INVESTIGATING THE APPLICABILITY OF SUSTAINABLE URBAN FORM AND DESIGN TO TRADITIONAL CITIES, CASE STUDY: THE OLD CITY OF SANA'A

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Keywords

Sustainability; urban form; density; walkability; connectivity; solar energy; space syntax; GIS.

Abstract

This research compared the traditional urban form of old Sana’a with the modern by applying three main basic principles of sustainability; 1. Form and density, 2. Walkability and connectivity and 3. Building energy. The method of inquiry was based on qualitative and quantitative methods and analysis using GIS, ECOTECT and Space Syntax modelling. The findings show that traditional form with its higher building density and compactness is a good model with regards to sustainable principles. Similarly, as to walkability index, traditional layout has higher rates of intersections and connected nodes and least angular changes with higher rates of integrations and choices in terms of Space Syntax properties than new layouts. Finally, the result of applying ECOTECT for urban solar analysis to confirm that the traditional pattern achieved sufficient values of solar access, exposure and shadows over different periods of the year. The overall results indicate that the traditional urban layout is more sustainable in terms of form and density, walkability and connectivity and urban solar energy than the new layouts.

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INTRODUCTION

Urban design represents the keystone to the manipulation and moulding of sustainable cities (Ritchie and Thomas, 2008). The new urbanism movement of sustainable urban design is concerned with innovating new comprehensive relationships of multidisciplinary form related to the urban structures and forms, natural environment, social livelihood, cultural values and economics processes. The new paradigm requires fundamental changes in current practices of urban form and design, environmental and economic forces with significant respect to the traditional social convention and cultural values (Talukdar et al., 2012). Sustainable urban design can be achieved through the development and management of comprehensive multi-level framework of urban design principles (Fleurke, 2009; Kazimiee, 2013).

Modernization, in Yemen cities, has caused the negligence of traditional urban form structure and the import of the western styles of urban form and design (Saqqaf, 1987). The organic urban fabric of the traditional towns is inharmonious with that of the modern, specifically in terms of its physical structure, built environment, urban form, as well as design characteristics that include built-form patterns and movement networks configurations (AL-Abed, 2011). The modern pattern emerged with two types of buildings: low-rise detached villas and apartment building blocks with orthogonal grid pattern of street network configuration. The traditional pattern, however, consists of high-rise vertical tower buildings that contain open spaces, such as social squares and green areas (AL-Sabahi, 1996; Serjeant & Lewcock, 2013).

In recent decades, the majority of the built environments were constructed in areas not controlled by the urban planning authorities (Lamprakos, 2016); where architects, urban designers and planners started copying the western styles after the end of Yemen isolation in 1962. This lead to the employment of imported modern standards, building methods and building materials (AL-Sallal, 2004).

The problems within the modern patterns can be classified to three essential sustainability principles:

- Form and density;
- Walkability and connectivity;
- Urban Solar Analysis.

SUSTAINABLE URBAN FORM MODELS

Traditionally built environments have inspired architects and planners to seek better urban forms based on some of their physical qualities that originate from new urbanism, new-traditional urbanism, an innovative movement in architecture and urban design using design-based principles in traditional urban forms (Talen, 2013). New urbanism's design principles are concerned with multi-scales alternating from buildings, plots, and urban blocks to settlements, streets, paths- routes and corridors- and eventually to whole urban forms. New urbanism communities strive to ensure that each neighbourhood contains housing of all categories: mixed-uses, varieties of shops, services, and activities capable of meeting the daily needs of many residents. These housing types are reached while being pedestrian-friendly (encourage local walkability) and increasing residential densities beyond the suburban norm (Haas, 2008).

New urbanism advocates design strategies based on traditional urban forms that aid in suburban and inner-city decline (Serge, 2011). Keys to new urbanism and traditional
residential designs include compact building patterns and mixing housing types for a wide range of incomes, providing for greater density and human contact and reinforcing human presence by taming the ubiquitous automobile (Talen, 2013). New urbanists believe that front porches, along with narrow streets, back-alley garages, shallow setbacks and street trees could promote the neighbourly characteristic of the old cities (Talen, 2013).

Wheeler (2002) argued that nineteenth-century neighbourhoods with diverse building types are now amongst the most vibrant, attractive, and popular districts. It was concluded that zoning was a major institutional force working against diversity of urban form. Neo-traditional development, or the new urbanism, emphasizes certain concepts of sustainable urban form. In terms of walkability, neo-traditional urbanism suggests pedestrian orientation and walkability settlements (Abdulla et al., 2017). As for density, it promotes higher residential densities than typical suburbs. Neo-traditional urbanism would have the distinct traditional architectural characters, and the encouragement of street life through features such as narrower streets, front porches, and a public open space (Naser, 2003).

Design Principles of Sustainable Urban Form

Form and Density

Compactness of the built environment is a widely acceptable strategy through which sustainable urban forms might be achieved. Compactness refers to urban contiguity and connectivity, which in turn suggests that future urban development should take place adjacent to existing urban structures (Wheeler, 2002). However, intensification, a major strategy for achieving compactness, uses urban land more efficiently by increasing the density of development and activity. The intensification of the built form includes development of previously undeveloped urban land, redevelopment of existing buildings or previously developed sites (Jenks and Burgess, 2000).

