 the Saudi Energy Efficiency Centre (SEEC) was established; to reduce energy consumption and improve energy efficiency to achieve the lowest possible energy intensity. The SEE Program focuses on three sectors; industry, buildings and transport. Remarkably, buildings account for 23% of Saudi's energy consumption with not surprisingly 70% being used for cooling.
The objective of the Program is to catch up with the rest of the world in terms of sustainability standards and energy efficiency codes (Fawks, 2014).

In Buildings the key energy efficiency initiatives have included:

- Updating the efficiency standards for small capacity air conditioners to ASHRAE standards(American Society of Heating, Refrigerating and Air-Conditioning Engineers),
- Developing an efficiency standard for large air conditioners,
- Updating thermal insulation product standards,
- Finalizing efficiency standards for residential lighting products,
- Developing efficiency standards for commercial and street lighting products,
- Updating efficiency standards for refrigerators and washing machines,
- Updating the Saudi Building Code energy conservation section (SBC 601) to ASHRAE standards,
- Developing a process to ensure proper enforcement of SBC601.

g) Natural Resources:-

There is a vast reserve of oil, gas and minerals in Saudi Arabia however, due to the topography and the climate of the country, water is a scarce resource.Therefore, in a country with the geography and climate of Saudi Arabia, water is a natural resource which must be highly valued and conserved. The Kingdom draws its water from four main sources:
The water is majorly drawn from four sources, including the surface water found in the western side of the country, ground water from aquifers, desalinated seawater and wastewater treatment (SAMIRAD).

Introducing Green Integrated Design Approach:-

A Green Building is a high performance building design concept that aims at creating energy-efficient, healthy and productive building with minimal impact on the local environment.
There is a global trend in the construction industry worldwide led by various national governments and international entities for improving the environmental conditions, sustainability and urban livability.
There are three basic principles of sustainable building design, as it follows:

a)Resource Conservation

- Energy Conservation,
- Water Conservation,
- Material Conservation.

b)Life Cycle Costing

- Pre- Building Phase,
- Building phase,
- Post Building Phase.

c)Human Design

- Preservation of Natural conditions,
- Urban Design site Planning,
- Design for human comfort.

Architectural Design Process and Integrated Design:-

The building envelope (walls, roof, floors, and openings) plays a critical role alongside mechanical systems in providing visual and thermal comfort. A well-insulated envelope allows the designer to reduce the size of climate control systems. Windows and glazed doors should be selected and specified to contribute to the goals of the project, whether this is through solar admittance, day lighting, and/or solar rejection (Kwok, 2007).

A green roof can provide many advantages, it plays an aesthetic role by extending the form of the project and creating a place of refuge. In the early design process stages, climate control systems should be determined, according to the specific requirements of each project.

Green heating and cooling systems have basic advantages over conventional heating and cooling technologies include using natural ambient conditions to the fullest extent to provide heating and cooling for a building.
These ambient energies are typically renewable and non-polluting. Passive strategies have the capacity to deliver heating and cooling strictly from environmental resources on site. However, a climate control system should be designed to be simple, both in operation and installation.

Strategies and Trends in Sustainable Design:-

Good design for sustainable architecture is achieved through integration of the principles of traditional architecture with modern technology and systems. Sustainable build environment can be accomplished by saving the natural energy resources, reduce building material consumption increased the durability of buildings, providing occupants comfort, energy savings and operating cost, reduce pollution and waste and savings through reuse and recycling. An environmentally balanced building is a building designed in accordance with the concept of sustainability, in harmony and compatible with its environment, as well as allowing for resources saving for future generations (WBDG, 2015).

Sometimes, architects, engineers and building designer have the best of intentions to develop a green building, but they may face a lack of information about specific strategies, which hinders decision making. The intent of this section is to provide a brief guide for a range of green strategies. The information is specifically intended to help the designer understand the purpose of each strategy.

The fundamental premise of this research is that if appropriate strategies are not included during the schematic design phase, they will never be included. This is generally true, as many such strategies are demandingly form-giving. Once fundamentally bad decisions regarding building orientation, massing, and interior layout have been made it is nearly impossible to come back and incorporate working daylighting, passive heating, or passive cooling systems. Opportunities for green architectural strategies are common in the conceptual and schematic design phases; they are sparse during design development.

