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Traditional Yemeni Architecture and Its Impact on Energy Efficiency

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Abstract:

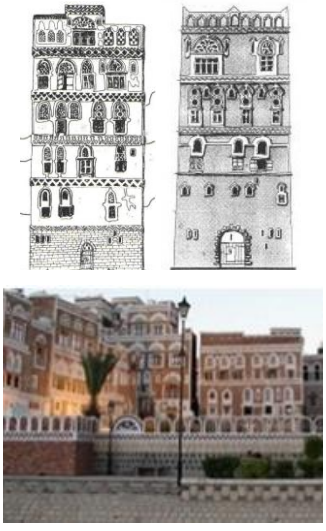
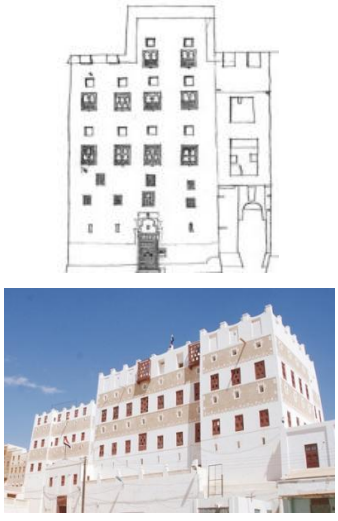
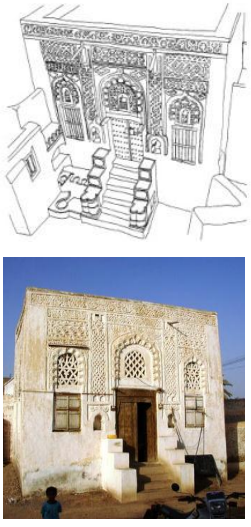
The ancestors 'interaction in the past with the surrounding environment and natural resources was part of the way they stay on this land in harmony, where the optimal use of resources to adapt to climatic conditions, therefore the sustainability for them by acclimatization and coexistence with the surrounding environment, so it was spontaneous in the dealings of ancestors with the environment, and did not It was random at the same time, but was based on the inheritance of those experiences through learning through the principle of "trial and error", so traditional architecture was designed in the past to be sustainable architecture in an indirect way (it grows from nature and when the building's life cycle ends, the building's resources decompose and return to nature without any negative impact on it).The research aims to study the types of buildings in Yemeni architecture that have appeared in different urban environments and regions in Yemen through an analytical study of techniques, methods and architectural elements of some buildings and their impact on energy efficiency, then focus on analyzing and studying the environmental components of the traditional sana'ani building by studying and understanding the environmental elements For buildings. Consequently, we find that Yemen is one of the few countries that have preserved these characteristics over hundreds of years, dependent on their local natural resources and integrated with the environment.

Key words: Yemeni architecture - energy efficiency.

I. TRADITIONAL LOCAL YEMENI ARCHITECTURE

The traditional Yemeni architecture differed in its different natural, climatic and geographical components from one region to another, according to the requirements of the building and the surrounding environmental life in the different regions, which can be divided based on the natural resources and materials available for construction in different regions, as well as the terrain that varied from one region to another[1].(Table.1).

Table 1: Yemeni architecture in different regions.Source: Authors.

	Mountain regions architecture	Desert regions architecture	Coastal regions architecture
The main façade[2][3]			