Three major themes are evident in current debates on compactness as an important strategy for achieving desirable urban forms (Burton, Jenks, and Williams, 2013). The longest established and most common theme is that a contained and compact city has a corollary of rural protection (Islam, 2008). The second theme is related to the promotion of the overall quality of life, including social interactions. The reduction of energy consumption is the basis of the third major theme.

Movement

Movement network which lacks many vital qualities, such as functional hierarchy, pedestrian movement facilities, continuous pedestrian routes, significant complex detours, safe streets transit, and sidewalks (WorldBank, 2010), discourages walkability; one of the important activities of urban design. There is an inherent conflict between lower densities and a good transport system, in which the presence of lower densities encourages the use of cars. These densities make facilities difficult to provide without imposing a degree of car travel, which is environmentally damaging.

Passive Solar Design

Passive solar urban design is essential to achieving a sustainable urban form. Generally, the idea of this design is to reduce the demand for energy and to provide the best use of passive energy in sustainable ways through specific design measures. This design affects the form of
the built environment though, for example, the orientation of buildings and urban densities (Ritchie and Thomas, 2008).

The urban area, described as the “urban microclimate”, “has a different climate from the countryside” (Barry and Chorley, 1998). Compared to open country, built urban sites have larger areas of exposed surfaces per unit area of ground cover. Because of the larger area, potentially more solar radiation can be collected on a built urban site than on a flat, open terrain, especially in winter. In the city, a surface’s exposure to the sun at any given time is largely determined by the built form, as well as the streets’ widths and orientation. To improve public spaces such as streets and squares, some instruments could help to achieve urban spaces that can be better designed (Cubillos-González & Castillo-García, 2016).

Yannas (1998) summarized some design parameters for improving urban microclimate and achieving environmentally sustainable cities: (1) built form-density and type, (2) street canyon width-to-height ratio and orientation, (3) building design, (4) urban materials, and (5) vegetation and bodies of water. Interaction between energy systems and urban structure takes place at all spatial scales ranging from the region, city, and neighbourhood to the individual building (Owens, 1992). So far, sustainable forms have had a crucial role in the reduction of energy usage.

CASE STUDY

Sana'a city has been selected as a case study because it is one of the most rapidly urbanizing centres in the Yemen cities. Sana'a is one of the cities listed in the World Heritage list being the capital of Yemen, the political and administrative status which has a long history of urbanization and the rapid development of its settlements. Multifaceted transformations occurred in the city through social-cultural, economic as well as historical factors which caused changes in the life style of the people and encourage them to be orientated towards preference for new urban patterns and the high rate of development of new settlements.

![Image of Sana'a city's urban fabrics](Source: Authors)

Figure 1: The selected samples of the various urban fabrics in Sana'a city (Source: Authors).

Traditional urban settlement was selected as a sample representative of all settlements in the ancient town and its organic pattern. Development processes that are characterized by vertical extended, which still retains the unique characteristics as existing settlement. The traditional settlement also indicates a slight discrepancy in terms of the built forms where the
mixed character of the traditional tower type with low-rise buildings, especially buildings services. Architectural experiences and practices accumulated on the basis of inherited profession for several generations, extending from the first century BC, the Islamic Ages to the present day, but the chosen settlement evolved in the Islamic period, which is characterized by its unique urban pattern. This is based on the subdivision of small residential neighbourhoods and its centres as the mosques and urban gardens, and the housing clusters grouped around it.

Haddah area is a residential settlement newly planned in 1972. Haddah was designed on the basis of the low-density residential plots dedicated to high-income residents. The settlement design adopted non-mixed development approach with predominantly residential use, which indicates that the vast majority of the plots were classified to cover the low plot coverage. Selection of the Haddah settlement was motivated by clearly interpreted salient features of the low-density of the most residential units dedicated to high-income, who prefer modern urban lifestyle.

Haddah is located along Seventy Street with high accessibility additional to its neighbouring settlements occupied by high-income, this may further low-density development processes compared to other samples of the study. In contrast, large areas booked by some traders for investment have caused the region to not develop fully, as well as the existing situation of development, which refers to the considerable variations in the building forms with particular reference to the urban physical and visual features.

The project of urban development for the city of Sanaa, was designed by the planners of the United Nations in 1980, defined Sa'wan area as one of the modern urban development zones. Saw'wan is one of the formal settlements in Sanaa city whose urban development emerged gradually during the period between 1980 - 1990. The settlement is characterized by vast residential developments, diverse building types, intensified building forms largely due to its design strategy that took into account the need to accommodate relatively high density for the medium and low income. Furthermore, its location is in the middle of the traditional urban core and adjacent to the centre of the modern city (AL-Hasabah district) in addition to the rapid development processes and vertical densification, which was introduced in most of the units and buildings. All of these characteristics might distinguish this settlement from the other study samples for comparison, investigation and detailed analysis. The diversity seems a distinctive feature of the building forms and densities with a slight variation of the plot sizes in the urban scheme. Intensified buildings classifications have reached settlement to the saturation state, which led to a noticeable change in forms and densities of the buildings by replacing one- two floors to the vertical densification with multi-story and mixed-use residential and commercial.