Strategies include both active and passive strategies for sustainable design. There are, however, many more passive strategies. These require early implementation in the design process and are typically more form-shaping. The overall focus is upon those strategies that would (or should) be implemented during schematic design.
Following this introductory discussion, this section investigates the nature of the design process and discusses the green/integrated design process.

It also presents several strategies, each strategy has a brief description of principle and concept, a discussion of architectural and implementation issues, a procedure (with associated tables and charts) to assist with preliminary design sizing, key issues to be aware of when implementing a given strategy, as well as conceptual sketches and examples demonstrate each strategy.The definition of sustainable building design may vary from time to time yet, there are six fundamental principles persist, according to (WBDG, 2015), they are:

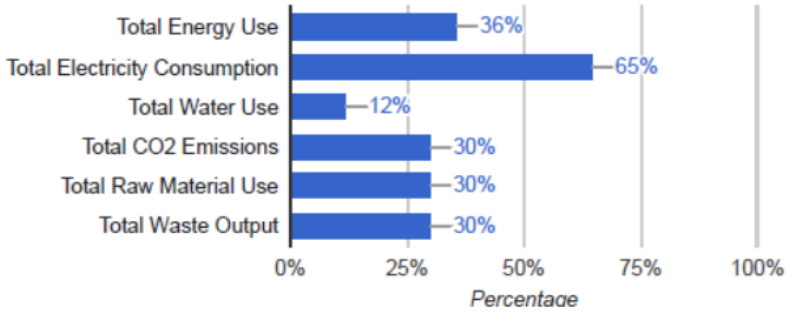
a) Site potential optimization:-

There are many factors that determine site optimization including proper site selection, consideration of the reuse or of existing buildings, the location, orientation, and landscaping of a building affect local ecosystems, transportation methods, and energy use. Site design should integrate with sustainable design to achieve a successful project.

b) Energy use optimization:-

It is becoming very important employ strategies to reduce energy consumption, increase efficiency, and maximize the use of renewable energy sources. Enlightening the energy performance of existing buildings is important to increasing energy efficiency and conservation (Figure 6).

Figure 6. Example of the impact of the building industry on the environment in the USA (Source WBDG, 2015)



c) Water conservation and management:-

Fresh water is becoming increasingly scarce resource in many parts of the world therefore a sustainable building design should adopt efficient water usage and management, including on-site use reuse or recycle.

d) Building space and material use optimization:-

A sustainable building should be designed and operated to use and reuse materials in the most efficient and sustainable approach throughout its entire life cycle and must be adaptable for reuse during its life span. It is essential to achieve an integrated and smart use of materials that maximizes their value, reduce pollution, and saves natural resources.

e) Indoor environmental quality improvement:-

The indoor environmental quality (IEQ) has a major effect on a building occupant's health, comfort, wellbeing and productivity. A sustainable building design should optimize natural lighting, engage proper ventilation and moisture control, enhance acoustic performance, and avoid the use of materials with high volatile organic compounds VOC emissions that can cause health and environmental damage. Principles of Indoor environmental quality IEQ also requires occupant control over building systems such as lighting and temperature.

f) Building operational and maintenance optimization:-

Building operation and maintenance issues should be considered in the early design phase of a facility to improved working environments, higher productivity, reduced energy and resources consumption and costs, as well as avoid prevented system failures. Including building operators and maintenance staff in the design and development phases guarantee efficient operation and maintenance of the building.

Green Design in Saudi Arabia and the Gulf Region:-

Saudi Arabia and the Gulf region are amongst those developing countries that witness fast urbanization where their infrastructures are facing a huge demand by the increasing construction projects and urban development in their major cities. This section introduces the current trends in construction and building industry concerning green architecture and sustainable built environment in the Gulf region, taking Saudi Arabia as a case study.

This section also examines and analyses several case study buildings and projects built recently in KSA and successfully adopted sustainable and energy efficient strategies.

Examples of Green and Sustainable Buildings in Saudi Arabia:

Example 1: King-Fahad National Library in Riyadh:-

The project is a redesign and refurbishing the old existing building of the library to improve its use and performance, as well as introducing green building strategies to enhance the building's sustainability efficiency. In this context, stainable design advocates universally encourage retrofitting existing buildings rather than building anew. Retrofitting an existing building can often be more cost-effective than building a new facility. Designing major renovations and retrofits for existing buildings to include sustainable design attributes reduces operation costs and environmental impacts, and can increase building resiliency. (WBDG, 2015).

