

The Principles of Sustainability in The Tower House of Shibam

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Abstract:

With the increasing interest towards the need to achieve the principles of sustainability globally in all aspects of life in general and architectural activity in particular, as it has a greater impact on the environment, It has become necessary to focus on re-examining traditional Yemeni architecture and its elements, as the Yemeni urban heritage, contains many pieces of evidence that take precedence in the use of natural building materials and techniques within the realization of their social, economic and cultural characteristics, which have proven over time to the extent of their harmony and suitability for the environment. This paper aims to study the architecture of the traditional tower houses in Shibam and their natural environmental treatments which it was able to achieve comfort for its residents, and that is through studying its characteristics, dimensions, and description of its spatial organization, and thus analyzing it and its elements to derive what can be used to achieve sustainability for our contemporary architecture.

Keywords:

Traditional Tower House, Shibam, Sustainability

1. Introduction

The idea of sustainability started after Brutland defined it as “The development that meets the needs of the present generation without sacrificing or harming the ability of future generations to meet their needs.” Which is represented in three pillars: environmental, social, and economic sustainability, this definition was published by the non-governmental committee established by the United Nations in 1987. [1]

Based on the importance of achieving the principle of sustainability and the extent of its impact on the environment and human beings, it was necessary to take advantage of our traditional heritage, which is full of many applications through which our traditional architecture was able to reach the urban environmental balance, This embodies the saying of the pioneer of mud architecture in the Arab world,

Hassan Fathi, “The architect should not assume that this heritage is an obstacle to him, and when all the power of human imagination is supported by the weight of a living heritage, as the resulting artwork is far greater than any artist can achieve when he has no heritage to work with or when he willfully discard his heritage”. [2]

The Republic of Yemen is located in the southwest of the Arabian Peninsula in the continent of Asia. In an important strategic geographical location, it has eastern borders with the Sultanate of Oman, northern with Saudi Arabia, western with the Red Sea, and southern with the Arabian Sea, accordingly to the diversity of terrain in Yemen between mountains, plateaus, coastal plains and deserts, different architectural styles have resulted according to the location, climate, and available natural resources. And With regard to the unique and diverse traditional Yemeni architecture, which contains many architectural elements, including the phenomenon of the tower house in Shibam, William Porter says, "The extraordinary and unique character of the current architecture in Yemen must be recognized", and This is confirmed by Jacques Senier, "that this architecture has no equal, neither in the Mediterranean civilization nor in the ancient world of the East, and that it was present in the fifth century BC in Hadramout" and Kee Shirley also says, "The tower houses are unparalleled models in the world". [3]

The city of Shibam was famous for its skyscrapers in the heart of the desert, which were built of mud. Its history is associated with Wadi Hadhramaut and its construction dates back to the fourth century AD. [4] The city of Shibam is considered one of the architectural masterpieces that astonished the world with the rise of its high-rise buildings that reach 6-8 floors of mud and natural materials available in the region and its use with innate intelligence and inherited experience that expressed the genius of the people of Hadhramaut Valley.

2. Location and Climate

The city of Shibam is one of the cities of the Hadhramaut Valley, which is located in eastern Yemen, southeast of the Arabian Peninsula, It has an important strategic location that allowed it to control the surrounding areas and make it the most protected commercial city in Wadi Hadramawt, where it is located on a hill 6-10 meters high and is surrounded by agricultural fields on three sides (Northeast, west, and south, it was for the main road).[6]



Figure 1. The map of shibam (google).

It is exactly located at 48.64 east longitude and 15.91 north latitude, at an altitude of 680 m above sea level, The climate of the city of Shibam is very hot and dry in summer and very cold in winter with little rain, only from 50 mm to 125 mm annually. The winds move from the southwest to the east and have hot westerly winds. [7]

3. Shibam City Characteristics

The location of the city of Shibam was on a high hill so its houses looked like defensive castles, and its architecture appeared in a unique style because of the interaction of several factors, including geographical, economic, social, and religious factors. The climate also had a great impact, as the buildings were designed considering the surrounding climatic conditions.