METHODOLOGY

In order to accomplish the research objectives, and the specific research context, a cross-sectional design strategy was adopted. The research methodology is based on triangulation approach that used two or more methods of data collection procedures within a single study. The research combined quantitative and qualitative methods. The main principle is that the research questions must be focused, the strengths and weaknesses of each method must complement the others, and the methods must be selected according to their relevance to the nature of the phenomenon being studied. The methods used are: field observation, archival data and simulation.
Field observations

Field observations have been reliable in this research as a primary data collection method to identify the built form typologies, building characteristics and density features. Also added to the list are plot properties as well as sub-urban schemes classifications and street network patterns with open space configurations. It entails making observations to the main parameters and variables of building forms such as building types, sizes of buildings, number of floors, building use and materials and roof types. This phase also included field observations that focused mainly on three major categories which includes:

- Field observation recorded the important variables of building forms such as building types, sizes of buildings, number of floors, building use and materials, and roof types. These indicators are explained in detail in the buildings form characteristics.
- It includes observations of key variables for density properties such as buildings density, room occupancy ratio, plot coverage, and floor area ratio. The observations included recording all buildings and plots for five different samples of the study. These variables are detailed in the density features.
- The observation includes recording main indicators of plots. It observes the Plot sizes, Plot ratio, Plot exposure, Plot boundary definition for each of five plot schemes in the study samples.

The second phase of field observation identified variables related to the street network that includes identifying the street grid pattern and the configurations of urban spaces, the manner of pedestrian flows within the street network as well as activities within urban spaces which included the characteristics of street network for five samples selected.

The third observing phase is identified by the key variables in terms of thermal comfort and solar potentials. It includes recording and measuring urban scheme patterns, built form types, street widths, urban coverage, setback distances between the buildings, the building height to street width ratio, measure front and rear and the side distances of buildings and exposed plots and many of the key parameters affecting utilizing of solar energy.

Archival data, documents and drawings

Sub-urban schemes and plans, drawings and maps provided the most prominent data sources and basic inputs in analytical procedures and calculations processes of built form typologies, building types, plot layouts, plot exposer, the street grid pattern, the configuration of open spaces and setback distances, and types of densification. These data were gathered from various departments in the Ministry of Public Works, Urban Planning Authority, the Municipality of the capital, the General Authority of maintain the historical cities among other sources. The analysis of plans and drawings included calculations processes of the main variables for this study such as the sizes of buildings, plot sizes, plot coverage, plots ratio, floor area ratio and many important parameters. As well, it has been conducted to explore and compare the modifications and changes made to the layouts and compare them on the existing situation.

Aerial photographs represented a fundamental data source for this study. However, before detailed measurements, the research employed a set of aerial photographs, which interpret the urban expansions and changes in development areas conducted on the built-up parts of the city of Sanaa during different periods. A series of aerial photographs collected at different periods – namely 1937, 1962, 1972, 1990, 2002, 2010 - provides an overview of the urban
extensions and the spatial growth trends and urban transformation types of the city of Sanaa. Aerial photographs indicated different stages of new urban developments and classify patterns of various urban forms. It also provided a basis for the identification trends of urban transformation and densification processes. The urban forms patterns, street network configurations, and open space pattern within its different built environments were observed through analytical processes of aerial photographs and maps during the periods 1962, 1972, 1990, 2002, 2010 for all five samples of the study.

**Simulation and Generation Tools**

- Three software were used in this study: Space syntax, GIS, and Ecotect.
- Spatial Network Analysis/Modelling and Urban Regeneration

Several techniques were designed to predict and assess the walkability and pedestrian flows in the urban settlements with its local roads network. This includes axial line-based space syntax model, point-based space syntax model, and urban network analysis toolbox.

**Axial Line-based Space Syntax**

The axial line-based analysis of the urban street structure and its networks pattern is closer to the approach of the space syntax technique. It establishes many key parameters for a walkability and connectivity in the street network, such as connectivity, local integration and control values. This method was adopted and has been widely applied to be predicted and to generate solutions to many problems in urban street network such as predictable nature of pedestrian and vehicle flow which affects the analysis of crime and human way-finding process (Hillier, 1997).

The implementation of GIS database method is also an effective methodology for assessing walkability and connectivity in urban networks but it is somewhat restricted by certain requirements in order to conduct algorithm simulation to generate axial maps, methods adopted by Batty and Rana (2004) as well as Turner et al (2007). Presently, there are more effective methods of assessing pedestrian movement and flows within the settlements related to the angular segment analysis that are linked mainly with pedestrian movements through using shortest block-distance paths between nodes and intersections of the urban road networks (Turner, 2007).