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Region	Sana'a	ShibamHadramout	Tehama
Type	Tower building	Tower building	A courtyard house
Materials	Stone, Mud brick, clay	Dried bricks (clay), gypsum	Mud brick, Clay, palm branches, gypsum
Environmental elements[4][5][6][7]	• Building thick walls of mud bricks, as it works as a thermal filter by using thermal convection delay and internal heat preservation • Use wood as breakers in the windows, to prevent cold air at night, and reduce thermal gain in summer. • Use white and light colors in the external finishes, which reflect the sunlight from the facades of the building and not absorbed. • Using the garden (Al-Bustan) as a courtyard open to the surrounding buildings, where it works as a thermostat that softens the atmosphere and creates balance in temperature. • The size of the openings are designed to meet the building's needs for ventilation and lighting, as well as the use of sunlight • The use of Mashrabiya in the upper floors to reduce sunlight and to control ventilation. • Use the stairwell as a wind catcher, which is used to regulate the heat inside the building and reduce the heat load in the summer.	• The difference in height and regularity of buildings helped to provide shadows between buildings, and to reduce the external climate impacts. • Use clay as a thick outer covering achieves thermal insulation and provides a suitable internal thermal environment. • Use white plaster to cover the ceiling and external walls, to reflect sunlight and prevent heat gain. • Irregular streets were used to reduce the impact of the wind, and the courtyards were used to ventilate and soften the atmosphere inside the building. • The openings consisted of upper and lower parts, so that the air was moved using the pressure difference. • Use the wooden mashrabiya to protect the openings from direct sunlight, provide natural light, and benefit from natural ventilation.	• Narrow streets, providing shade space, and reducing hot winds in summer. • Use mud bricks to build double walls, to protect the building from the effects of the external climate. • Use white plaster to cover the ceiling and external walls, to reflect sunlight and prevent heat gain. • Use a patio as a thermostat, which opens up the building voids. • The openings consisted of upper and lower parts, so that the air was moved using the pressure difference. • Use the wooden mashrabiya to protect the openings from direct sunlight, provide natural light, and benefit from natural ventilation.

II. THE TRADITIONAL SANA'ANI BUILDING

The tower buildings are the predominant in the old city of Sanaa, and they are considered one of the most important features of the city, where the buildings appeared as a continuous block forming the sky line in harmony with the surrounding mountainous nature, and these buildings were built from 4-9 floors according to the need[8].(Figure 1,2) shows the traditional buildings in old sana'a.

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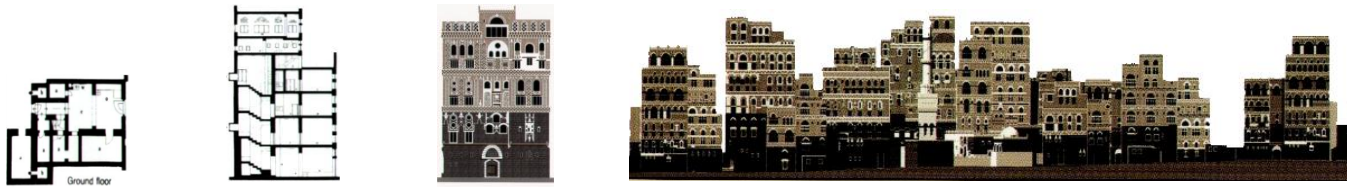

ground floor section Elevation Sky line in the old city of Sana'a

Fig 1. Traditional tower buildings in old Sana'a[8].

II.I. Local building materials:

The architectural elements in the local Sana'ani architecture contributed to reducing energy consumption, whether at the stage of manufacture, installation or maintenance, and when the building is ends, the materials return to nature (such as stone, mud bricks, clay)[9], and wood was also used in the ceilings and windows, as it performs good insulation In the external weather in winter and summer through the building envelope [4], gypsum has been used in the interior finishes, as it has proven to be anti-rot and does not allow the growth of fungi and harmful microorganisms on it, and all of these materials are characterized by the possibility of reuse again after the end of the building[10] (Fig. 3).

