The Old City of Ghadames: an epitome of desert environment engineering

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Abstract

The Old City of Ghadames (OCG), one of Libya's major desert cities and a world heritage site, played an important role as a cultural and trade center between the Mediterranean and Africa for over 1400 years. This role was enforced largely by the city's sustainability that was the product of highly developed desert environment engineering practices. The objective of this paper is to analyze these practices and demonstrate their effectiveness in light of the present challenges to the city's sustainability. The city's urban planning, architecture and adobe construction were perfect adaptations to social needs, religious values, resource limitations, harsh environmental conditions and remote location. Planning was conducted on the levels of the oasis, the city, the neighborhood, the street and finally, the individual house. Each of the city's 7 neighborhoods had its own properly located and sized public places. The 4storey house design was based on human scale and needs. Buildings were connected "wall-to-wall" for insulation and maximum space utilization making the neighborhood one large building. The streets were covered to provide protection from heat, cold, wind, dust and rain with openings for light and ventilation. Effective protection against the harsh environmental conditions was also achieved through site selection, compactness, use of highly insulating building materials and routine maintenance. Water - a precious commodity in the desert – played a major role in the city's sustainability providing building materials and food. This role was effected through well-developed water resources management practices. The OCG was, thus, an outstanding example of sound engineering practices providing comfort, functionality and costeffectiveness in a uniquely "Ghadamsi" architectural style and traditional construction materials and techniques; hence the well-deserved historic name

"Jewel of the Desert". However, environmentally-induced aging and the interruption of routine maintenance have caused serious damages to many of its buildings forming a real threat to its sustainability and spurring efforts to conserve it with tangible results despite the unconventional challenges associated with such operations.

1 Introduction

The old city of Ghadames (OCG), one of Libya's major desert cities and a UNESCO registered world heritage site, played an important role as a cultural and trade center between the Mediterranean and Africa for over 1400 years. This role was enforced largely by the city's sustainability which was the product of highly developed desert environment engineering practices.

The city's urban planning, architecture and adobe construction, water and agricultural engineering were perfect adaptations to social needs, religious values, resource limitations, harsh environmental conditions and remote location making the OCG an outstanding example of sound engineering practices providing comfort, functionality and cost-effectiveness in a uniquely Ghadamsi architectural style and traditional construction techniques; hence the welldeserved historic name "Jewel of the Desert".

The Jewel is loosing its luster, however, because of environmentally-induced aging and the interruption of routine maintenance resulting in the deterioration of many of its buildings and forming a real challenge to its sustainability. Efforts are being made to conserve it, however, with tangible results despite the unconventional challenges associated with such operations. The objective of this paper is to analyze these practices and demonstrate their effectiveness in light of the present challenges to the city's sustainability. To achieve this objective, the city's geographic and climatic characteristics are summarized along with its major urban features. This background is followed by an analysis of the environmental considerations in the fields of planning and architecture, building materials and construction techniques, and water and agricultural engineering. Based on this presentation, conclusions are made stressing the advanced environment engineering practices and their role in the city's sustainability.

2 Geography and climate

The OCG was located about 600 kilometers southwest of Tripoli, Libya's capital and a few kilometers from the Tunisian and Algerian borders. The city - occupying about 8 hectares of the oasis total area of 215 hectares - lies semiisolated within a completely arid uninhabited zone. Its elevation is about 350 m AMSL.

Desert climatic conditions prevail with dry hot summers and cold winters. Extreme summer day and winter night temperatures range from 55.2 °C to -6.5 °C while annual temperatures average 22.2 °C. Dryness is reflected in the low annual relative humidity which averages 33 %. Consequently, evapotranspiration rates are extremely high averaging around 2700 mm per annum.

Rainfall is scarce in Ghadames with an average annual precipitation of 36 mm. The maximum recorded annual, monthly and daily rainfall intensities were 182, 65.8 and 44 mm, respectively.

Dominant winds are north to north-east and easterly in the summer and westerly in the winter. Dusty southern winds dominate during the spring and fall. Average wind speed is 3.5 m/s, but may reach 7 m/s during sandstorms.