**Point-based Space Syntax**

The method of Point-based space syntax deals with a flexible concept of distinct points derived from road maps of the urban network structure. This method involves a computable process of deriving the urban space syntax parameters while generating approved methodology in Space Syntax which refers to the semantics of point-based values which are often based on estimated values. It provides variety of derivations of continuous changes in the generated space syntax value between two nodes connected in the urban network structure. In contrast, the evaluation of the node structure in GIS depends on the Analytic functions of the several surfaces that can be performed to create morphology related to the analysis of discrete point values.
Urban Network Analysis Toolbox

Both Axial line-based space syntax and Point-based space syntax deal with points and lines (nodes and edges) to generate urban street network where the nodes interpret the intersections of the road networks while the edges explain the segments of the street structure (Crucitti, Latora, and Porta., 2006). The limited interest only to the analysis of points and lines (nodes and edges) are not sufficient to explain the theoretical and practical applications of the generated results in the urban context, without taking into consideration the building arrangement and its locations. It represents a perception without building level related to fun-weighted form of graphic representations (Sevtsuk and Mekonnen, 2012). This method relies primarily to spatial street network analysis with open-source database in ArcGIS. Analysis method adopts the graph centrality measurement of the spatial network of buildings that provides five different types of measurements such as betweenness, closeness, reach, gravity index and straightness (Sevtsuk and Mekonnen, 2012). Urban Network Analysis includes a set of historically separate methods of graph analysis and accessibility analysis into one framework all-together.

This study uses the metric distance (along the roads) within the evaluations of the integration and choice of accounts which provides useful information and indicators as the radius of this measurement, thereby explaining how the radius shows how far the calculations are reaching. The metric distance analysis provides measurements of integration and choice through least angle segment analysis within a metric radius. Accordingly, the integration and choice measures identifies two variables that are the nature of human movement. When pedestrians select their destinations, they are more often a close distant one and there are less often a distant to any destination. They often choose the available paths that are a series of segments which can pass through it. Navigation as regards the pedestrian walkways within the network paths is done by using the least angular changes model. It is therefore likely that the possibility of movement between the various destinations and routes can be effectively evaluated by measuring both integration and choice all together which defines the smallest change angular distance between all paths. Therefore, it makes sense to give a true account to the movement of pedestrians.

Ecotect (Autodesk® Ecotec® Analysis)

Ecotect is an environmental analysis software tool that allows designers to simulate building performance. Ecotect provides a wide range of simulation and analysis functions required to study how an existing building or new building design will operate and perform. It is generally recognized that Ecotect is one of the few tools with which building thermal performance analysis is made simple, reasonably accurate and visually responsive to the needs of non-technical users.

RESULTS AND ANALYSIS

The analysis included three measures of investigations:

- Form and density characteristics,
- Walkability and connectivity properties,
- Urban solar analysis.
Form and Density Characteristics

Building form characteristics

There are significant differences among the three selected samples in the city of Sana’a which included old Sana’a, modern Haddah, and modern Saw’wan. Building form and attribute were studied and evaluated based on multiple comparison procedure. The results indicated different variation among different settings. Different parameters were studied and investigated that included: Building types, building height, building size, lot size, density, plot coverage and floor area.

- **Building types**

There are three different types of buildings varying according to urban standards and typology. Firstly, tower attached building type for extended families characterizes the traditional settlement pattern. Second, the individual single family detached building type characterizes the modern Haddah settlement. Third, prevalent in the modern settlement of Sa’wan, a mixture of building types from semi-attached single floors of a single family to the detached low-rise buildings of one family and semi-attached multi-story multi-family buildings. The comparative analysis shows the dominance of the attached tower building type in the traditional town, a single detached building type in modern Haddah, and semi-attached multi-story building type in modern Sa’wan.

- **Building height**

Building height greatly affects the relationship between form and density. Field observation illustrates the clear contrast and difference in the building heights. Tall buildings were high-rise tower buildings in the traditional settlement and multi-story building heights in the modern Sa’wan. On the contrary, building height in the modern Haddah settlement were low-rise (one or two floors).

- **Building sizes**

The analysis results indicated significant variations between the sizes of the buildings in all samples in Sana’a. The building sizes vary between small size to big size, ranging between 35 m² to 72 m² (the traditional settlement), 100 m² to 150 m² (Sa’wan) and 200 m² to 400 m² (Haddah). This can be related to the subdivision pattern layout of the plot sizes.

- **Plot characteristics**

The results clearly revealed variation in plot sizes which can be closely related to the development processes of the organic urban arrangement in the traditional settlement and the sub-division urban layout in the modern settlements. The modern urban settlement in Haddah consists of chess-like gridiron subdvisions with typically similar large plot sizes, while Sa’wan settlement has relatively small plot sizes. However, the organic urban layout in the traditional settlement consisted of a mixed set of the plot sizes, mostly small sizes, depending on social status and tribal customs.
Density characteristics

Population, housing, and occupancy densities

The results indicated variation in urban density; both old Sana’a and modern Sa’wan settlement have relatively high populations and building densities. In contrast, Haddah modern settlement which has relatively low population, building densities, and room occupancy. The overcrowding index can be related to the floor-area ratio; the highest occupancy rates were recorded in the traditional old Sana’a with 2.3 person per room, and 3 floor-area ratio. Occupancy rates are relatively low in the modern Haddah and Sa’wan settlements; 0.9 and 1.8 person per room and 1.2 and 2 floor-area ratio respectively.

