The Smart Mosque of the Arabian Gulf: Solutions from the past for a sustainable, energy-efficient Mosque

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Abstract

This study examines the smart mosque as a concept, developed through innovations in materials and technologies adopted to provide thermal comfort conditions and energy- efficient environments, in order to promote a sustainable mosque. The paper first provides a theoretical underpinning of the smart solutions applied in historical mosques with a critical review of its philosophical and practical framework. Second, it will examine the efforts made by the Gulf states authorities in the last decade to pursue smart mosque projects in the region, by reviewing a number of possible smart solutions which can be applied to the mosques in order to achieve sustainability in design. Although this concept is relatively new, this paper will argue that there are many historical mosques in the Arabian Gulf, in addition to many examples drawn from the various Islamic regions, that responded to the prevailing environmental conditions, within the technological and scientific advancement at the time, and had the 'smart design concept' rooted in its design through its architectural and interiors programs.

1 Introduction

Throughout the Islamic history, the mosque has represented itself as a quintessential building of Islamic architecture, expressed by its domes, minarets, mihrabs, ornamentations and many architectural and spatial elements. While its architectural appearance has evolved gradually, the vast regions of Islamic lands and the Islamic civilisations have contributed in advancing the architectural and construction mechanism to accommodate the climate and social-economic conditions, based on the variety of materials, designs and availability of resources. Khaled Azzam (2008) argued that 'harmony between man and nature and vertical link with God is reflected in traditional Islamic architecture and city planning where the master-builders always sought the full integration of the built environment with its natural surroundings.' [1] In essence, the mosque as a building have played a major role in prevalence of the Islamic literature of art and architecture, but most importantly, it embodied the Islamic philosophy concept of sufficiency 'Ektifa'a' 'اكتفاء' in its physical structure to meet the comfort levels of thermal conditions and provide air ventilation systems, resulting in enhancing the spirituality and tranquillity of the place by maintaining a sustainable interior environment.

What follows is an attempt to identify those old inventions to create a sustainable historical mosque, which seems significant to understand the contemporary concept of 'smart mosque' and the recent endeavours of building smart mosques in the Arabian Gulf region, particularly in The United Arab Emirates.

2 An Architectural Treatise for the Historical Mosque Innovations: Constructions Methods and Materials

From the early establishment periods of Islam, the mosque has been the central of the Islamic communities and retained its position throughout the Islamic history. Even though, worshippers will visit the mosque five times a day to perform the five obligatory prayers, its role extends far more and beyond its religious purposes, and therefore, it cannot be defined only by its formal architectural context, but as a sacred place, derived its identity from the spirituality and socio-political meanings drawn from Islamic faith, and 'by definition one that transcends regional boundaries in its symbolic and functional sense, if not in its formal realisations' [2]

The first mosque built in Islam was in Madinah, which was the house of the prophet Mohammed (PBUH) and acted as model for the hypostyle mosque in Arabian Peninsula and the Islamic region in general. The main dominant feature was the central courtyard, which embraced by muslim builders as design element for the mosque for many centuries later, A spatial arrangement that transcend through time and adopted by many Islamic cultures, such was the case in the great mosque of Damascus built during the reign of Umayyad caliphate al-Walid (705-715), the mosque of Ibn Tulun built in 884 during the Tulunids period and al-Aqmar mosque constructed in 1125 dating to the Fatimid era (Fig 1).

In addition to its social and political functions, the courtyard as an exposed space to the sky, represent the aspiration of the worshipper's heart towards Allah. But, at the same time, the courtyard serves as a cool air reservoir mainly in hot-arid climates [3]. The central position of the courtyard in the mosque's architectural composition was intended to be an open space, typically enclosed by porticos 'Riwaq' and also as a transitional spatial space leading to the main prayer hall, the courtyard openness and position allowed the air to flow into the interiors via the Riwaqs which helped in cooling the interior spaces and increased the air velocity based on the wind speed, which aid in the air ventilations process in the interior spaces, utilising the positioning of the openings and layouts of mosque's components.

