Title: Potential of Vertical Forms: Learning Sustainability from Yemeni Tower Architecture

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Potential of Vertical Forms: Learning Sustainability from Yemeni Tower Architecture

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Abstract

Extreme transformations have taken place in the architecture of Yemen during the last forty years as a result of several important political, economic, and social forces. The vertical forms that gave Yemeni architecture its unique identity have transformed into horizontal forms that have no roots or identity. To realize this transformational process, there is a need to understand how the tower forms succeeded in keeping a balance among complex relationships of environmental and socio-cultural variables; and why the modern horizontal forms failed to do so. The study explores design-oriented guidelines embedded in the traditional tower architecture based on a methodology that perceive architecture as a natural outcome of several environmental impacts, with specific consideration to both socio-cultural and physical factors.

Keywords: Yemen, Sana’a, Tower House, Vernacular, Sustainable, Bioclimatic

1. Introduction

The vernacular tower architecture of Yemen has always been known for its strong character, remarkable identity, deep cultural meaning, and ecological harmony. Unfortunately, the new architecture that emerged after forty years of transformations is mediocre except for few cases, compared to the vernacular architecture, and is not satisfactory for most people for the following reasons:

- It is weak and has no identity or belonging whatsoever; it is a cheap mix of Yemeni and Western styles and lacks cultural meaning. To the contrary of this, the vernacular architecture of Yemen is known for its strong character, remarkable identity, and deep cultural meaning.
- It lacks order and unity at all levels: from detailed level of form and façade design to the space design level, and from the selection and use of materials to the construction methods employed.
- It is alienated in its society because it provides minimum consideration to socio-cultural needs such as privacy and sociability.
- It is alienated in its environment because of its negative effect on the environment. It is not environmentally sustainable and its reliance on, or integration with, natural resources of energy, vegetation, or water is minimal.
- It gives little or no consideration to human comfort issues, especially thermal comfort.

To realize this transformational process, there is a need to understand how the tower forms succeeded in keeping a balance among complex relationships of environmental and socio-cultural variables; and why the modern horizontal forms failed to do so. Rather than limiting itself to highlighting the values of traditional architecture, the study explores design-oriented guidelines based on roots from the traditional tower architecture. To achieve this, it casts the light on the potentials and values of the traditional tower form in a comparative analysis with the modern horizontal-form house, based on socio-cultural and ecological requirements. The research methodology depends mainly on abstracting complex architectural environments into more simplified, yet more comprehensive and meaningful, relationships model. The research approach depends on observation and comparative analysis of common architectural practices, and employs computer modeling to check some environmental issues.

2. Background

Lewcock (1986) gave a detailed description of the architecture of the old city of Sana’a. The predominantly square tower houses impress the visitor with their height (fig.1.) Many houses are more than five levels high, the largest commonly having seven, eight, or even nine levels. A view of the city from a distance, with many hundreds of these houses soaring above the city walls, makes an unforgettable impression. The streets are generally narrow and flanked by towering houses with no sight of vegetation or water to relieve the eye, yet behind the houses and extending right up to them there are frequently large gardens. The gardens (or the urban gardens) of the old city of Sana’a occupy one fifth of the city area; thus almost every house has a view through its
windows into extensive gardens.

The tower house walls are built of 50 cm squared black volcanic ashlar stone on the lower levels (i.e. up to approximately 6-10 m above street level) and 40 cm baked exposed brickwork above that (Lewcock, 1986; Lane, 1988.) The roof consists of a frame of wooden beams set 50-60 cm apart, covered by branches and twigs, on top of which lie layers of finely sifted earth, wet and compact, up to a thickness of 30 cm. The lower floor is frequently double-story in height and used for animal keeping and storage. The higher floors are residential quarters and include rooms that are functionally polyvalent and non-specific; rooms can be used interchangeably for eating, sleeping, recreation, and domestic tasks. This flexible use of living space is reflected by absence of cumbersome furniture. The top floor usually has a small square room used as an observatory space and has the largest windows in the house located around the space. The rest of the windows in this house type are small on lower floors and relatively large on higher ones.

A study by Al-Oulfi (2000) analyzed Yemeni architecture in different locations by giving a comparison of architectural forms and elements. It provided a historical background in which the Yemeni architecture was compared and related to other architectures in the Arab region and in the world. It described the modern movements in Yemeni architecture and discussed the issue of how a sustainable architecture be created in the country in the modern era.

A previous study showed that the vernacular house in Sana’a provided better thermal comfort than the modern house (Al-Sallal et al, 1995); yet very few of these buildings were built in the last two decades. That was because of the dominance of Western design ideas and imported materials which were not developed to meet the bioclimatic and functional needs.