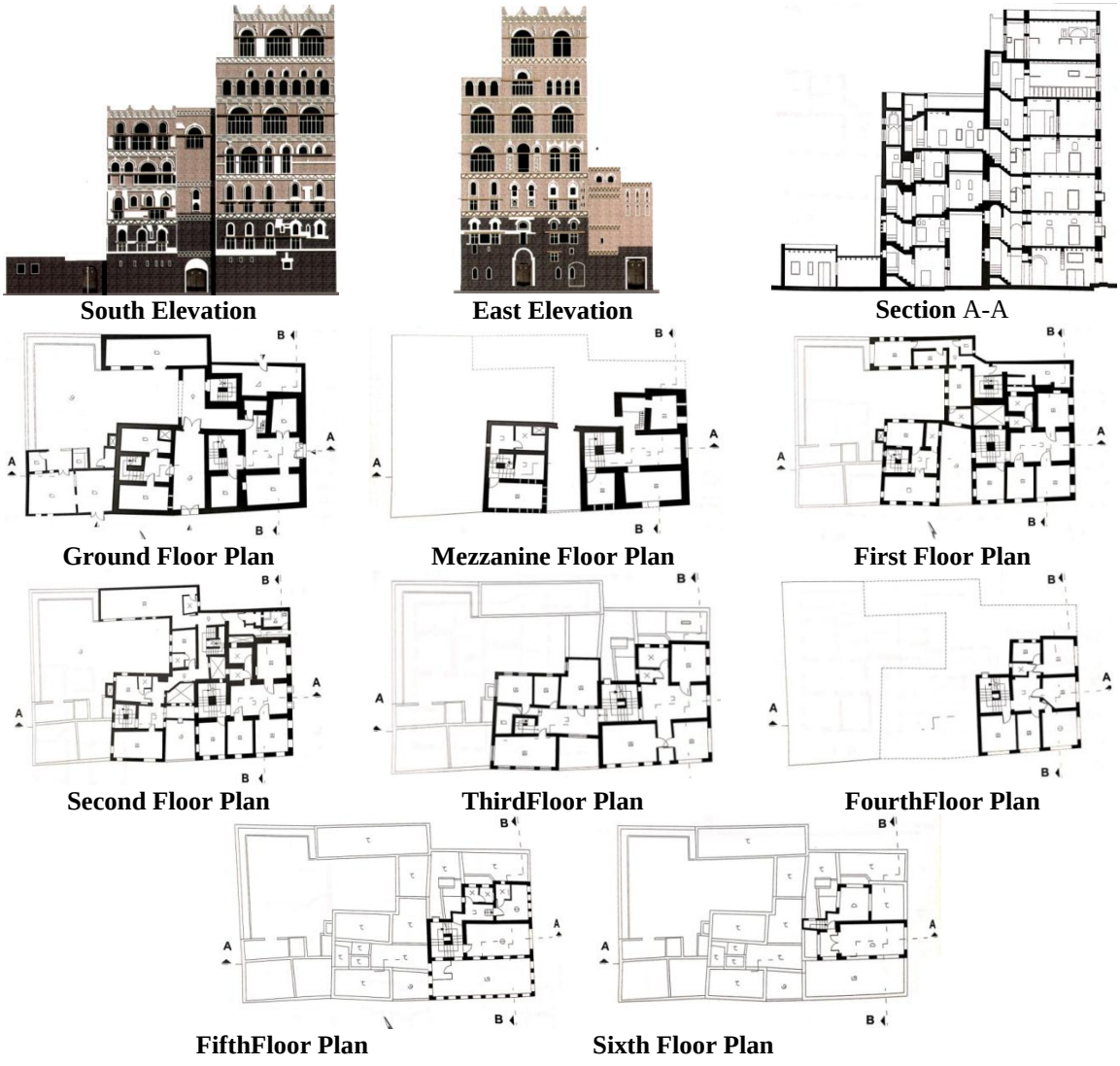

Fig 2. Design of a traditional building in old Sana'a [8].

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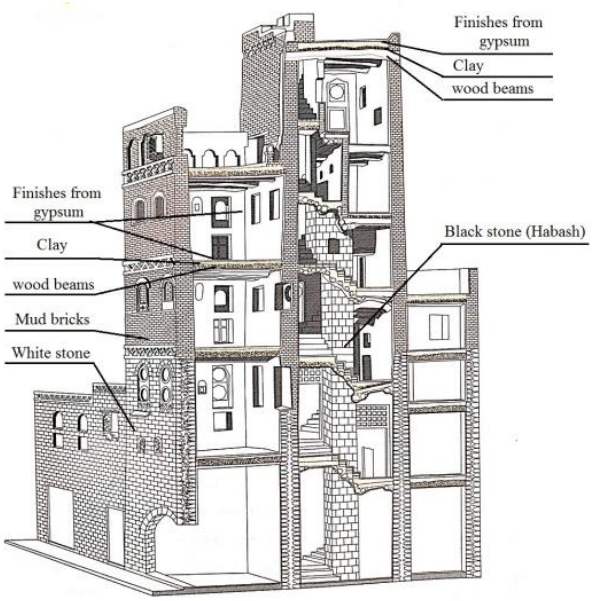