Plot coverage

Results of the rate of plot coverage in the samples of Sana’a show clear contrast with significant differences. The highest plot coverage ratios appeared in the traditional and modern Sa’wan settlement while the lowest appeared in the modern Haddah.

Floor area ratio

Floor area ratio was considered as an effective indicator for examining the relationship between form and density in the study samples. The analysis of the floor area ratio shows varying values between the different urban form patterns. The high rate of the floor area ratio

Figure 2: Building form characteristics, including building type, building height, building size, lot size, density, plot coverage and floor area of the three selected areas in Sana’a (Source: Authors).
has emerged in both the traditional settlement and modern Sa’wan settlement with a slight contrast. However, minimum floor area ratios appear in modern Haddah settlement.

Figure 3: Density characteristics which include: population density, building density, room occupancy ratio, plot coverage, and floor area ratio of the three selected sites in Sana’a (Source: Authors).

Walkability and Connectivity Properties

This section identified of the key street patterns and open-space configuration features and the classification of the main variables affecting the walkability and connectivity principles in the local road networks of Sana’a; in addition to the analysis of the underlying urban parameters of the properties of the urban blocks, link ratios, connected nodes, intersection types as well as a geometric analysis of road networks in the five selected samples. It investigated the urban movement networks in Sana’a which have been divided into three main classifications of the street network structure according to the urban Zones in Sana’a. The investigation includes examining of the organic road pattern in the old sector as well as the modern street pattern in the new sector. The new pattern has been classified into two streets configurations: the iron-grid streets pattern in Haddah settlement, and the fragmented-grid street network pattern in Saawan settlement.

The analysis included the classification and identification of the street grid patterns for the three study samples as well as the analysis of many considered indicators related to walkability and connectivity. It recognised many important connectivity indicators that could be divided into three sections:

A. The first section is about indicators related to the metric parameters (shape and density); this involves the blocks shape, street density and other measures such as: block length, block size, block density, intersection density and street density. These
indicators were applied to all the three streets networks patterns in the selected samples.

B. The second section includes the main parameters related to the Topological features of the street configurations such as: node-link ratio, connected nodes ratio, link-nodes ratio and intersection types. These parameters have been examined in all the streets patterns of the study samples.

C. The third section includes several variables including streets syntactic measures which are related to geometric features of the street patterns; an example of these variables is: the least angular changes (Integration through-movement, closeness, choices to-movement and betweness).

The analytical processes included the separate measurements of all these variables on the streets networks in the selected settlements.

The Metric Parameters (Shape and Density)

The traditional roads pattern in old Sana'a is a hierarchical configuration of a coherent structure. The diverse hierarchy is distributed by the wide spaces and streets in accordance with the movement requirements as well as the environmental needs and factors. The main street (the first hierarchy) of the old town extends from north to south and divides the city into two halves. The Plaza occupies the urban street at its forefront. The street is 10m to 4m wide; there are many commercial activities along street. Secondary routes are branching out vertically from the main road heading towards the east and west, these streets are from 8m to 3m wide. The main and secondary road (the second hierarchy) represents the main thoroughfares of the city. The commercial activities, the Great Mosque, public buildings, urban facilities and other urban public spaces are distributed along this road.

The third hierarchy includes the narrower side streets and cul-de-sacs; this hierarchy is characterized by a hierarchy of functional movement which results from the private and semi-private network. A hierarchy is mainly used to allow access to residential clusters and homes. This network is vertical to secondary streets; it is oriented towards the north and the south for optimal utilization of the potential of solar energy. This type of Hierarchy represents the service streets, and it provides the privacy feature to residents than to the cul-de-sacs. This hierarchy is completely integral to the main road network.

Buildings clusters are organized externally on social squares and internally around urban gardens in small blocks surrounded by the narrow side streets providing access (through cul-de-sacs) to the grouped residential houses. Urban blocks schemes are often irregular small and varying significantly in length to width ratio; this created the old town organic geometric forms and the urban structure’s irregular blocks.

**Block Length**

Fragmented Organic structure includes many urban blocks in small sizes organized as small clusters within urban gardens or social squares. Traditional block lengths vary (mostly small) between 50m to 1,700m. The vast majority of blocks have small lengths ranging between 50m to 450m. Small urban blocks are identified by the short lengths of blocks with small distances. These short lengths of blocks formed many small intersections with shorter lengths and a greater number of nodes according to the small size of these blocks. Therefore, the shorter blocks ensure the shortest trip distances and a greater number of
paths between destinations. Consequently, there is a high level of connectivity with more choices. Moreover, the blocks small lengths encourage the pedestrian movement.

![Figure 4: organic configuration of traditional networks, link lines, connected and un-connected nodes, and intersection types at the organic road configuration in old Sana’a settlement (Source: Authors).]