3.1. The urban fabric of the city

The urban fabric of the city consists of residential blocks formed from adjacent buildings interspersed with narrow streets or alleys that formed paths from east to west and from the north to the south, in addition to seven mosques and five public squares in which the people and residents of the city gather. There is also a market area in the main square of the city, around which administrative and public service buildings are gathered, such as schools, the market, and the palace, which was the seat of the ruler. [8]

The city is surrounded by a wall of adjacent external buildings, dimensions 375 * 275m, interspersed with some narrow spaces between the non-contiguous buildings, which were closed by high walls, as it is considered an important defensive means for the city, in addition, it has only one entrance from the southern side, which leads us directly to the main square of the city. [9]



Figure 2. This is a Scheme to illustrate the general planning and urban fabric of the city of Shibam [5].

3.2. The tower house in shibam

The dwelling is a result of the interaction of several variables that produced an architectural achievement unique from the rest of the dwellings of Arab and Islamic cities, as the tower house in the city of Shibam expresses the harmony between the economic and social factors in the community with the natural factors and the surrounding climatic conditions in addition to the prevailing technical methods at that time.

There were more than 500 houses in the city. Then, according to the statistics of Eckert and Wagner in 1933, the number decreased to 433 houses [9] According to the census of the General Authority for the Preservation of Historic Cities in Yemen in 1998, the number reached 429 houses, inhabited by about 2453 people. The heights of the houses vary from 7 floors to the ground floor, and there are medium-rise houses

with 3-5 floors and high houses with 6-8 floors. [10] The ages of the houses also differ from one house to another, as some of them date back to the fourth century AD, some of the houses have been carved on their doors dating back to 1740, and others date from 1880-1915. [9]

3.2.1. Factors of forming the tower house in Shibam

The formation of the tower house in Shibam was affected by many factors, the most important of which we will mention:

a. A security factor

Due to the fact that the city of Shibam has been subjected to many wars and the succession of the ruling states on it, this dwelling resembles a fortress, and often its idea was derived from the guard towers, The external shape is also designed for defensive motives to provide safety, through its high altitude, which contributes to monitoring enemies, in addition to the fact that the limited horizontal position of its entrance is better in protection than the sprawling horizontal projection. [11]

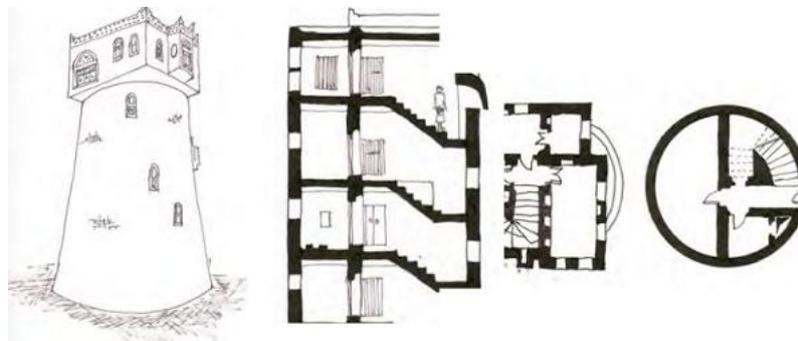


Figure 3. Two plans, a sector, and a facade of a guard tower, from which the idea of the tower house in Shibam was derived [12].

b. economic factor

The location of the city of Shibam is of strategic importance to the surrounding areas, as it is located on an earthen mound surrounded by palm trees and fields. Therefore, Shibam was an important commercial center in which all commercial convoys converge, Since it is exposed to a lot of wars, it was necessary to design the tower housing, considering the necessity of securing food, so the design of the house was based on several floors, so that the lower floors were assigned to services, Including (hand mill _ stores for grain and dried vegetables, as well as places for raising sheep and birds)The tower house fulfills its function to the fullest extent, therefore the dwelling is considered a self-sufficient unit to some extent that can provide food for its inhabitants for a period of time. [12]

c. social factor

Providing privacy for the residents of the tower house is the most important thing that the design of the house achieved through the distribution of functions on the multiple floors and their relationship to each other, The function of the room at the horizontal level ensures that every floor has a good relationship with the outside while emphasizing the importance of the concept of privacy. In addition to considering the society's requirements to maintain family cohesion, as the house includes one family consisting of a grandfather, parents and grandchildren. [3]