Fig.3: A section showing the building materials for the traditional Sana'ani building [8].

II.II. Building form

- The orientation in traditional tower house to the south.
- The thermal gain of tower buildings is more than small ones in winter, where most of the walls are exposed to solar radiation and heat gain in winter, and the area exposed to solar radiation in building decreases in summer, therefore the temperature decreases in repeated floors.
- The long axis of shape tower building extends from east to west, which means that long side of building is facing north and south, this allows placing most of windows in northern and southern walls. As a result building can control solar thermal for heating and cooling in summer and winter months[11] show(Fig.4).
- The shape in tower building was designed to create large areas for walls to increase thermal gain in winter, and reduce solar gain in summer due to size of ceiling relative to mass.
- The interior building design was based on primary and secondary spaces. The main spaces are oriented to south and used in winter, and the secondary spaces (spaces associated with movement, service) have been directed to north.
- Using the back yard (Al-Bustan)to soften atmosphere, create balance in temperature, and purify the air from dust [1].show (Fig.5).

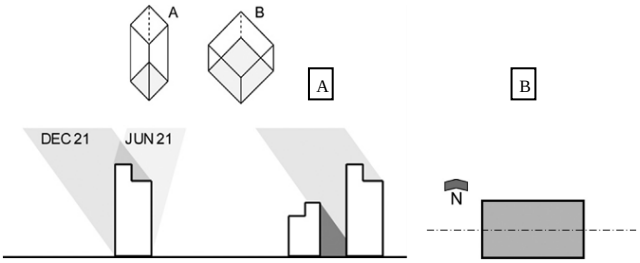

Fig.4:(A)The effect of the tower building shape on the thermal gain in winter and summer, (B) The axis of the elongation and the direction of the tower building [11].

Fig.5: House back garden (Al-Bustan). Source: http://www.yementourism.com.

II.III. Building envelope:

The traditional tower building is built from local materials that do not allow warm currents to enter building during day or cold at night. The walls of southern building that have stored warmth are slowly lost during the night, and therefore traditional building provides thermal balance during entire day, as well as during seasonal changes across year [7]. The building envelope consists of the following:

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II.III.I.Walls

The walls are built with different thicknesses, where thickness of walls is 50 cm or more in lower floors, thickness of walls decreases whenever we go to top of building, and we notice difference of materials so the construction of e first floors is made of stones, as they are very hard and work as load-bearing walls for rest of floors, while upper floors are built of mud bricks Which works as a heat filter between internal and external thermal conditions, which is known as delay heat load and internal heat conservation, consequently providing a suitable thermal environment inside building[12].

II.III.II.Ceiling:

Local resources were a basic source in process of building roofs, so wood was used as beams that control width of rooms, walls, stairs, and use of branches trees linked, gathered on those wooden beams, they are covered with mud, which is part of the finishing work, then they are covered with white plaster, which reduces Thermal loads on the roofs [4].

II.III.III.Openings:

The openings appear different configurations in traditional tower building through organization, shape, as well as their location on the facade and their ratio in the wall (the relationship between the solid and voids), so the openings were affected by materials and construction methods, depending on use and functional need of building's space, and we note that openings are one part, which is the window Used to ventilate voids, provide natural light, and solar radiation entry, or two-part openings, the lower part is a window and upper part (Qamariah) work for lighting, and there are openings consisting of three parts, the third part is a small upper opening beside (Qamariah) used for ventilation, By taking advantage of temperature differences, which works to expel hot air, by effect of pressure differences [4].