Building Design and Cultural Considerations:-

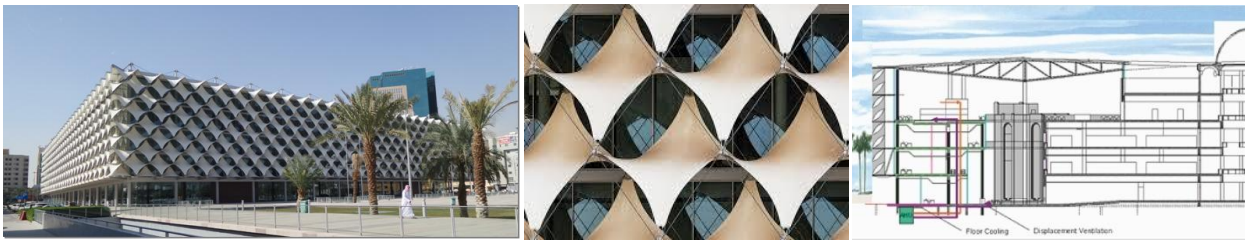
- The new design integrates the old domed-roof library with the new building and combines regional building traditions with modern technology (Design Build Network).
- The original library structure will has been kept as it is and been enveloped by the new structure.
- The new design preserved the dome shape but the old concrete one was replaced by a glass dome for sustainable purposes.

The architect, Gerber Architekten, has developed a cuboid building surrounding the existing library on all sides, thus presenting the National Library as a new architectural image within Riyadh's urban space (Arch Daily, 2014).

Identifying the greenstrategies employed in the project:-

- Replacing the old concrete dome with a steel and glass dome that continues to be a cultural symbol of the library and bring natural lighting.
- The entire former roof of the existing building, which occupies an extensive area, now provides a reading landscape flooded with light and offers a special atmosphere that will encourage the exchange of knowledge in this way. The whole building is covered by a new roof, punctuated by skylights under which white membranes gently distribute the light throughout the entire interior (Figure 7).

Figure 7. King-Fahad National Library in Riyadh, redesigned and refurbished to include green design strategies(AAS Arch., 2014)



- This façades have been developed to include ventilation and cooling for the building by means of layered ventilation and floor cooling. In this way, thermal comfort is increased and energy consumption significantly reduced by using certain methods and technologies for the first time in the Arab world.

Example 2: SAMBA Bank Headquarters:-

The Saudi American Bank's new headquarters provides a remarkable icon for the bank and offers a smart supple design that allow for future expansion. The tower consists of forty stories and is located at the Financial Plaza in King Abdullah Financial District, the Riyadh's new business central district. The project provides a total of one million square foot of office accommodation above ground, on top of basement retail levels that connect to the district-wide shopping mall.

Building Design and Cultural Considerations:-

The building is diamond-shaped on plan and centered on a top-lit, full building height atrium. The spaces can function as individual reception areas to support multiple tenancies if required.

The topmost floor accommodates a vivid open-plan suite, including two sitting areas (*majlis*) and executive spaces with panoramic city views, and it is linked by a grand stair to the executive level below. A podium 'branch' building annexed to the lower five floors of the tower contains customer banking facilities. The podium's roof aligns with the restaurant level to form its open-air seating terrace and also includes a dedicated prayer room within a large pavilion.

Identifying the greenstrategies employed in the project:-

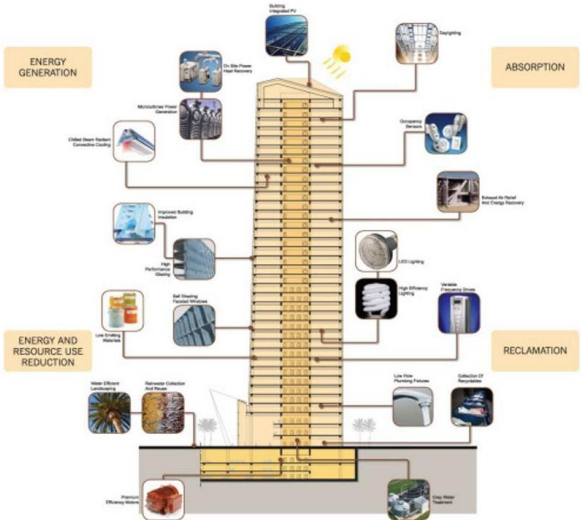
- Forming a raised canopy that protects the atrium from direct sunlight, and reflects indirect light deep into the office floor plates by its tessellated glass interior.
- Creating a northern elevation punctuated by three four-story sky gardens, which allow daylight to reach the atrium, and encourage social interaction as well.
- Crafting an innovative three-dimensional façade that reduces energy consumption and maintenance demands, as well as it gives the building a distinctive presence (Figure 8).