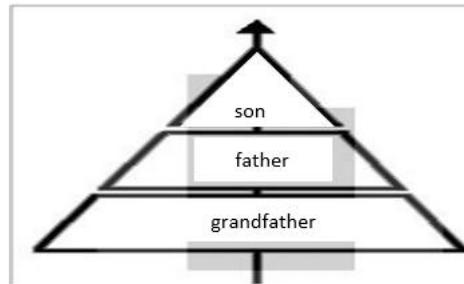


Figure 4. Scheme to show the distribution of family members in the tower house in Shibam.

d. natural factor (torrent)

Water is an important element in Wadi Hadhramaut as it is considered one of the most important physical determinants in the region, which contributed mainly to determine the shape of the city in general and the emergence of the tower pattern in particular, as the city's residents needed their proximity to water sources in addition to considering the safety factor from torrents and floods, This led to the rise to the top in the construction of their homes and their inability to expand horizontally, especially since their homes were built of mud, so it was necessary to shed light on this aspect due to its great influence in making design decisions. Although the city of Shibam has a dry climate and rains do not occur in it significantly, where Hadramout Valley receives an annual average of 50-60 mg of rain [10], however, a few showers of rain can gather in the southern valleys forming torrents or floods that may end within hours if they are few and within days if it was a big flood.



Figure 5. Floods gathered in the city of Shibam [10].

3.2.2. spaces distribution

The interior spaces in the tower houses in the city of Shibam are classified according to their achievement of many functions, which do not differ in many ancient Yemeni cities, but it is possible that one function overwhelms another due to the internal and external influences on the house, which may change with the passage of years.

a. The economic function

Where the ground floor and the first floor have been allocated for the economic function and all the special activities in it. There are some houses near the market where these rooms open onto the street which they are narrow corridors and used as shops for buying and selling as these shops contribute to supporting the family economy, as for the rest of the rooms on the ground and first floor, foodstuffs such as grains, dates, firewood, and coal are stored, and there is also a room allocated for grinding grains. On the first floor, foodstuffs are also stored, in addition to rooms used

for animals such as goats and chickens. As for the connection between the floors in the Shibami house is done through stairs that wrap around a column of stone and supports the upper floors. [10] There is also a vertical opening called (ALshamsah) that starts from the ground floor to the highest floor of the house. [7]



Figure 6. Achievement of the tower house in Shibam for economic function [13].

b. Residential function

The number of floors that perform this function varies from one house to another according to the height of the house as well as the number of floors. Usually, the floors are allocated from the second to the fifth according to the requirements of the space of the house and how the family operates these spaces, as the residential function starts from the second floor, where it is intended for men and their social gatherings, in order to consider the privacy of the women in the house, as this floor contains a spacious room (Al mahtharah) Extended with central wooden columns and decorated with carvings, in addition to the interest of the owners of the house in the decoration of the walls for these rooms [13], As for the third and fourth floors, it is intended for women and children, as it consists of spacious rooms to receive guests from women, and also the kitchen in order to be close to the lady of the house [14], The fourth floor consists of several rooms varying in size. The house also contains open-roofed rooms called (riom) that are used for sleeping in the summer to adapt to the city's hot climate, in addition to rooms without windows for storing winter clothes [10], As for the bathrooms, they are small and clean rooms, and at the end of them, they contain a hole in which the waste is taken out into rooms that are emptied from time to time, as the sewage is delivered through open trenches outside the city. Currently, a sewage network has been established in the city. [13]

It should be mentioned that on the upper floors there are many horizontal corridors extending for several meters connecting the houses with each other, where women use them to move between the houses without the need to go to the street, and where it was also said that these corridors were used in the past to move between the houses during the period of political conflicts.

c. spiritual function

This function is clearly manifested on the last floor, which is a small room called al-Tayyarim. As well as in some houses, the last floor contains rooms used for newlyweds to enjoy privacy, as it opens through a door to open areas called (riom) where the residents of the house use them in their summer, especially in the hot weather in the area and enjoy the clear sky, [10] which It has small windows that allow a vertical view to the door of the house to know who is calling.



Figure 7. Middle columns in spacious rooms [10].



Figure 8. The paths between the houses [16].



Figure 9. Details in the tower house of shibam[15].