Fig. 1: View of the prayer hall arcade from the courtyard, left, from the top: The Great Mosque of Damascus; the mosque of Ibn Tulun and below is a view of the al-Aqmar mosque's courtyard. [4,5]

Apart from the courtyard, the Muslim builders very often plant palms and trees within the vicinity and around the exterior boundary wall of the mosque to provide shade and to control the winds. The passive design strategies were employed by taking advantage of the natural urban environment, but it was also dependant on the convenience of availability of skilful craftsmen and natural materials, such as clay bricks, palm, fronds or trunks, stone, stucco, wood and many others natural resources.

2.1 The Historical Mosques of the Arabian Gulf: Environmental Solutions

In the Arabian Peninsula, there were also cleverly designed ventilation systems, implemented in many historical mosques and palaces, like those in the mosque of Qasr Al-Hokoum in Riyadh, in central of Najd region, the mosque dated to 1810 AD and built during the reign of first Saudi state. The mosque was built of adobe which have the ability of operating as an insulation against the heat during summer season due to its natural properties as 'It has good resistance to heat travel through the wall, owing to its thermal mass and the organic property of its constituent compositions. Consequently, lesser cooling energy is required in summer, when brought under comparison with modern building materials' [6]

Furthermore, in Riyadh, like all Najdi towns, the walls were thick with featureless facades, except where they were perforated on upper levels by patterns of openings in the form and lancets to provide the circulation of air and to allow the sunlight in. [7] (Fig. 2).

Fig. 2: The details lancets and ventilation triangles of Subalat Mudi in Dir'yyah. Source: (Facey, 1997, p. 104, p. 95). [8]

The contemporary version of the mosque was constructed in 1992 where the Jordanian architect Rasem Badran was commissioned by the Riyadh Development Authority (RDA) to design the mosque with traditional Najdi architecture, nevertheless, Badran's version was effectively responsive to the environmental conditions by adopting similar construction methods used in the old version of the mosque, in his design, he was not only respecting the traditional local architecture but also the innovations that was used in the old mosque to provide smart solutions against the hot and harsh climate of the deserts (Fig. 3) those solutions are as follows:

1. 'Openings for natural light and ventilation are provided above each column head, and columnar structures and beams contain the ventilation ducts of the air-conditioning units on the roof. Each unit can be controlled individually to adjust cooling needs according to the occupancy of the mosque, resulting in reduced operating costs.' [9]
2. The exterior walls of the mosque are clad in local limestone, and the restrained use of small triangular openings organised in patterns both resembles traditional building practices and helps to diminish the harsh glare of the sun in the interior spaces. [10]
3**.** He designed series of courtyards, which pre-existed in the old mosque, to recreate the spatial connection between the mosques urban and interior space to facilitate the circulation of movement of worshipper across the site while providing an ecological solution by allowing the air to ventilate through the mosque's spaces.

The adaptation of the architecture to the local environmental culture was also witnessed in the sultanate of Oman, at the south east of the Arabian Peninsula, where the country's historical mosque architectural scene offers interesting insights into the environmental designs due to the geographical nature of the country.

Fig. 3: Badran's study of the lighting, ventilation tower and air conditioning systems. [11].

The historical mosque of Oman has shown environmental design which responded, in turn by adopting few, but effective construction strategies, that can be summarised as follows:

1. The inner region mosques, which were dominated by the Ibadi branch of Islam, can be described as austere in its architectural representations. Those mosques are characterised by an oblong prayer hall with windows placed on the side walls of the qibla wall- the wall oriented towards mecca, with relatively high ceiling which allows the hot air to rise and results of creating air circulation through the windows and the small openings placed on the top of the walls.
2. Another environmental architectural features that are commonly found in the mosque of Oman, is the use of buma, a small copula constructed at the east-southern corner of the prayer hall and opened to the roof that is made of palm trunks, palms branch and reeds. The buma itself, can be considered as one of the remarkable traditional Omani smart solutions to prevent the dust and rainfall from soiling the mosque or damaging the roof and the walls of the interiors. Examples can be found in the mosque of Musilmat (Fig 4).