In a recent study, Al-Sallal (2001) investigated the balanced synthesis of form and space in the vernacular house of Sana’a, and how that was used as the chief means to mitigate the effect of the climate and provide the functional requirements of culture. The approach depended on a number of methods for analysis of common architectural practices such as passive solar thermal performance analysis, solar access and shading analysis, and observation and literature survey of cultural aspects. A summary of the study’s outcomes provided rules of thumb that can be applied in design. Al-Sallal (1996a) employed three-dimensional computer modeling for visualizing solar access and shading in the traditional housing cluster of Sana’a historical city. The study found that their urban pattern, orientation, and the houses vertical forms helped to maximize solar access in the winter from south, while avoiding it in the summer.

In two different studies, Ayssa (1990, 1994) investigated the traditional window shutters and attachment as comfort producing procedures and the internal air movement in the vernacular houses of the old city of Sana’a. Al-Sallal (1993, 1996b) investigated the role of indigenous fenestration to reduce energy requirements in the Sana’a house using computer simulation. Another study by Al-Sallal and Cook (1992) documented the indigenous window of Sana’a and analyzed its design variation in size, shape, and number based on climatic influences and functional requirements. It categorized the window design according to its components and described the geometry and function of each component. It concluded that the separation of window into components gave better flexibility in controlling the different functions and more design opportunities.

3. Analysis: Potentials of Tower Form

The vernacular architecture and urban design of Sana’a followed certain conventions that were well known and practiced by all its inhabitants. These conventions are history-long experiences that have been developed throughout the life of the city to satisfy the human socio-cultural needs and to respond to the requirements of climate and environment. The people’s abiding by these conventions resulted in a consistent architectural language that gave a very
unique identity to Sana’a architecture and preserved it for long time. The modern architecture in contrast has failed to achieve these values. Sana’a tower houses are surrounded by beautiful views of green gardens and a skyline of the decorated towers’ façades and minarets, all with a background of remote mountains and blue sky. These fascinating views, combined with the mild climate, encouraged the opening of Sana’a buildings to the outside, while those of other parts of the Islamic world open to inside courts. The slender vertical form of the tower house proved better than an extended horizontal form for socio-cultural requirements (Al-Sallal, 2001). Some significant points need to be revealed as follows:

- **Privacy and Safety** - Spaces that need a high level of privacy are located on upper floors that are usually used by households to ensure privacy and segregation of men and women. The concept of the multi-storey house helped to provide several levels of privacy; the higher the floor is, the more private it becomes. Utility spaces such as storage areas are usually located on the ground floor. To keep the privacy of women using the outdoor courtyard space and prevent them from being seen by strangers in the street or in other houses the roof walls are usually made high. The modern house on the other hand is isolated from the community context around it by the existence of high fence walls, constructed for privacy and safety reasons.

- **Visual connection** - to provide views to all rooms, the Sana’ani people chose the tower as the appropriate form. While the verticality of the form provided better views angles and multiple view ranges from different heights (i.e. distant views of the mountains and sky and near views of the Sana’a gardens and architectural façades), the limited floor area maximized the number of spaces with access to the outside views. On the other hand, the visual link in the modern house to outside views is very restricted, especially in the ground floor, by the existence of high fence walls.

The vertical form of the traditional tower house provides significant bioclimatic advantages over a horizontal form that is equal to its volume and floor area, existing in the modern house design (Al-Sallal, 2001). Some significant points need to be revealed as follows:

- **Solar Exposure** - The change of the solar altitude from high angles in the summer to low angles in the winter makes the vertical form better than a horizontal one, for both summer and winter in Sana’a. The vertical form in winter allows a higher exposure to the sun through its large vertical surfaces than the horizontal form (i.e., mainly through its south façade because east and west façades can be assumed to be blocked by attached buildings), as seen in Table 1 for the case of December, 21. This higher solar exposure, offered by the vertical form, results from the relatively low solar altitude angles of the winter that allow the sun to see more vertical surfaces (i.e., walls) than horizontal ones (i.e., roofs). Furthermore, the vertical form in summer allows a lower exposure to the sun through its vertical surfaces than the horizontal form, as seen in Table 1 for the case of June, 21. This lower solar exposure offered by the vertical form result from the relatively high solar altitude angles of the summer that allow the sun to see less vertical surfaces than horizontal ones. Accordingly, if the form can provide less areas of horizontal surfaces (and larger areas of vertical ones), this would result in limiting solar heat gain. In fact, the horizontal form is not appropriate at all because it will increase greatly the solar heat gain through its large roof area. Also, the tremendous reduction in the number of floors in the horizontal form results in exposing a higher proportion of its indoor spaces to direct contact with the roof that is usually hot in the summer, because of the high solar heat gain. Table 2 shows two examples for comparison; a vertical form, 12 m * 12 m * 30 m (i.e., 4320 m²), that represents a typical 8-storeys tower house building and a horizontal form, 32 m * 18 m * 7.5 m, that represents a 2-storeys imaginary building. The vertical form building would experience solar heat gain through a roof area of 144 m² while the horizontal form building would experience solar heat gain through a roof area of 576 m², which is 4 times the roof area of the vertical form. Consequently, the vertical form is better than the horizontal one during the winter because it helps in promoting solar heat gain and during the summer because it helps in reducing the amount of solar heat gain.