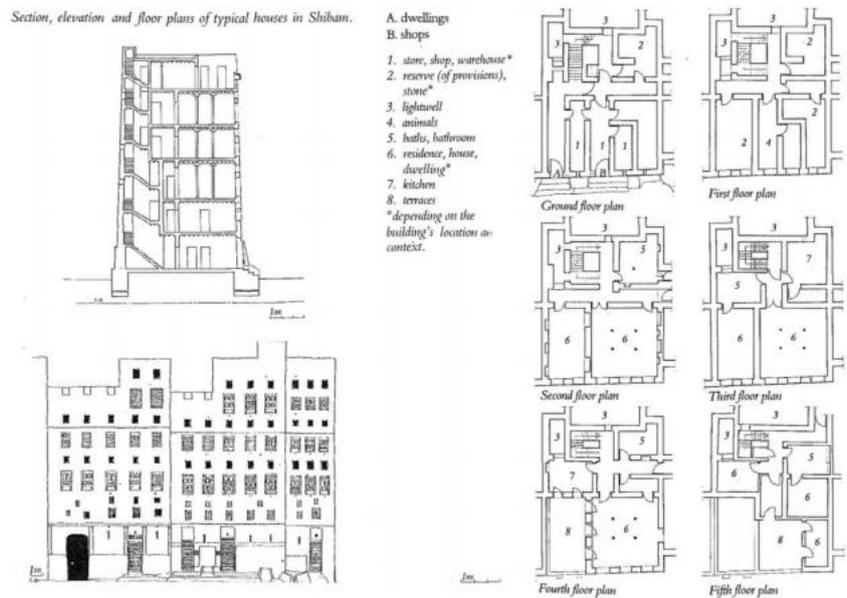


Figure 10. Layout of the traditional house in shibam(source:UNESCO, 2007).

3.3.3. Building and construction technology

As a result of the inheritance of experiences and the innate remembrance enjoyed by the builders of the city of Shibam, their mud buildings were able to achieve environmental compatibility with nature, and the desert climate prevailing in the city,

thus these buildings have survived for many centuries and have a special character of their own.

The construction process of the tower house is carried out by local workers and local building materials and includes the following stages:

a. The foundations

The site is prepared for the excavation process, where it is one or two meters deep, but mostly 1.6 meters and 1.5 meters wide, which are strip foundations, then a layer of animal dung is made with a thickness of 3 cm, after that put a layer of salt was made with a thickness of 8 cm and wood sticks (palms or Elb) with a diameter of 10-20 cm were laid on it, Then a layer of ash was made 2-3 cm thick with the addition of unpolished pieces of crushed stone 45-50 cm thick. [10]

The construction continues until it reaches the level of the ground and then gradually decreases inward until its thickness reaches the width of three bricks, then the construction of the stone wall begins with a height of 50-100 cm above the surface of the ground, after that it is covered with ash and light to preserve it from weathering factors. [16]

b. The walls

After preparing the raw bricks in a site outside the city, it is transferred to the site to start the construction process, Where the construction is done by placing bricks horizontally on the stone foundation, where two bricks are placed horizontally and transversely so that the width of the wall becomes 150 cm, then, the construction continues to rise to the lower lintel of the openings, after that the twigs of (elb wood) are placed over the openings, And sometimes along the walls and left to dry, then the construction continues to the ceiling and left to dry for a year and completion in the next winter. As for the stairs, they built by a strong and thick wall of stone and the peace sessions are wrapped on it. [10]

The thickness of the walls between floors varies from bottom to top by decreasing when changing the size of the brick used on each floor, as well as the method of stacking it during construction so that the thickness of the mud wall decreases, as a result, the wall thickness is in the ground and the first floor 86 cm, second floor 69 cm, third floor 57 cm, fourth floor 46 cm, fifth 34.5 cm, sixth floor 28.5 cm and seventh 23 cm, by making outward inclinations that appear clearly on the exterior facades of the house. [17]

c. Roofs

The roof is built upon completion of the construction of the walls by placing wood sticks (elb wood) in a regular, parallel, and perpendicular manner on the walls with a distance of 30 cm between them, Then the branches of trees (yabbour) are placed in a transverse way on them and covered with mats that are made of palm fronds, after that a layer of clay and straw is placed with a thickness of 15-20 cm. [18] After the clay dries, a layer of slaked lime is placed in it and covered with a layer of slurry, As for the wide spaces, vertical columns are placed at the end of the horizontal elb wood sticks and they are bounced on the ground with a small stone and their height does not exceed 3.5 meters. [7]

d. the stairs

The stairs are built at the height of the house using mud bricks, 1.5 * 1.25 meters in size, and plastered with lime and ash. The house of the staircase is built of wood and covered with mud and straw. [7]