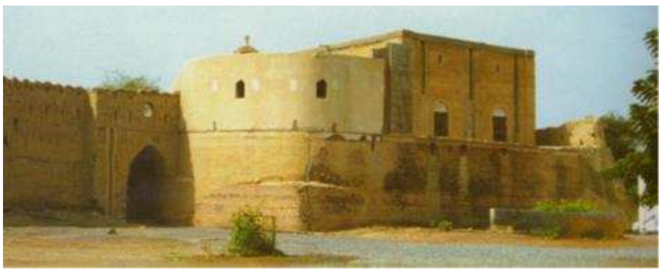

Fig. 4: Musilmat mosque, showing the windows and buma. [12]

3. The ablution, which is an essential ritual to be performed by the worshipper before conducting the prayers; a ritual process that required the use of water on the exposed body parts, whereas the water facilities are usually found in the direct surroundings or in the frontcourt of the mosque, but in the case of Omani traditional mosque, the ablution area is a major architectural elements that has responded to the ecological conditions with consideration of the availability of water resources, where the potential availability of water in the aquifers in the mountain, runs in tunnelled water channels (locally known as falaj) and link the aquifers in the mountains to the cultivable land in the plains, and considered to be the determined factor of the location of the mosque.(Fig. 5) Melamid (1986) defined 'falaj' as, 'the termini of falaj, or qanats, the underground channels that bring water from aquifers to cultivated areas, were the prime factor in the siting of settlements in this desert region.'[13]

The water here is utilised based on the proximity of the water channels to the mosque and thus, resulting into minimising the time and cost of providing the water required to perform the pre-prayer ablution process for five times a day, which typically consume a large amount of water.

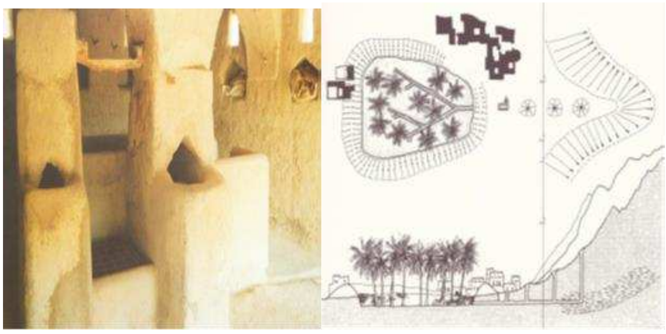

Fig.5: To the left; Ablution area Omani mosque, with falaj running underground. To the right; Schematic layout and section of a falaj showing the associated gardens which have been excavated down to the falaj level. [14] [15].

While Oman historical mosques has shown different smart solution to accommodate the environmental conditions**, the historical mosque of Bahrain**, on another hand, has achieved more different approach to tackle the hot-arid climate, that usually last for most of the year, except the months from November to March, where the weather become mildly cooler. Furthermore, when we look at Bahrain, it was predominated by the neighbourhood mosques 'freej', In recent history, there were only two Friday mosques which were built at the core of the Muharraq island adjacent to the ruler's palaces: a) Sheikh Isa Bin Ali Al-Khalifa Friday mosque, built in 1870; and b) Sheikh Hamad Bin Isa Friday mosque also known as the southern Jmai'a, which has been demolished since then. [16] the two mosques were designed with wind tower (known as 'malqaf' or 'badgir') and historically, have been found in many coastal regions from north Africa to Pakistan, this tower represents an environmental architectural instrument that employed the passive technology, and can be described as one of the smart innovations that Islamic architecture have produced.

Fig. 6: Wind tower in sheikh Isa Bin Ali Place. [17]

3 Advancement in Technological Applications in 21st Century Mosques

In Islam, there are no sacristy associated with the mosque elements, on contrary to Christianity or Judaism, the Quran or hadith-prophet's teachings, have not specified any guidelines or constrains when it comes to designing a mosque, but it emphasised that the mosque must be a clean space oriented towards mecca. The contemporary mosque today, is a result of inspirations, influences and innovations derived from many cultures, that evolved throughout the history. In this sense, the mosque has the flexibility to absorb new accretion of architectural design elements.

The global trend of designing buildings with low-carbon emissions to maintain a low energy consumption is forcing the mosque as a building to implement the strategies of passive design, but at the same time provide the mosque's visitors with the comfort of thermal and air ventilations levels. In the region of the Gulf, where the buildings are exposed to the heat most months of the year, the issue is even more imperative, however, the current efforts to implement these strategies in the region are unsatisfying and don't measure up to the international achievements in these domains.