3 Major features of the Old City of Ghadames

The OCG lies within the south-western part of the oasis which encloses it almost completely. It consists of seven neighborhoods locally known as streets surrounding the eternal Ain AlFaras spring, the source of life for the city throughout its long and prosperous history (Fig. 1).

3.1 Neighborhoods

A neighborhood is comprised of a main "large" street with several "smaller" branching alleys leading to "yet smaller" passage ways. Streets, alleys and passage ways are curved. Houses are located on the street, alleys and passage ways. Each neighborhood had its properly located and sized public places including a main mosque, a number of mosques for men, women and children, zawias, Quranic schools and public squares utilized for different cultural activities. Bench-like sitting places for different age groups are placed at strategic locations along the streets, alleys and passage ways. The streets, alleys and passage ways are covered except for light holes regularly spaced along them.

The cities neighborhoods contain over 1600 buildings comprising about 1350 houses, 242 public and private (shops, stores, etc.) buildings, 23 mosques, 10 zawias, 10 Quranic schools, 7 entrances and 7 gates [1].

3.2 Houses

Ghadamsi houses are practically identical in their architectural design which is a perfect response to the human needs and scale and to the economic and environmental constraints both on the individual and community levels. They differ only in areas which range from 30 to 80 m2 with larger houses belonging to larger and/or richer families. A house is typically constructed in four levels with a total height of about 12 m.

The ground floor consists of the entrance and the farming tools store. Stairs from this floor lead to the bathroom and thence to the living room in the first floor. The living room which is the most used space in the house is heavily decorated with gypsum works, ornaments, brass works, mirrors for extra space, light reflection and personal use, and local handicrafts making it a mini-museum with eternal attraction for family and guests. It also contains small storage spaces for different purposes. It is surrounded by the Kubba, a socio-religious miniroom, main bedroom and boys room. The split third floor consists of girls room while the fourth split level contains the food storage rooms. The kitchen is

located on the roof to allow for smoke to raise and disperse into the atmosphere away from the living areas below. Every house has a special, more durable wall on its roof which is reserved for women and children to walk on during daytime away from men in accordance with socio-religious norms.

Conversely, the outside of the house is very simple with no decorations or markings except for a standard door made of palm-trunk sections thus exhibiting a unique simplicity and equality between residents regardless of socio-economic or other status privileges.

Natural lighting of the house during the day and ventilation are secured through a large light hole in the roof projecting into a smaller one in the living room floor thus ensuring that light and air reach all floors. The roof hole is closed during rain and sand storms. Other small "windows" on the outside walls are used for the same purposes.

A unique, but common feature of all spaces in the Ghadamsi buildings is the full respect for human scale. Another is the full utilization of all spaces in the house. This way, the house, although very compact, is quite functional and comfortable at the same time. This compactness translates into minimum materials and energy inputs making the house cost-effective and, thus, available to most if not all families.

House walls are laid next to one another in bee-hive like structures. Spaces are intertwined in such a way that units of one house may lie above or below those of other houses. This way, the city acts as one monolithic structure with exceptional abilities to withstand wind forces, dust, heat and cold.

4 Environmental considerations as a basis for planning and architecture of the Old City of Ghadames

Planning of the OCG was conducted on the levels of the oasis, the city, the neighborhood, the street and finally, the individual house. The city was sited within the oasis and not away from it as is the case commonly for most oasis cities. This way, the city was protected from wind storms which are dampened by the large number (over 30,000) of palm trees (Fig. 2). The trees and greenery of the orchards surrounding the city also provided continuous shading and humidity necessary to counter the heat and dryness of the city's climate.

The narrow curved corridors (streets, alleys, passage ways) acted as tunnels for air/wind coming into the city breaking strong winds as they go along from narrow to narrower corridors.

In addition to its advantageous location, the city's orientation, in a southerlynorth-easterly direction, ensured protection from the dominant winds and maximum ventilation. The presence of a hill south of the city provided protection from the sandy southern winds which pass over the city to the oasis (Fig. 3).