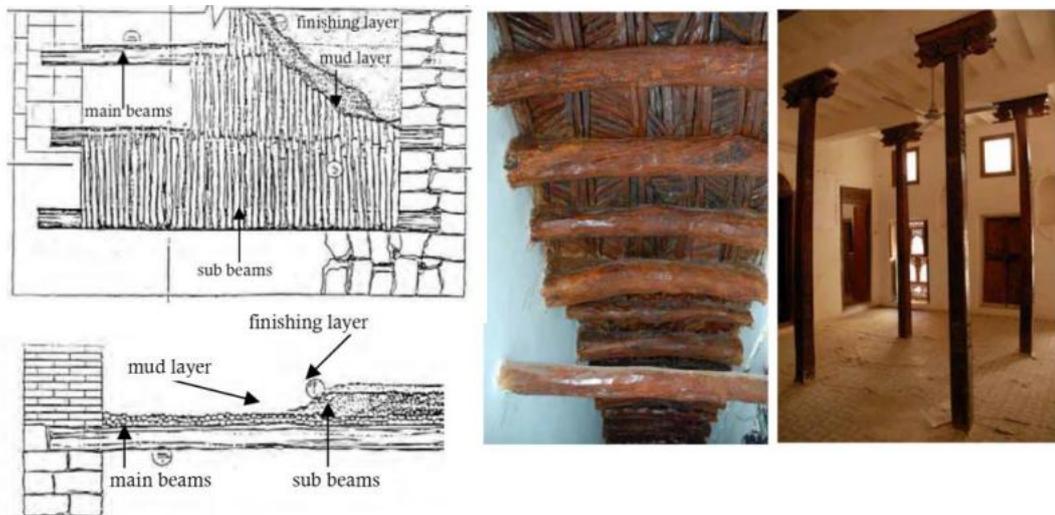


Figure 11. Roof details in the traditional house of shibam [15].

d. Plastering of interior and exterior walls

The house is being plastered from the outside in two stages :

The first stage is by placing a layer of clay and hay, adding a quantity of sand and leaving it to dry, after which a layer of clay and sand is made so that the process is from the upper floors to the lower floors to protect the building from moisture and salinity, After that, the ceilings and upper floors are painted with (alnourah) to prevent rain, while the lower floors are covered with slurry to protect against moisture. The outer wall on the ground floor is reinforced with a supporting wall of stone (hamth) 1.5-2 meters high and an acute-angled triangle section that protects the foundation from the intrusion of rainwater into it. [17]

After that, moved to the interior walls, where they are covered with a layer of lime and then polished with a stone (Al-Qada'a) then the walls are painted with lime diluted with water to give them a bright white appearance. [10]



Figure 12. Facade finishing process [10].

4. Environmental Design Solutions in the Traditional Tower Houses of Shibam

The traditional tower house in shibam contributed greatly to the compatibility with the surrounding environment and the prevailing climate in addition to the local building materials and its observance of the social, economic, and cultural aspects of the family and society, through many environmental solutions that were considered when the design process, so its observance of these aspects helped greatly in providing climatic comfort inside the house, in addition to the variation of the design of spaces, open spaces and open surfaces in harmony that changes from one chapter to another according to the climatic conditions:

4.1. City planning

Because the city of Shibam is located in the middle of the valley and is surrounded by fields and orchards of palm trees from the north, east and west sides, this contributed to softening the atmosphere and the weather of the city in part, and even if it obscured a percentage of the solar radiation reaching the city [7], The city was planned that the houses would be close and compact to obtain the largest percentage of shade, and a high height while abandoning the idea of the inner courtyard known in the hot areas to save space, with the need to plan the streets so that they were of a narrow area, but shaded from the tower houses adjacent to it, This closeness of the buildings also helped to create narrow corridors and alleys that contribute to the speed of air movement within the city. As the decrease in temperature resulting from the increase in the proportion of lumpy buildings leads to a rise in the corresponding relative humidity rates that reach the thermal comfort of the human being. [19]