**Block Size**

Traditional urban scheme is characterized by the variety of urban blocks and the small size of these blocks as well as the irregularity in terms of the blocks shape and size. Blocks are often relatively small and clearly diverse because of the differences in length and width. In some blocks, one single residential unit represents an independent urban block. Although the organization of buildings is around one large urban garden at the backyard, it is subdivided in the front into many small blocks. The study reveals that majority of the traditional residential blocks are small ranging from 500m$^2$ to 5000m$^2$. These small block sizes create shorter lengths providing more intersections and nodes which means shorter distances. It promotes the reduction of distances between the various destinations, and, thus, encourages walkability as it offers the highest number of possibilities and choices for pedestrian movement.

**Block Density**

Urban Organic scheme is characterized by the spontaneous arrangement of the irregular urban blocks. It includes many urban blocks with small sizes. Moreover, the basic principle of the Yemeni architecture is based on the organization of multi-storey tower buildings on a small footprint. This footprint is located on small areas of urban blocks in order to preserve agricultural land. The use of small areas contributed to creating the largest number of urban blocks in the smallest possible area.

The total number of traditional blocks is 174 blocks which is located on an area of 277443.08 m$^2$ (27.7443 hec). Thus, the block density (as an indicator of connectivity) measures at 6.3 blocks per hec. This high-density means that there are many shorter intersections and closer choices and a higher number of nodes. Therefore, trip distances become shorter due to the larger number of nodes and routes toward destinations. Accordingly, the connectivity values in this settlement are high and the walkability and pedestrian encouragement are much higher.
Intersection Density

The types and number of intersections are significant variables in identifying walkability and connectivity features. The diverse intersections' structure in the organic Sana’a pattern is the result of the fractional hierarchical configuration in its network with many of T-type intersections, a few of X-type intersections and numerous cul-de-sacs. On the other hand, the modern grid configuration formed many of the X-type intersections without cul-de-sacs, while the fragmental grid pattern in Sa’wan’s network have a larger number of both T and X-type intersections with no cul-de-sacs.

The measures of the connectivity values in terms of the intersection density indicate that the high-density of intersections can be found in both the traditional pattern network and the fragmented grid network in Sa’wan. They have more hierarchy and many of various T-types intersections and a few X-type intersections with more cul-de-sacs. This high intersection density means more multi-choices, high-values of connectivity and more possibilities for encouraging walkability, (Table 1).

Street Lengths Density

The hierarchical fractional characteristics of the organic road patterns have constituted a dense diversified arrangement of the configuration network elements. The dense diversity can be justified by the fractional configuration of the small networks which are distributed extensively across the routes, paths, mazes, social squares and roads. Street density can be calculated by the number of linear meters of the street network per square kilometre. The traditional roads are characterized by dense short lengths within its paths and routes. The characteristics of these roads provide more possibilities for choosing between paths which means moving with higher connectivity. The traditional configuration has shorter streets often ranging from 5m to 100m. The total street lengths are 15152.95m (15.153 km) while the average street length is 20.785m. The street density is 0.5462 km per hect. This high-density creates the higher values of connectivity and more choices to destinations and more possibilities to navigate at the desired places. Furthermore, this ensures creating good social interaction.

Connected Nodes Ratio

The complexity of the traditional network pattern creates a diversified configuration of the intersections and nodes. Moreover, the diversity of intersections has formed many connected nodes, X and T intersections and cul-de-sac. X-type intersections create more connected nodes between the routes and paths with open spaces. While T-type intersection in cul-de-sac roads creates many of non-connected nodes which is dedicated to house entrances and courtyards of residential units in order to provide more privacy.

Connectivity indicators were analysed in terms of the connected nodes. Measuring the connected nodes ratio denotes more ability and possibility of movements across node intersections. This indicates a high level of movements within routes, paths, open and semi-private spaces. Many cul-de-sec paths provide better movements to the private and semi-private paths and spaces in the traditional network. Connected nodes ratio measured at 1.0535, which is a high ratio. This allows shorter trip distances and more desired walkability. The traditional pattern contained open spaces that
contribute to the enhancement of the movement possibilities due to the area that contains the high-ratio of the connected nodes ratio provided by the open spaces.

**Link-Node Ratio**

The traditional pattern of the road networks is characterized by a big variation in nodes, segments, intersections and links. Connectivity in the traditional configuration is particularly higher in dead-ends and not only in intersections. The high links-node ratio increases the level of connectivity in the corridors and routes; it reduces the trip distances for pedestrians. Figure 4 in appendix B explains the node maps of the traditional road pattern.

The total number of nodes in the organic network is 692 which is a very high number in the overall traditional settlement. Furthermore, the number of links is 729. Therefore, the link-node ratio is also high with 1.0535. This high ratio improves the possibility of a better connectivity as well as walking and movement in all settlement sites. (Table 1).