- **Solar Access** - The verticality of the tower house also helps to improve solar access especially to higher floors that are usually used as living spaces by households and include the best rooms. Locating main activities’ spaces on higher floors maximizes the chances for solar access and consequently promoting solar gain; lower floors are largely shaded due to the tall neighboring buildings and their existence on narrow streets.
**Table 1.** A comparison between a vertical form and a horizontal form: perspective views of both forms as seen by an imaginative eye located in the center of the sun during different hours of the solar solstices days (i.e., Dec., 21 and Jun., 21) and sol solar equinoxes days (i.e., Sep., 21 and Mar., 21).

<table>
<thead>
<tr>
<th>Time</th>
<th>Dec., 21</th>
<th>Sep., 21/Mar., 21</th>
<th>Jun., 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00 AM</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>10:00 AM</td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>12:00 N</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
<tr>
<td>2:00 PM</td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
<tr>
<td>4:00 PM</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
</tr>
</tbody>
</table>

- **Solar Orientation** - The living spaces are frequently oriented to the south to benefit from the winter sun and also to escape the summer sun that strikes north façades; a phenomenon that occurs only in the summer time on locations near the equator, such as Sana’a (latitude of 15° 31’), where the sun moves towards north of the equator. Sana’a tower houses generally do not experience low altitude sun, coming from east or west orientations, because their east and west sides are usually protected by attachment or proximity to other neighboring buildings. A house can be made more energy efficient simply by designing the plan so that the order of rooms in which the normal daily sequence of activities occurs ‘follows’ the path of the sun (Watson, 1983). Specific rooms or functions in the Sana’a house
are planned to coincide with solar orientation. People change their diurnal and seasonal patterns of the interior use to benefit from the climate’s assets or to escape its liabilities. The flexible use of living space and the absence of cumbersome furniture help the normal daily sequence of activities to follow the path of the sun.

- Airflow - Upper floors are warmer than lower floors as a result of convective airflow currents; i.e., hot air moves to higher strata while cold air moves to lower ones. The form of the Sana’a traditional house improves this effect by its vertical proportion and employs it to heating living spaces located in higher floors while cooling storage and service spaces located in the lower floors.

**Table 2.** A comparison between a vertical form, which represent a vernacular tower house of Sana’a, and another imaginary horizontal form, assumed to have the same total area of floors.

![Perspective view of both forms as seen by an imaginative eye located in the center of the sun on Dec.21, 2:00 PM](image)

<table>
<thead>
<tr>
<th>Physical Aspects</th>
<th>Vertical Form</th>
<th>Horizontal Form</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area of floors</td>
<td>1152 m²</td>
<td>1152 m²</td>
<td>Assumed to be equal</td>
</tr>
<tr>
<td>Number of floors</td>
<td>8</td>
<td>2</td>
<td>Number of floors of vertical form = 4 times that of horizontal form</td>
</tr>
<tr>
<td>Roof area (also floor area)</td>
<td>144 m²</td>
<td>576 m²</td>
<td>Roof area of horizontal form = 4 times that of vertical form</td>
</tr>
<tr>
<td>Floor Height</td>
<td>3.75 m</td>
<td>3.75 m</td>
<td>Floor height of both forms are equal</td>
</tr>
<tr>
<td>Total Height</td>
<td>30 m</td>
<td>7.5 m</td>
<td>Total height of vertical form = 4 times that of horizontal form</td>
</tr>
<tr>
<td>Volume</td>
<td>4320 m³</td>
<td>4320 m³</td>
<td>Volume of both forms are equal</td>
</tr>
<tr>
<td>N or S Façade Area</td>
<td>360 m²</td>
<td>240 m²</td>
<td>N or S façade area of vertical form = 1.5 times that of horizontal form</td>
</tr>
<tr>
<td>E or W Façade Area</td>
<td>360 m²</td>
<td>135 m²</td>
<td>E or W façade area of vertical form = 2.7 times that of horizontal form</td>
</tr>
</tbody>
</table>

**4. Basis for Sustainable Design-Design Guidelines**

The traditional tower house was constructed according to certain conventions; some are stringent, to respond to the socio-cultural and environmental needs. Its design is constrained by a number of rules that specify its form proportion, orientation, zoning, and space arrangement. These rules can be used as basis for sustainable design (see Table 3 and Table 4).