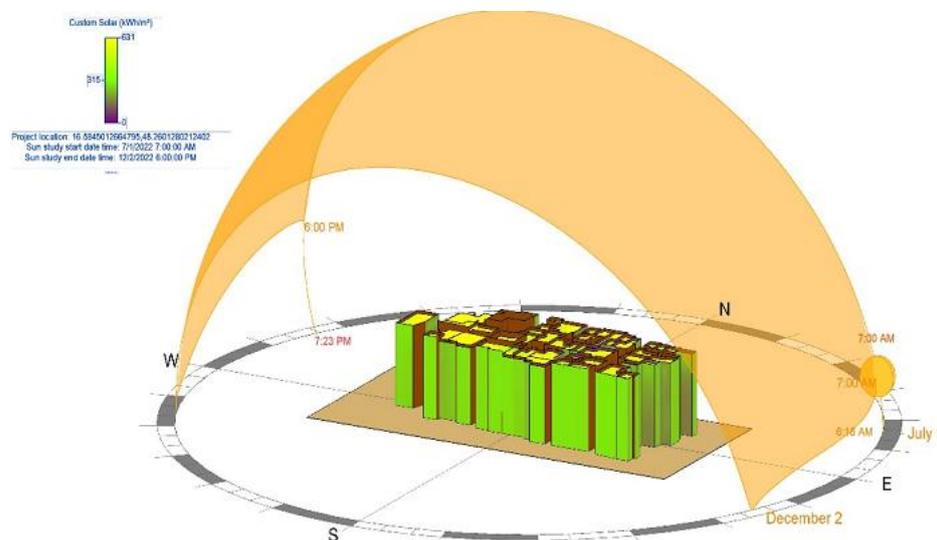


Figure 13. By using the Revit program, the plan shows the path of the sun and the shade areas resulting from the convergence of buildings in the city of Shibam, From July to December (Author).

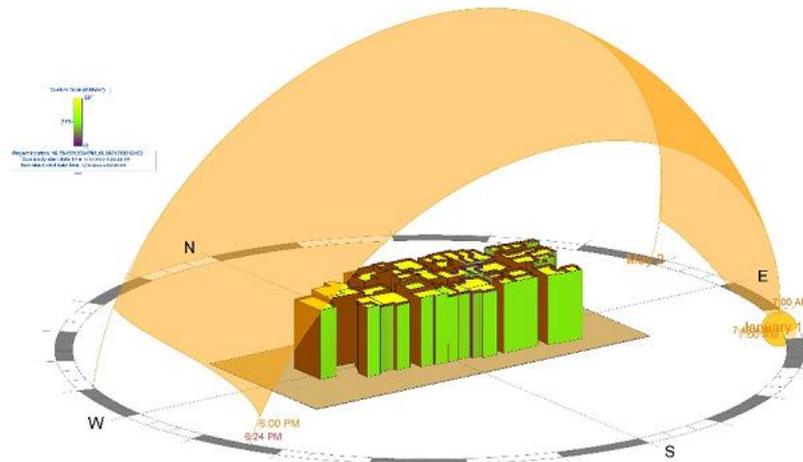


Figure 14. By using the Revit program, the plan shows the path of the sun and the shade areas resulting from the convergence of buildings in the city of Shibam, From January to May (Author).

4.2. The shape of the building

There is a direct relationship between the rate of heat loss and the ratio of surface area to volume (S/V), according to studies of the rate of heat loss and the effect of variables on it. As we mentioned, the tower houses in Shibam are high and multi-story with a square or rectangular shape. These shapes contribute to reducing heat gain in summer and less heat loss in winter, as the amount of energy decreases in descending order as the height of the building increases, this is because that vertical buildings in which the area of horizontal surfaces is less exposed to external influences, therefore have the lowest percentage of energy gain in summer. As for the winter, it is quite the opposite, so these tall buildings are the most gaining of energy, thus Al-Dumaini asserts “that multi-story buildings do not lose more than 60% of the heat leakage in the cold weather at night while the single-story buildings lose more than 90%, which causes the building to cool down as a result of the external climatic conditions”. [20]