The most common challenges of managing mosque energy consumption, can be addressed as follows:

1. **The pattern of usage of the mosque in relation to the operation of the air-conditions:**

The inflow of users to the mosque at five times during the day to preforms the prayers, which usually takes 15 to 20 minutes, with exception to the Friday and Ramadan prayers which last longer. However, the mosque for the rest of the day stays unoccupied, and through a close inspection, it was found that the air-conditioning still operating for a significant portion of the day, which results in wastage of energy. In fact, it was also found that often, lights of the interior spaces and the exteriors were not switched off after the mosque's visitors leave the premises.

In 2016, the Abu Dhabi Executive Affairs Authority collaborated with Masdar Institute of Science and Technology to create alternative energies solutions, and they have found that 'two of the appointed prayer times coincide with peak electricity usage in the middle of the day, when air-conditioning consumes up to 75% of the UAE's electricity during the summer months. As the thousands of mosques spread across the UAE fill up with worshippers who require high levels of air-conditioning, demand for electricity is increased, which is why developing optimal energy management approaches to deal with cooling are essential to the UAE's energy security.' [18] the research orientated institute attempted to develop a device that can control the usage of electricity and their efforts was successful in terms of developing 'tailored sensors which ensure mosques' air-conditioning systems are consistently utilized in a more optimal way, so as to achieve thermal comfort with minimum energy requirements' [19]

Another approach to reduce energy consumption, is to design the mosque's façade with intention to provide the suitable amount of the natural energy exploitation, to minimise the energy required for ventilations, lighting and cooling.

2. **The control over the water wastage**

As mentioned earlier, the ablution ritual consumes large amount of water, and this process leads to great wastages of water resources. The crisis of water scarcity is a major global issue and, especially in the Gulf region, for example 'In the UAE, for example, 51 per cent of the water supply comes from groundwater, a resource that is predicted to become depleted in the decades to come.' [20] the pressing threat of desertification is high, and the current progress to improving water management and provide alternative, sustainable solutions are very little.

Considering the wastage of water in performing the ablution five times a day, and the increasing number of populations in the region, a correcting measure should be implemented. One approach is to create a simple recycling system, which can collect, treat and reuse the ablution water. (Fig. 7)

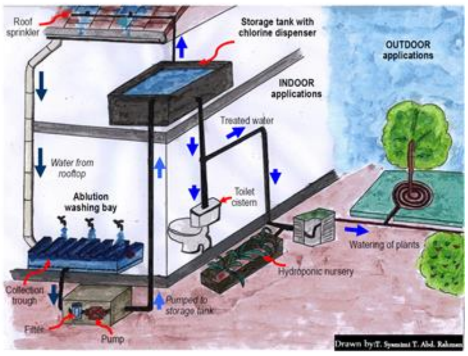

Fig 7: a drawing of simple recycling system for the ablution water. [21].

3.1 Other technological alternatives for a smart mosque

1. The use of solar panels system to generate energy to be utilised for running the air-conditioning, lighting and many other energies required functions of the mosque.
2. The use of innovative technologies in maintaining the energy, such as the thermal energy storage system which is based on the concept of phase change materials (PCM). The mechanism of this system uses a building mass as storage medium and adopted the employment of night-time cooling

concept, furthermore 'they can either capture solar energy directly or thermal energy through natural convection. Increasing the thermal storage capacity of a building can increase human comfort by decreasing the frequency of internal air temperature swings so that the indoor air temperature is closer to the desired temperature for a longer period of time.' [22]

3. LED Lights:

In addition to its electrical characteristics, the LED lights consume less power energy to function, an advantage that can be efficient to attain a lower electrical energy consumption.

4. Double-glazed windows.

Which act as insulation, reducing the external heat flow in transiting into the interiors, which results in less usage of the air-conditioning.

4 Conclusions

The review of the historical mosque has yield that the mosque in the past has responded to the environmental conditions by adopting solutions that can be described as innovative and smart in nature. Meanwhile, the main issue of the mosques in the Gulf is the high rate of building new mosques, especially on the freej level, where many environmental aspects are often disregarded. The focus should shift to utilise simple smart solutions as implementing sensors, water recycling systems and solar panels. The idea is not only to build mosques with smart technologies but to integrate these technological applications into the current mosques, to maintain a sustainable, environmental-friendly mosques.