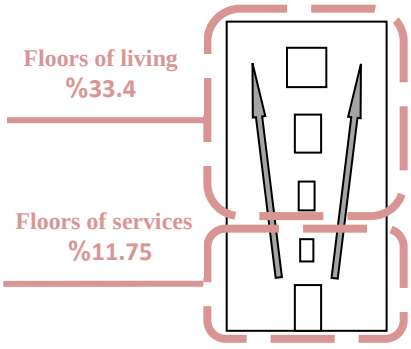

Fig.6:The size of the openings increases from bottom to the top.Source: Authors.

The ratio of Openings to solid for external walls:

The relationship of solid with open in tower building varies on different floors, according to functional and construction considerations. Most of buildings on first two floors are used for services and upper floors for living, and by studying these openings in building's envelope, we find that ratio of openings in main interface is sizes of openings are determined according to importance of directions and they come following order in terms of importance: the eastern, southern, western, and then northern facades (Fig.7).

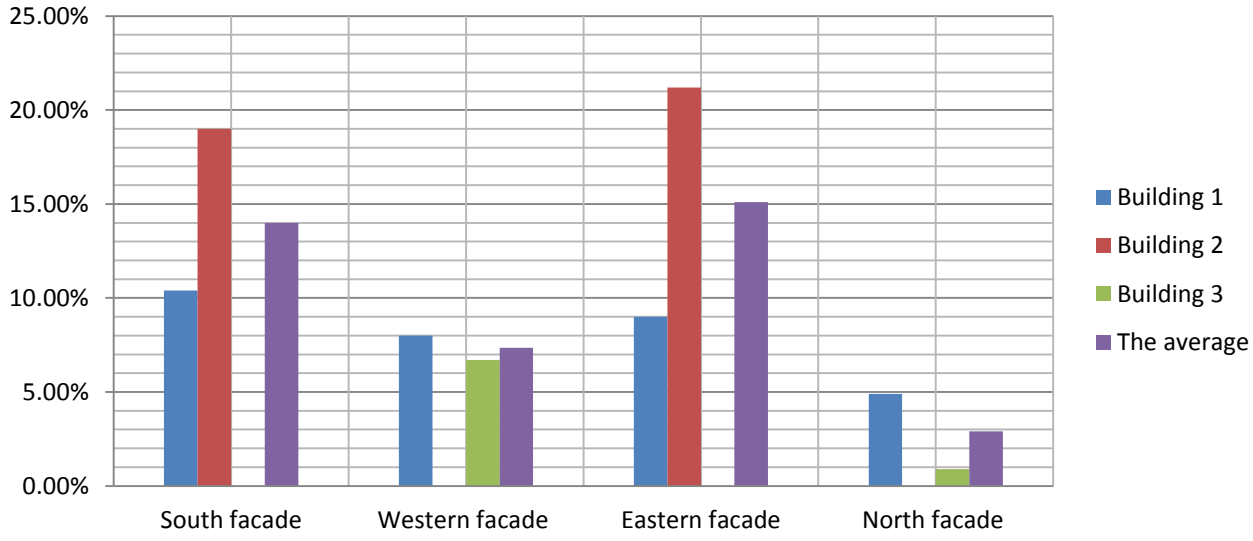

Fig.7: The ratio of openings in different facades of buildings. Source: Authors.