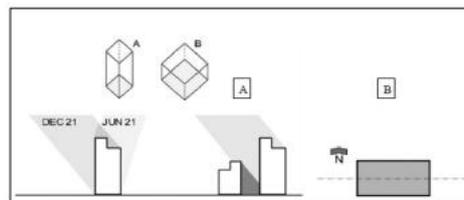


Figure 15. (A) The effect of the tower building shape on the thermal gain in winter and summer, (B) The axis of the elongation and the direction of the tower building. [23]

In addition, the presence of a lot of protrusions in the facades of buildings (the continuation of the external walls above the roofs) misleads the roofs to reduce the time of exposure to direct sunlight and thus reduce heat transfer, which act as breakers of sunlight also and prevent it from falling on the façade. [15]

4.3. The building's orientation

The rate of thermal performance and thermal comfort in the building is effectively affected by the orientation of the building by considering the increase in radiation in winter and its decrease in summer, because given that the city of Shibam has a dry semi-desert climate and houses are exposed to the north and northeastern winds that carry harmful dust, in addition to the hot dry winds, where the city of Shibam is

considered one of the cities most exposed to solar radiation. [8] as well as due to the awareness of the residents of the city of Shibam of the importance of the impact of climatic factors on their homes, this climatic specificity intervened in the design directly or indirectly in a way that suits the surrounding environment by designing the houses, as a result, they were directed to the south to reduce the impact of solar radiation in the summer and make the most of the sun's rays in the winter considering the appropriate thickness of the walls. [19]

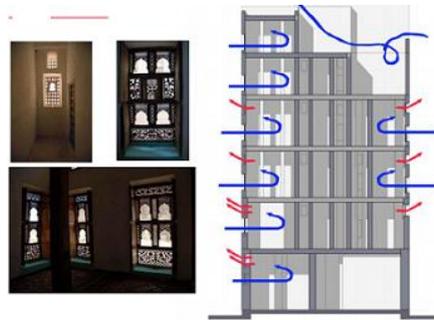


Figure 16. Air movement in traditional houses of Shibam[15].

As for the wind trend, they blow from the southwest to the east, so because the west winds are hot and not desirable, the rooms are directed in the east to protect them from the western winds and from the afternoon sun. [7]

4.4. The spaces distribution

The vertical shape of the tower house contributed to the ease of air flow from the lower floors to the upper floors, through the transfer of hot air currents to the upper floors by means of convection, thus this contributed to obtaining warmth on the upper floors used for living while cooling in the lower floors used for stores and services. The tower house in Shibam also contains open-roof rooms called Al-Ryum, which are used to sleep in the summer to adapt to the city's hot climate, In addition to the presence of a vertical opening next to the stairs, starting from the ground floor to the sky called (ALshamsah), which is used for ventilation and lighting, also the longitudinal or circular windows located at the top of the staircase wall to provide ventilation and lighting for the ground floor in which there are no openings. Also because of raising the living spaces, so they are not affected by the conduction factor of sunlight from the earth, and this has been proven through living experience and through some research that contains statistics on the extent of residents' satisfaction with their buildings. Therefore, the traditional buildings provided them with the required needs thermal comfort without using any electrical devices for cooling or heating. [17]

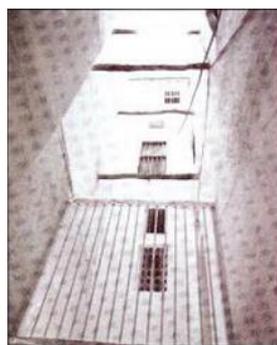


Figure 17. AL- shamsah [10].

4.5. Thickness of the walls

The thickness of the walls decreases as the building rises to the top, because of the mud walls are characterized by time lag, so the mud walls with a thickness of 40 cm delay the temperature by about 15 hours and thus can achieve the best thermal value than the 20 cm thickness cement walls, which contributes Reducing the energy used for thermal improvement [20] also because shibam has a hot, dry climate, a difference is made in the height of the floors in order to take advantage of it in the gathering of hot air in the upper part of the space, thus providing a comfortable indoor climate in the space.