To minimize exposure to the harsh ambient environmental conditions, city buildings including houses did not have yards. Moreover, the streets, alleys and passage ways were covered to provide protection from heat, wind, dust and rain with openings (shafts) for light and ventilation. Houses and other buildings had a minimum of relatively small windows. They were also connected "wall-to-wall" for maximum insulation and space utilization making the neighborhood one large building with one rooftop. Effective protection against the harsh environmental conditions was, thus, ensured through site selection, orientation, building design, compactness.

Buildings were densely compacted between the Ain AlFaras spring and the oasis orchards to minimize walking and transporting distances making the trip between the city and oasis short and scenic at the same time.

Daytime lighting of covered streets, alleys, passage ways and buildings utilizing solar energy provided a clean and sustainable source of energy indefinitely.

5 Environmental considerations as a basis for building materials selection and construction technologies

5.1 Structural elements, materials and methods of construction

The structural elements and materials of construction of a Ghadamsi house are shown in Figure 4. Foundations are made of hard limestone "rocks". Walls are made of adobe blocks bound with mortar made of the same material (white and black soils containing some clay). To prevent capillary motion of water into the adobe walls, foundation rocks are placed without a binder. Wall thickness is highest at the ground level and decreased upwards in response to the decrease in loads on these walls. They are plastered from inside using fine local gypsum and whitewashed with lime. The outside of the walls is plastered with clayey soil. Top walls are crowned with a thin parapet with triangular shaped corners bearing a unique Ghadames design.

Roofs are made from palm trunks cut into semicircular sections and placed such that the flat side of the section is perpendicular to the roof plane (Fig. 4). This arrangement ensures maximum structural strength. Trunk sections are covered with palm branches tightly jointed and tied together to form one big mat. This mat is covered with palm fronds (leaves) to ensure impermeability of the adobe mix mortar which is placed on top of it. A thin layer of gypsum is added to ensure usability and water tightness.

5.2 Environmental considerations

All building materials are available locally. Construction and rehabilitation are performed by local skills employing traditional methods developed over many centuries. Thanks to this availability of materials and skills, the city's sustainability has been maintained for over 1400 years [2]. Moreover, using the same architectural patterns and the same building materials in all buildings resulted in a unique Ghadamsi architecture that is original, simple, economical and attractive.

Construction and rehabilitation activities are usually conducted with due consideration to optimum environmental conditions. Practical experience has proven that such activities are best conducted during winter to summer seasons,

but not during the fall. Use is also made of solar energy which is available throughout the year in drying of materials and structural elements.

Adobe blocks are the main component of construction in the old city along with binding mortar made of the same materials. The use of these materials, which have excellent insulating properties, along with the compact intertwined walls of sufficient thickness along with the architectural considerations outlined above limit the temperature variations inside the city significantly between 15 to 25 °C in contrast to the large variations around it (- 6.5 to 55 °C) [3].

Part of this dampening may also be attributed to the use of roofs constructed of several layers of insulating materials, external gypsum plastering and whitewashing of roofs and facades with light reflecting lime. It was estimated that only 15 % of the energy falling on buildings actually reaches the inside of these buildings [3]. Moreover, the transfer of energy (heat or cold) is gradual because of the relatively longer time it takes to cross several insulating thick layers thus creating a dampening effect. Another part can be attributed to the lack of yards and the use of only a few small openings in the buildings as was explained above.

The use of materials was minimized as a consequence of optimum design resulting in conservation of materials and energy. Different sizes of adobe blocks are used according to loads and heights. Demolition materials were recycled for use in making new adobe blocks, mortar or fill for floors and roofs. Construction and rehabilitation operations were carried out collectively so that the best skills are involved ensuring quality control, speed of construction, and best use of materials. Customary rehabilitation practices during certain social occasions also provided an excellent guarantee of efficient rehabilitation thus minimizing deterioration and subsequent structural damages.

Buildings were made of the same materials employing the same traditional techniques. Therefore, they presented a cost-effective and sustainable means of construction.

The above consideration make the buildings sound proof as well ensuring a high sense of privacy in a very compact environment.

6 Environmental considerations as a basis for water supply, sanitation and agricultural engineering

The city was located around the eternal Ain AlFaras spring with the orchards surrounding the city demonstrating clearly the advanced sense of planning of the city's founders. This sense was confirmed further by the extensive leveling operations undertaken to render some of the land around the spring amenable to irrigation by gravity and the transfer of good soil to replace local soil which is not suitable for agricultural uses.