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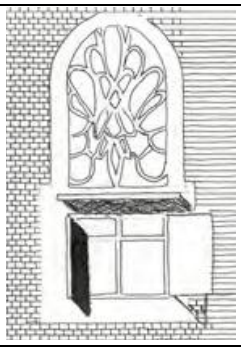
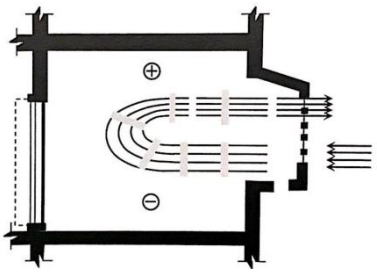
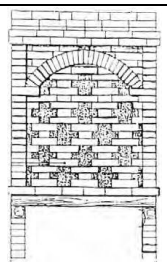
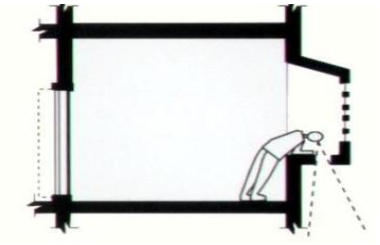
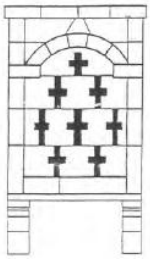
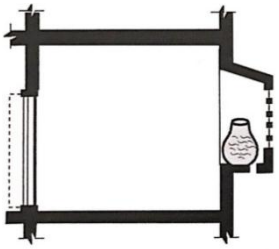
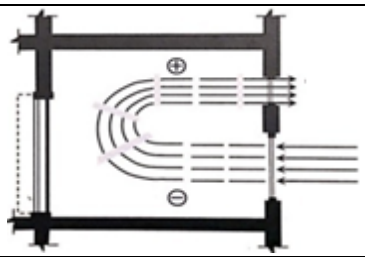
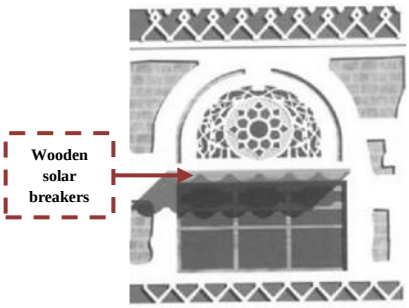
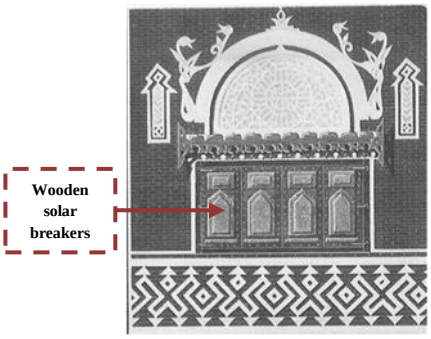
Table 2: Types of openings in the Sana`ani building. Source: Authors.

<table>
<tr><th>Openings</th><th colspan="3">Function</th></tr>
<tr><td rowspan="3">Window topped by a Qamariah</td><td colspan="3">Openings used for ventilation, lighting, and the Qamariah for lighting only[13].</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>window with two circular Qamariah</td><td>window with a semi-circular Qamariah</td><td>window with a rectangular Qamariah</td></tr>
<tr><td rowspan="3">Mashrabiya</td><td colspan="3">Al-Mashrabiya is used to control air flow, reduce temperature of air stream, helps to see from the inside of building to outside, it is also considered a solar breaker due to salience of Mashrabiya from envelope of building [11].</td></tr>
<tr><td colspan="2">  </td><td>  </td></tr>
<tr><td colspan="2">Wooden Mashrabiya</td><td>A section that shows the role of the wooden mashrabiya in entering the air into a space in the building</td></tr>
<tr><td rowspan="3">Observation window</td><td colspan="3">Window for ventilation and observation[14].</td></tr>
<tr><td colspan="2">  </td><td>  </td></tr>
<tr><td colspan="2">Observation window</td><td>A section that shows the role of the observation window</td></tr>
<tr><td rowspan="3">Water cooler window</td><td colspan="3">Used for cooling and preserving food and water[2].</td></tr>
<tr><td colspan="2">  </td><td>  </td></tr>
<tr><td colspan="2">Water cooler window</td><td>A section that shows the role of the Water cooler window</td></tr>
<tr><td>(Alshaaqus) Small openings</td><td colspan="3">The role of the very small openings to expel the hot air when the windows are closed, and when the window is opened, the air inside the voids is renewed due to the difference in the level of the openings</td></tr>
</table>