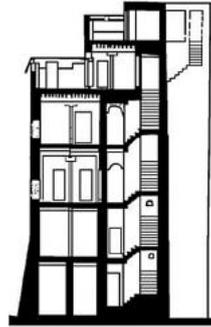


Figure 18. A section to show the thickness of the walls and its decreasing as we go up [7].

4.6. Façade elements

The design of openings and windows has helped reduce the impact of solar radiation entering the house, as ventilation holes were designed above the windows to create air currents at night that help to change the air, in addition to the vertical opening in the house (al shamsah), which contributed to providing natural ventilation from the top, where it is carried out from it Sunlight and air move from one floor to another. [10]

The field studies proved the existence of low openings that open on the alley to allow the largest amount of air to enter the living room, the air exits from the upper openings adjacent to the ceiling to expel hot air, so achieving the principle of mutual ventilation in addition to considering the movement of external winds with appropriate ventilation openings. In addition to the presence of various covers on the windows of palm fronds (mashrabiya) that are considered as breakers of the sun's rays and allow air to pass through them. [6]

4.7. Building materials

Due to the location of the city of Shibam within the hot tropical climate, which is characterized by the fact that the weather is very fluctuating between night and day within the same day, this results in a large difference in the rate of heat and humidity during the hours of one day. which thermal transfer in summer, storing heat in winter during the day and releasing it at night, where the total coefficient of heat transfer for the clay material is 2 W/m² lev. [10]

The use of mud in construction reduces costs and wastes energy. As the mud building process provides an energy consumption rate of 10-20 times, compared to building with cement or bricks, due to the preference for manual work. In addition, the mud walls help to stabilize the moisture content inside the space. 45-55% Moreover, the process of installing and painting these walls does not result in much waste. [7]

Furthermore, Walls built of mud mixed with straw have the ability to isolate heat and consequently save energy because they can repel very large electromagnetic waves. [19]

The ceilings exposed to direct sunlight, a layer of lime was made, as it is considered one of the cheap and good treatments because the absorption coefficient of the sun's rays is 21%, but it needs regular maintenance. [15]

According to (Bakhlah , Hassan, 2012) The use of the white color on the ceiling has the effect of reducing the temperature of the indoor air by reducing the surface temperature and reflecting the falling sunlight, as the white color is able to reduce the temperature of the indoor air from 0.1 to 2.3°C, thus the internal temperature decreases from 0.8 to 3.9°C, when there is a high rate of decrease in the outer surface temperature ranging from 2.5 at night to 22.8 at noon. [22]

In addition, Using Wooden yawbour pieces used in the ceiling resist termites. [10]

Furthermore, Make a layer of lime and ash in the ceilings to protect against rain, wind, and sunlight reflection. in addition that the use of rock salt, cattle dung, and alelb sticks in the foundations has several advantages, such as Preventing the leakage of ground insects to the upper layer of the foundation, which helps absorb shocks under the stone foundation, also preventing the erosion of the walls from the inside and outside, which occurs due to capillary permeability and has the ability to reduce the heat transfer process from the soil to the inside of the building. [7]

5. Conclusions

Through what is presented in this paper from the analysis of the tower houses in Shabam, set out that they have been characterized by characteristics that helped in their sustainability, as considering the society's behaviors, beliefs, and culture secondly and the link of the environment with the climatic, physical and geographical conditions finally through the following:

- The urban planning of the city was designed according to the needs of the community and its social and climatic beliefs.
- Creating an appropriate architectural environment through the optimal design of the spaces between buildings, considering the unity of neighborhood, interdependence, and belonging on the one hand, and achieving the privacy of the individual and family on the other.
- The creation of various architectural elements such as mashrabiya, as well as the optimal use of local building materials such as mud, timber, wood, and others, contributed to achieving thermal comfort.
- The tower houses of the city of Shibam are characterized by their use of local building materials within the surrounding environment, which they are non-polluting, whether during manufacturing, implementation, operation or demolition and reconstruction, as they come from the land and then return to it at the end of its cycle without causing any negative effects.
- Optimum utilization of energy through openings for ventilation and lighting, in addition to devising local means capable of facing the climate. As the openings were used to achieve different functions such as ventilation and lighting, blocking sunlight, or reducing heat or cold according to the need and at different times and places.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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