**Built-form configuration** - the long axis of the tower house form is oriented east-west which makes the long side of the building faces north and south. This allows to place the majority of the windows into the north and south walls and accordingly to exploit solar heat gain for heating in the winter and to reduce it in the summer. The horizontal aspect ratio of the built form (i.e., length to width) falls within 1:1.6 to 1:2, which matches the general rule of thumb for moderate to arid climatic zones (Yeang, 1999). The vertical aspect ratio (i.e., length to height) falls within 1:1.5 to 1:2:5. This verticality of the form proportion provides several potentials, as seen in Table 4 sections A and B.

**Arrangement of indoor spaces** – it should be considered as a factor in bioclimatic design as its position can help to promote or reduce heat gain. The south orientation of the traditional Sana’a house is usually reserved for the best rooms. Less important rooms are oriented to east or west; then service spaces are oriented to north. Being near the equator, the geographical location of Sana’a (i.e., latitude of 15º N) is in fact an asset, since it helps to satisfy the orientation requirements of both heating and cooling in one zone (i.e., the south-oriented zone). This, in turn, makes the south-oriented zone of the Sana’a house as the most valuable one especially if it is exploited wisely to provide other significant needs (e.g., socio-cultural, functional, and behavioral needs.) in addition to the bioclimatic considerations. Matching between ranks of thermal zones, based on appropriateness of orientation, and ranks of rooms, based on frequency of use, type of user, and type of activity, is observed in the floor-plans of the Sana’a houses, as seen in Table 4 section C. The vertical arrangement of spaces in the tower house also follows
certain rules. Rooms that require more privacy are usually located in higher floors, while those that are higher connected to the public (or street) are placed in lower levels, as seen in Table 4 section D.

**Facade Design** – If the indigenous Sana’a houses are distinguished from others by their fascinating façades, the unique windows are without doubt their most outstanding elements. The variation in the horizontal arrangement of windows (shapes, sizes, and number) is a result of climatic influences such as solar motion and wind direction. South façades have larger windows with more components and controls than north façades so as to exploit solar energy for heating. The variation in the vertical arrangement is a result of socio-cultural influences such as the people’s activities and traditions. While higher floors have large windows to maximize visual connection to outside views, lower floors have smaller windows for privacy. The distinction of these windows lies not only in their delightful designs but also, and more importantly, in their different functions. The people in Sana’a found that the integration of the different functions of a window could be performed more efficiently by separating the window into components; each was responsible for one or two main functions (Al-Sallal and Cook, 1992). This, in turn, provided more flexibility in controlling each function. The variation in function from one space to another is reflected in the variations in the size, shape, and number of windows. Generally, the indigenous window has four major parts: the upper section, the lower opening, the vents, and the overhang (Fig. 2). Each part has a different function. One window can consist of some or all the parts, depending on its main function and its location on the façade as well as the plan of the house.