<table>
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<th>Parameters</th>
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<th>Haidalah</th>
<th>Sana‘wan</th>
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<td>Number of Dead End Nodes</td>
<td>224</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Connected Node Ratio (CNR)</td>
<td>Number of Dead Node Ratio</td>
<td>468 / 692 - 0.676</td>
<td>80 / 81 = 0.9876</td>
<td>301 / 301   = 1</td>
<td></td>
</tr>
<tr>
<td>Link to Node Ratio</td>
<td>Link-Node Ratio</td>
<td>729 / 27.7413 Hec = 26.2757</td>
<td>120 / 42.721 = 2.8989</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>692 / 27.7413 Hec = 25.9421</td>
<td>81 / 42.721 = 1.8960</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>26.2757 / 24.9421 = 1.0535</td>
<td>2.8989 / 1.8960 = 1.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Or 729 / 692 = 1.0535</td>
<td>Or 120 / 81 = 1.4814</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intersection types</td>
<td>Total Number of Intersections</td>
<td>424</td>
<td>32</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of T intersections</td>
<td>392</td>
<td>33</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of X Intersections</td>
<td>32</td>
<td>19</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X1-intersections</td>
<td>13</td>
<td>3</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X2-intersections</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T1-intersections</td>
<td>132</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>T2-intersections</td>
<td>22</td>
<td>0</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T3-intersections</td>
<td>95</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Geometric Analysis (Least Angular Change)**

This section included the walkability and connectivity measurements in the street networks of Sana'a following an analytical methodology different from the earlier parts. It also concerned with an investigation of walkability and connectivity in five diverse street patterns through the geometric street analysis. The geometric street analysis (least angular change) is one of the most important measurements that checks the walkability and connectivity parameters. It uses two important indicators: the integration measure (To-Movement, Closeness) and choice measure (Through-Movement, Betweenness). These two indicators are performed by **Adepth-map** program in *Space syntax* to identify the nature of pedestrian movement within the urban settlements networks in the selected sample.

The walkability and connectivity measure includes the geometric street analysis (least angular changes) that are conducted on different urban street structures in selected three samples of study in Sana'a. The geometric street analysis has been implemented to
generate the integration measure (to-Movement, closeness) and choice (Through-Movement, Betweenness) for the organic configuration in the traditional urban network, the Iron-grid orthogonal configuration in the modern Haddah settlement and the fragmented orthogonal Iron-grid configuration in the modern Sa’wan settlement.

The analysis of organic pattern segments in old Sana’a network has been extracted from the hierarchical coherent structure. Road structure is a fractional configuration comprised of a set of small segments in a complex and connected manner. It is characterized by a hierarchical coherent organization in addition to the diversity of its elements such as nodes, social spaces, paths and open spaces. Coherent path structure includes a consecutive series of small lines segments with less angular changes due to the existence of more zigzag and curved paths. These smaller segments are connected by a set of appropriately organized small nodes in all network partitions according to their function. The nodes are diversified: either connected at the intersection points and within the open spaces, or unconnected especially in the dead end.

Integration Measure (To-Movement, Closeness)

The integration measure, in the traditional settlement, show that the smallest street segments are significantly close-knit in different radii (200, 800). The fractional configuration in the organic pattern is basically a frequent complication of a matrix of segments of all the components of the road networks. Fractional segments created a compact structure of paths and more closeness which is composed mainly of more number of nodes, more closeness and intersects at the smallest distance.

Integration analysis as shown in Figure 5 explains that the vast majority of line segments (in red and yellow) have less distance due to the closeness of the segments to each other leading to more closeness between the original destinations within the street network. Therefore, the accessibility of the trips is increased as there are smaller distances between routes and paths of the original destination lines and all other routes and paths of the network. In addition, the possibility of easy movements is enhanced.

Choice (Through-Movement, Betweenness)

The fractional and hierarchical features with coherent zigzag, curved and broken properties of the organic line segments have formed more of the least angular changes between adjacent lines segments along the path to give the same thing between the subsequent paths and sub-paths. Betweenness in Organic-fractional composition has been formed through a series of successive matrix of angular changes between each Through-Movement network line segments. There are more choices available through shorter paths and more of the least angular changes.

The Analysis of Choice map as shown in figure 6 indicated that the vast majority of the segments in the network (in red) are laid on each other in the shortest routes between the network lines segments because of the least angular changes between each line segment. That means that the paths angles are almost straight in every network segments with the lowest angular changes between adjacent road segments under different radius. Consequently, the more choices with less angle change allowed a high-possibility of Through-Movement between each line segments which, therefore, gives high connectivity towards most destinations because movement is through short trip distances.
Figure 5: The Integration measure (To-Movement, Closeness) in the organic pattern of the traditional Sana'a town (Source: Authors).

Figure 6: Shows the choice measure (Through-Movement, Betweenness) in the organic pattern of the traditional Sana'a town (Source: Authors).

Table 2: Syntactic measure of geometric variables (Source: Authors).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Indicators</th>
<th>Parameters</th>
<th>Old Sana’a</th>
<th>Haddah</th>
<th>Saw’wan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntactic Measures (Geometric variables)</td>
<td>Integration (Closeness) and Choices (Betweenness)</td>
<td>Integration</td>
<td>134.684</td>
<td>46.3072</td>
<td>22.8515</td>
</tr>
<tr>
<td></td>
<td>Choice</td>
<td>843.709</td>
<td>171.74</td>
<td>225.344</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Node Count</td>
<td>153.27</td>
<td>102.84</td>
<td>20.4652</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Depth</td>
<td>179.84</td>
<td>465.44</td>
<td>21.064</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Segment Length</td>
<td>8.05348</td>
<td>56.4231</td>
<td>24.1675</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Connectivity</td>
<td>5.13229</td>
<td>4.96085</td>
<td>5.0585</td>
<td></td>
</tr>
</tbody>
</table>
Urban Solar Analysis

The old Sana'a, Traditional Climate Sensitive Urban form and Design, as climatic response, emphasize the most significance for climatic compatibility through; shadow patterns on a large rate; wind patterns between urban elements provide thermal balance; light and permeable building envelope materials such as stone, mud-brick, plastered and wood; and increased rate of urban greenery around most buildings to mitigate the UHI effect in urban space.