Water – a precious commodity in the desert – played a major role in the city's development, prosperity and sustainability. This role was a direct result of a well developed water resources management system. Water was distributed through a networks of five canals passing through or around the city and used preferentially at specified locations and times for drinking followed by ablution,

cleanliness, and, finally, for irrigation of orchards (Fig. 5). Irrigation water was allocated between farmers in accordance with sound agricultural practices based on crop water requirements and orchard areas. Interestingly, the flows in the five canals were proportioned in multiples of 3 with relative values of 1:3:9:27:81. Irrigation water uses, sales and ownerships were documented and updated annually as part of the management system responsibilities as were the daily allocations and canal operation and maintenance operations (4).

Thanks to the fertile soil transported to the orchards from outside the city and to the natural fertilizers consisting of human excreta collected from houses in the city and animal droppings in husbandries around the city, these orchards were quite productive supplying in excess of the city's needs of cereal, vegetables and fruits of all kinds. It is these fertile evergreen orchards with their countless proudly standing palm trees that earned the city its historic well-deserved name "Jewel of the Desert".

The green belt surrounding the city has also made the city inhabitable; it provided a large wind breaker, sand filter and a haven for farmers and nonfarmers alike especially during the extremely hot summer days. Evapotranspiration from the plants and trees supplied the humidity direly needed to counter the extra dry climate.

Moreover, the orchards provided a sustainable source of food and building materials which were essential for sustenance of life and prosperity of the city.

Domestic water supply was secured through assignment of specific locations for this purpose as well as allotting specific times during which canal accessibility was restricted to drinking water collection. Moreover, canal branches were extended to a few houses to provide domestic water continuously. As the spring was artesian, water was naturally hot making it suitable for bathing throughout the year providing yet another energy saving measure.

Water use inside the houses is necessarily economical. Traditionally, multiple uses are practiced so that the amount brought to the house and that disposed of outside the house or into the cesspit are minimum.

All Ghadamsi houses were provided with toilets. Because of the severely destructive effects of water on adobe – the material of construction in Ghadami houses – dry toilets were used. These toilets were located next to the living room for easy access. The cesspit into which these toilets emptied was closed completely so that odors were confined. Ash was added frequently to the blacksoil to adsorb any malodors. Upon filling, these cesspits were emptied through an opening on the street/alley and used as soil fertilizer. Fertilizers were so valuable that public toilets were provided inside the city as well as along passage ways in the oasis.

Rainfall was very scarce in Ghadames. As a result, adobe was used for construction of city buildings and orchard walls. However, to counter the rainstorms, building roofs were drained into adjacent farms or into the water canals inside the city. In places where this was not possible, special rainwater collection canals were provided. Ingenious designs ensured that rainwater was conveyed long distances to low-lying areas for disposal. Special shouts made by women standing on rooftops alert the residents to the rainstorm during late night hours so that they raise immediately to manually drain their house roofs.

7 Conclusions

Based on the analysis of the different environmental considerations applied in the design and execution of the old city of Ghadames, the following conclusions are made:

- 1. The old city of Ghadames is an outstanding example of an environmentally engineered desert city where human needs are met satisfactorily through full understanding of environmental conditions and natural resources;
- 2. The city's advanced architecture, building technology, water supply, sanitation and agricultural practices reflect a high level of planning, design and execution that can only be achieved by highly skilled persons with sound experience in these fields;
- 3. The Ghadames city model owed its success to the fact that the it provided unique technically simple solutions to complex socioeconomic and environmental constraints; full understanding of human needs and scale, environmental conditions and natural resource limitations of the area were demonstrated in the sustainability of the city for many centuries;
- 4. The local identity of the city is well represented in the city's architecture, building technologies, water resource management and agriculture;
- 5. Water played a major role in the sustainability of the city particularly as a source of building materials used effectively in the city's buildings. This role was ensured by excellent water resources management practices;
- 6. Sustainability was ensured through complete reliance on local materials and skills and sound environment management. Resource reclamation, recycling and reuse and conservation were practiced in all area including construction, water and wastewater, and agriculture.

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