References

[1] Adam, R., C. D. Hardy, M.P. & Charles, "Tradition Today Continuity in Architecture & Society", The Southampton: WIT., p. 100, (2008).

[2] Khan, H. (1990). The Architecture of the Mosque, an Overview and Design Directions. In Expressions of Islam in Buildings. Hayat Salam, ed. Singapore: Concept Media/The Aga Khan Award for Architecture. Great Mosque and Redevelopment of the Old City Centre Project Brief. Compiled by the Aga Khan Award for Architecture. Geneva: Aga Khan Award for Architecture, 2013.

[3] Sthapak, S., & Bandyopadhyay, A. *Courtyard houses: An overview.* Recent Research in Science and Technology, 6(1). (2014).

[4] R. Ettinghausen, O. Grabar, and M. Jenkins, *The art and architecture of Islam 650-1250*. New Haven, CT: Yale University Press, 2001.

[5] "Jami' al-Aqmar | View of the prayer hall arcade from the courtyard," *Archnet*. [Online]. Available: https://archnet.org/sites/2310/media_contents/6447. [Accessed: 20-Feb-2019].

[6] Sthapak, S., & Bandyopadhyay, A. *Courtyard houses: An overview*. Recent Research in Science and Technology, 6(1), (2014)

[7] [16] Al-Khalifa, H., "The Friday mosque of the Arabian Gulf: defining its spatial and formal languages-1975-2010," PhD thesis, Cardiff university, Cardiff, 2017.

[8] Facey, W., Dir'iyyah and the First Saudi State. 1st ed. London: Stacey International, (1997).

[9] [10] "Great Mosque of Riyadh and the Old City ... - archnet.org." [Online]. Available: https://archnet.org/sites/2167/media_contents/28377. [Accessed: 24-Jan-2019].

[11] J. Steele, *The architecture of Rasem Badran: narratives on people and place*. London: Thames & Hudson, 2005.

[12] [14] A. Al-Salimi, H. Gaube, L. Korn, F. al- Hafiyan, R. Kanaan, B. Mershen, and S. M. N. Priestman, *Islamic art in Oman*. Muscat: Ministry of Heritage & Culture, 2014.

[13] A. Melamid, "Interior Oman," *The Mutual Dependency of Force and Law in American Foreign Policy on JSTOR*, 01-Jul-1986. [Online]. Available: http://www.jstor.org/stable/214149. [Accessed: 14-Feb-2019].

[15] Costa, P. (ed), *The Journal of Oman Studies*. Volume 6, Part 2. Edition Unstated Edition. Ministry of National Heritage and Culture. (1983).

[17] Habeeb, R. *Test of Airflow in a Mono-directional Wind-catcher for various Wind Conditions using Computational Fluid Dynamics,* National Conference on Emerging Trends of Energy Efficiency in Buildings, Roorkee, India, (2012).

[18] [19] "Energy-Efficiency for a 'Smart' Mosque," *Khalifa University* | جامعة خليفة, 02-Jan-2019. [Online]. Available: https://www.ku.ac.ae/energy-efficiency-for-a-smart-mosque/. [Accessed: 22-Jan-2019].

[20] D. Bardsley, "Arab world's water scarcity alarms experts as region's population soars," *The National*, 09-Nov-2017. [Online]. Available: https://www.thenational.ae/uae/arab-world-s-water-

scarcity-alarms-experts-as-region-s-population-soars-1.673941. [Accessed: 15-Jan-2019].

[21] Suratkon, A. *SmartWUDHU': Recycling Ablution Water for Sustainable Living in Malaysia,* Journal of Sustainable Development; Vol. 7, No. 6; (2014).

[22] Pasupathy, Velraj & Seeniraj, *Phase change material-based building architecture for thermal management in residential and commercial establishments.* Renewable and Sustainable Energy Reviews Vol. 12, No. 1 January 2008 pp. 39 - 64. doi:10.1016/j.rser.2006.05.010