<table>
<tr><td></td><td colspan="2">to ensure the movement and renewal of the air[4].</td></tr>
<tr><td></td><td>  </td><td>  </td></tr>
<tr><td></td><td>Alshaaqus</td><td>A section that shows the role of an Alshaaqus opening in air movement</td></tr>
<tr><td>horizontal solar breakers</td><td colspan="2">It is a horizontal strip of wood above the windows, it is estimated to be 30 cm from the wall, and it is installed on a wooden stand, and it works to protect the windows from rain and provide shade from sunlight.</td></tr>
<tr><td></td><td colspan="2"> 
</td></tr>
<tr><td></td><td colspan="2">Wooden horizontal solar breakers</td></tr>
<tr><td>Vertical solar breakers</td><td colspan="2">Using wood as vertical breakers in windows, to block entry of cold air during night in winter, as well as reduce heat gain in summer.</td></tr>
<tr><td></td><td colspan="2"> 
</td></tr>
<tr><td></td><td colspan="2">Wooden Vertical solar breakers</td></tr>
<tr><td>Wind catcher</td><td colspan="2">Using the stairwell as a wind catcher, it is used for ventilation and temperature control inside the building between the upper and lower floors, as well as it reduces heat load during the summer.</td></tr>
<tr><td></td><td>  </td><td>  </td></tr>
<tr><td></td><td>Ventilation during the day</td><td>Ventilation during the night</td></tr>
<tr><td></td><td colspan="2">A section showing the movement of air inside the tower building through the stairwell in winter and summer.</td></tr>
</table>

II.IIII.Waste and pollution:

In the field of waste minimization and pollution, traditional Yemeni architecture provided a complete picture of waste management. A closed stream has been created that ends with a sedimentation basin for drainage of sewage wastes in the back side overlooking garden, and use of wastewater after treatment to water crops, and solids are dried to be used as fuel for ovens or as fertilizer for farms [11]show (Fig.8).

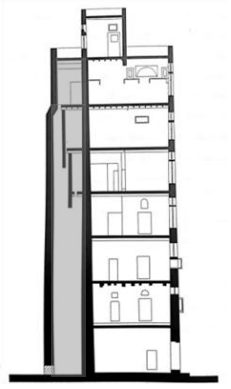


Fig.8: A section in the building where the drainage area is located. Source: Authors.

III. CONCLUSION:

- Yemeni architecture was formed on basis of its different environment due to terrain, which reflected construction pattern in each region and was shaped by local resources.
- The Yemeni man was able to adapt his architecture to surrounding environment, therefore the traditional local architecture automatically became a sustainable architecture.
- The Yemeni man used the surrounding natural resources in different areas to build his home.
- Buildings are designed to be energy efficient in a spontaneous way, by taking advantage of nature.
- Choosing materials that have a low impact on environment such as gypsum materials, studies have shown that it does not allow growth of fungi, and it helped to keep the balance of humidity inside building.
- Southern orientation in city of Sanaa worked to find a balance in temperatures in the summer and winter, as well as to find an acceptable level of thermal stability.
- The effectiveness of many elements and techniques in traditional sana'ani building, as it worked to achieve a comfortable environment for occupants of building, through openings that were thoughtfully placed in different facades, which achieved required balance of lighting control, ventilation and heat gain.
- The building materials that were chosen in traditional Sana'ani buildings do not affect environment, and when building is finished it returns to nature without affecting the environment, and thus the building life cycle was preserved from beginning of design until the completion of it.
- Study and understand applications and environmental elements in buildings through the style, elements and materials of the local building, which were used in the old buildings, and try to develop and benefit from them for any new building, in order to achieve the requirements and needs of the modern era.

Through the above, we recommend studying and understanding applications and environmental elements in buildings through method, elements and local building materials, which were used in old buildings, and trying to develop and benefit from them for any new building, in a manner that meets requirements and needs of modern era, in addition to working on the production of Modern materials , with same characteristics of old materials, and we also recommend research centers universities to develop Sana'ani architecture with contemporary architecture by applying them in building codes that can be used to produce new buildings.

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