<table>
<thead>
<tr>
<th>Design Issues</th>
<th>Sub-issues</th>
<th>Design Guidelines</th>
<th>Design/Performance Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-form configuration</td>
<td>Orientation of long axis</td>
<td>• The long axis of the tower form is oriented east-west</td>
<td>• Controlled by site characteristics</td>
</tr>
<tr>
<td></td>
<td>Horizontal Aspect Ratio</td>
<td>• The horizontal aspect ratio of the built form (i.e., length to width) falls within 1:1.6 to 1:2</td>
<td>• Affect solar exposure</td>
</tr>
<tr>
<td></td>
<td>Vertical Aspect Ratio</td>
<td>• The vertical aspect ratio (i.e., length to height) falls within 1:1.5 to 1:2:5</td>
<td>• Controlled by cost and family size</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Affect solar exposure, visual connection</td>
</tr>
<tr>
<td>Arrangement of indoor spaces</td>
<td>Horizontal arrangement of spaces</td>
<td>• South for distinctive and high occupancy living spaces</td>
<td>• Controlled by room’s frequency of use, type of user, and type of activity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• East and west for average and less occupancy living rooms</td>
<td>• Affect solar orientation and visual connection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• North for only services spaces</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vertical arrangement of spaces</td>
<td>• Spaces that require more privacy are located in higher floors</td>
<td>• Controlled by room’s frequency of use, type of user, and type of activity.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Spaces that are higher connected to the public (or street) are placed in lower levels</td>
<td>• Affect privacy and visual connection</td>
</tr>
<tr>
<td>Façade Design</td>
<td>Horizontal arrangement of windows</td>
<td>• South façades have larger windows with more components and controls to exploit solar energy for heating</td>
<td>• Controlled by climatic influences such as solar motion and wind direction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• North façades have smaller windows to avoid heat loss.</td>
<td>• Affect solar heat gain</td>
</tr>
<tr>
<td></td>
<td>Vertical arrangement of windows</td>
<td>• Higher floors have large windows to maximize visual connection to outside views</td>
<td>• Controlled by socio-cultural influences such as the people’s activities and traditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lower floors have smaller windows for privacy.</td>
<td>• Affect visual connection and privacy</td>
</tr>
<tr>
<td>Window Design</td>
<td>Size, shape, and number of windows</td>
<td>• Large windows mainly for viewing</td>
<td>• Controlled by Space type or activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Small windows mainly for ventilation</td>
<td>• Affect daylighting, ventilation, and view</td>
</tr>
<tr>
<td></td>
<td>Design of window components</td>
<td>• Main part for daylighting, ventilation, and view</td>
<td>• Controlled by the window main function and its location on the façade as well as the plan of the house</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Upper component (al-qamarya) for providing soft daylighting</td>
<td>• Affect daylighting, ventilation, and view</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Vents (shaqus) for ventilation only</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Overhang for shading</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Climatic and functional influence on form and space of the tower house in Sana’a.

A. FORM affected by CLIMATE
In winter, walls receive most of the solar radiation because of the relatively low altitude angle. In summer, roofs receive most of the solar radiation because of the relatively high altitude angle. Accordingly, form A (the tower form) is better than form B for the following reasons:
- It has larger wall area which promotes solar heat gain in winter.
- It has smaller roof area which reduces solar heat gain in summer.
- It provides appropriate solar access to higher floors in winter.

B. FORM affected by FUNCTION
Form A (the tower form) is better than form B for the following reasons:
- It has larger wall area which promotes more connection to the outdoor views.
- It has smaller core space that does not have connection to the outdoor views anyway.
- It is taller which provides more view ranges. Form A provides R1, R2, and R3 and B provides R1 and part of R2.
  R1: cluster garden
  R2: nearby gardens
  R3: city surroundings

C. SPACE affected by CLIMATE
To match between therm. zones and rooms:
1. Thermal zones are ranked according to its adequacy to provide thermal comfort. South is the best; east or west are average; north is the worst orientation.
2. Rooms are ranked according to its importance in terms of frequency of use, type of user, and type of activity.

D. SPACE affected by FUNCTION
The concept of multistory house provides several levels of privacy:
- L1: Spaces that need high level of privacy are located on highest floors.
- L2: Spaces that need lower level of privacy are located on middle floors.
- L3: Spaces that need lowest level of privacy are located on lowest floors.
Fig. 2. Components of the Sana’a traditional window (after Mathews\textsuperscript{2}, courtesy of the British-Yemeni Society.)

Conclusion

The vernacular tower architecture of Yemen has always been known for its strong character, remarkable identity, deep cultural meaning, and ecological harmony. The socio-cultural and the environmental values that exist in the design of the Sana’a tower house have been discussed with specific emphasis on: privacy and safety, visual connection, solar design, and airflow. To highlight the potentials of the tower house in achieving these values, a comparison between the tower house and the modern house has been presented. To achieve these values, the design of the tower house is constrained by a set of rules that specify its form proportion, orientation, zoning, and space arrangement. The study concludes by presenting these rules in a form of design guidelines (i.e., design issues, guidelines, and design/performance variables; as seen in Table 3) that can be applied as basis for sustainable design in Sana’a.

References


\textsuperscript{1} Information given in by Abd al-Hakim Al-Sayaghy, Manager of Public Affairs in the General Organization for the Preservation of Historic Cities of Yemen (GOPHCY) on 18 August 2003
\textsuperscript{2} With permission, from an article in a website titled ‘A commentary on Yemeni traditional architecture’, by Derek Mathews on the website http://www.al-bab.com