Figure 8. SAMBA Bank Headquarters (Source: Archello)

- Employing a rich textured façade consists of triangulated glass panels designed to respond to the extreme heat of the Riyadh's summer, and low temperatures with occasional heavy rains in winter. Each panel consists of facets, with opaque canopy panels and two different types of high performance reflective glass.
- Topping the tower by a 70-metre high spire, which acts as a radiator capturing cooling northerly breezes and using water to cool the roof-mounted array of advanced photovoltaic panels, thus enhancing their efficiency. The spire is also illuminated at night as a landmark for SAMBA.

- Promoting walking and using public transport by reducing the ratio of parking spaces (compared to an equivalent office development in Riyadh), and creating a covered pedestrian walkway that extends from the first floor to join the network of shaded routes that connect the district.
- Employing an advanced 'Power Tower' central to the building, comprises 70m spire central to the building and topping the 170m skyscraper. The Tower harnesses Saudi sunshine and concentrates it onto the photovoltaic panels. This tower system is fully sustainable strategy, which using recycled water and exhaust air to keep the panels cool and working efficiently.

Figure 9. Green strategies employed in the project (Source: Archello)



- Utilizing the photovoltaic panels also to provide the required energy to the LCD screens operating inside the building (Figure 9).
- Engaging smart lighting strategies, by using a Dalmatic system controls Dali lighting throughout the shell and core and office fit-out areas of the buildings, which provide highly flexible, intelligent, and energy-efficient control of lighting through a combination of presence detection and daylight-linking.
- Monitoring the complete system operation and managing it centrally through graphical head end software.

Example 3: King Abdullah University:-

The maiden green building initiative was taken by Custodian of the Two Holy Mosques, at that time, King Abdullah in 2010, in Saudi Arabia. The King Abdullah University for Science and Technology (KAUST) in Jeddah was the first green building constructed in the Kingdom (Arab News, 2013). It was also announced as one of the winners of the American Institute of Architects' Top 10 Green Buildings awards, according to Elgendy 2010.

The campus project was designed by HOK Architects and was completed in September 2009.KAUST's new campus is Saudi's first LEED certified project earning a Platinum certification, the highest rating in the US green building rating system and the world's largest LEED Platinum project (496,000 m^2).

Building Design and Cultural Considerations:-

In order to achieve these goals and to respond to the extremely hot and humid climate of the north Red Sea, the project team led by HOK Architects sought inspiration from the traditional architecture of the Middle East.

These traditional design inspirations included:-

a) The compact planning of the traditional Arab cities of the Middle East:-

This feature of bringing buildings closely together helped minimize the areas of the buildings facades exposed to the sun and encouraged passive ventilation between them. This shading and ventilation helped temper exterior microclimates which together with reduced outdoor walking distances, are both critical to fostering outdoor activities and interactions.

b) The Traditional Souk:-

Like the Souk, or traditional marketplace, which was often shaded and passively cooled and ventilated, the circulation thoroughfares within the campus are shaded and passively cooled. They are also characterized by

dramatic natural lighting via their roofs and social spaces.

c) The overhanging Arabic Bedouin tent:-

The project designers were inspired by the Bedouin tents to create a monumental roof system that spans across the campus's building masses to block the sun from buildings' facades and from the pedestrian spine. This helps to facilitate natural ventilation and to filter light (Figure 10).

Figure 10. Shaded outdoor spaces; Patio's perforated roof; Mashrabiya-like shading devices; and Lattice like shading for the library (Source: Elgendy 2010)

d) Traditional passive ventilation strategies of the traditional Arabic houses:-

The designers of the campus were also inspired by the design of wind towers that encourage airflow in pedestrian walkways. The wind towers used are the solar wind tower or solar chimney.

e) The traditional Mashrabiya:-

The Mashrabiya, or wooden latticework screen, inspired the design of the campus's shading devices. Like the Mashrabiya, the design of the shades was both to filter the sun as well as create beautiful light and shade patterns.

Identifying the greenstrategies employed in the project:-

The high temperatures and humidity levels of the project's site location had tremendous effects on the project's green design strategies. The designers have successfully implemented several strategies to maximize the environmental benefits of the project as it follows:

a) The Site

- Creating a campus that depends more on pedestrian and alternative transportation systems, which include public transportation, bicycles, Segway, community-shared electric vehicles, and buses (although Arabia is almost completely reliant on private cars as the primary means of transportation);
- Establishing a 50 meter buffer zone to protect the coral and mangrove boundaries from construction activity, and treating storm water before it leaves the site to the surrounding ecosystems;
- Using light-colored paving materials to increase solar reflectivity and decrease the overall outdoor temperatures, as well as to decrease the impacts of the heat island effect and solar heat gain.

b) Passive Design

- Orientations the building to limit harsh eastern and western sun exposure.
- Using appropriate shading on the northeast and northwest facades to minimize harsh morning and evening solar gain.

Figure 11. Solarwind tower and ventilation diagram (Source: Yan, 2013)

- Maximize daylighting to improve occupant comfort and to reduce lighting demand.
- Shaping the compact form of the campus as fingers with shallow floor plates to allow natural daylighting to access all perimeter spaces well as some of the interior spaces.
- Optimizing natural ventilation by taking advantage of prevailing Red Sea winds (from the North and North West) and to use wind as a cooling mechanism. Also, using two solar wind towers to maximize natural ventilation (Figure 11).

c) Energy conservation and generation:-

- Selecting the most efficient mechanical and electrical systemsappropriate to climate; to further decrease energy demands.
- Employing low energy cooling techniques such as chilled beams, heat recovery wheels, and displacement ventilation to reduce the cooling and ventilation loads.
- Utilizing high-efficiency lighting with controls such as daylight and occupancy sensors to reduce lighting use while increasing occupants' productivity.
- Engaging a campus-wide building automation system to help reducing energy use.
- Featuring renewable energy generation such as installing large solar Photovoltaic arrays on the campus's roofs for electricity generation, as well as solar thermal arrays for heating domestic water.

d) Water conservation:-

- Implementing several strategies to reduce the amount of potable water needed to irrigate the KAUST campus. Including treating gray and black water to be used for irrigation.
- Planting native vegetation and adaptive plants on site that require less irrigation, to reduce irrigation water demands.
- Utilizing efficient drip irrigation systems to reduce the amount of potable water lost to evaporation and runoff. In addition to irrigation water saving.

e) Operations, maintenance and post occupancy evaluation:-

- Implementing a sustainable operations plan which includes using green cleaning materials and an extensive recycling program that includes composting of all food waste.
- Using electric vehicles for all services and maintenance staffto reduce their fossil fuel consumption, which would complemented with the installation of renewable energy powered vehicle charging stations.
- Implements plans by the campus facilities management to continuously assess the energy use and the occupants' thermal comfort.
- Assessing the effectiveness of mechanical systems to guide adjusting their settings to ensure maximum occupant comfort.
- Measuring all energy and water consumption by the campus's automation systems, sub-meters and controls installed to allow for future increase in efficiencies of all systems.

Summary and Conclusion:-

The research has introduced the environmental considerations for green and sustainable architecture, it has identified the essential factors that affect green building design and sustainable urban development. The study has also defined various elements and procedures required to achieve a successful green architectural design. This research has found that understanding the various environmental considerations for sustainable architecture and implementing green design can improve buildings energy efficiency and generally enhance the quality of the built environment in hot countries, such as Saudi Arabia.

The research method has included a case study approach to analyze and evaluate existing environmental considerations and sustainable building examples in Saudi Arabia. This research paper finds that the implementation of sustainable and environmental design need resilient and endless support from the government and the building industry.

The paper also finds that reintroducing passive and green strategies from vernacular and Islamic architecture heritage can boost contemporary sustainableandgreen built environment in the Gulf region.

The research recommends that the concerned governments should obligate and implement adequate regulations to help reducing the high consumption of energy and natural resources as well as guarantee a prosperous future for new generations. The key to a successful application of sustainable strategies and promoting environmental design resides witheducating and training architecture and engineering students, as well as professionals. Reversing the

current trend of degradation in the environment requires strong marketing of the concept of green design, and ongoing education of the public and stake holders.

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