Table 3: Climate condition and heat stress in the city of Sana’a (Source: Authors).

<table>
<thead>
<tr>
<th>Annual Average</th>
<th>Sana’a</th>
<th>Surface Temperature Increase Projection for 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average High (°C)</td>
<td>26.8</td>
<td>3-5°C for all three selected samples.</td>
</tr>
<tr>
<td>Record High (°C in June)</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Average Low (°C)</td>
<td>11.3</td>
<td></td>
</tr>
<tr>
<td>Record Low (°C in January)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>198.5</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>12-75</td>
<td></td>
</tr>
</tbody>
</table>

Shadow Patterns

Shadow patterns influence effectually on thermal balance in urban form based on urban geometry, wherefrom or whence the patterns exposure of building envelope materials to solar radiation, also the gainer's heat in building mass. Another efficiency, the patterns of airflow in urban canyons, make up when heat radiation is changing between building mass and adjacent atmosphere.

In Sana’a, shadow patterns lie on a large rate of building surfaces, roofs, open space, and streets due to variations in building mass and built form. Its streets and social squares are enclosed by traditional vertical housing. The average building height is between 15 meters up to 30 meters while street width is around 3-10 meters, and length of social square is about 30 meters maximum. It follows, therefore, the ration of length to width (H/W): first, at street level or section, it varies from 2/1 up to 5/1. Secondly, at social squares varies about 1/2 and 1/1. Furthermore, within urban structure, the permanent shadow is attained in urban space at least 6 hours and 45 minutes a day while other urban areas have reliable continuous partial shadow patterns.
Figure 7: A typical South-North oriented public space in Sana’a has complete shadow during 11 out of 12 hours (out of 14) on a typical 21th June (Source: Authors).

Wind Flow Patterns

Wind flow patterns of Sana’a city are often two types: moderate wind flow from South and West (sea breeze), sandy and hot wind flow from North and North-East (desert wind), and cool wind flow from East (highland wind). In summer, hot and dry winds flow from North-East, which come directly into urban spaces to rarefy the hot temperature of June in Sana’a. There are strong relationships between traditional urban design elements and wind factors. Firstly; semi-circularity walls enclose the city around (9-14 m height); secondary, compact and continuous built form both interplay positively for control of orientation and scatter the hot wind above the canopy layer of the city. In above the canopy layer formed air flow that provides a reverse pressure and absorbs the heat and humidity out of the urban space.

Table 4: Shadow hours in Sana’a for typical south-north oriented open space on typical 21 June (Source: Authors).
Daily average shading percentage

The calculated measures of the daily average shading percentage indicates that the shading percentages at the traditional urban form of densely detached and compact building patterns have almost similar values during daily hours (09:00-16:00) in all months. This result indicated that most building surfaces (especially the long – axis south – oriented ones) were shaded sufficiently especially during the months of March and June while the shading percentages in September and December are less, mostly in the north – oriented building surfaces.

Daily Average Incident of Solar Radiation (ISR)

The Incident of Solar Radiation was recorded with moderate value and slight variations within both the traditional urban form and detached urban form in Haddah. The Incident of Solar Radiation (ISR) in modern dense pattern with semi-attached in Sa'wan was relatively high during most of the day (figure 10).
The traditional urban form has an inside air temperature almost within the comfort band while the detached urban form in modern Haddah record was almost outside the band. The semi-attached urban form in modern Sa'wan has recorded readings outside the comfort band as well.

Figure 10: Incident solar radiation – Daily average Wh/m² of the three case studies (Source: Authors).

CONCLUSIONS

The sustainability potential in the traditional urban form and design is the essential issue that has been dealt with in this study. It is an attempt to take advantage and learn lessons from the past designs to extract applicable solutions for the urban problems that exist in the Yemeni cities, especially in Sana'a. This was done through investigating the efficiency and effectiveness of traditional urban solutions practiced in a successful way for a long period. Fundamental sources of urban design solutions can be built upon the successful traditional urban solutions as they can teach us how to understand the principles of sustainable urban form and design.

Thus, the traditional urban practices were founded on the principles of design in the context of urban sustainability. This study investigated the sustainability potential of urban form and design in the traditional architecture of the ancient town of Sana'a and their applicability on three basic principles ranked as the leading principles of sustainability form and urban design theorized in the New-Urbanism movement.

The traditional urban form and design in ancient Sana'a have unique characteristics related to its built form arrangement and organic narrow street configuration which are harmonized holistically with the local environmental climatic conditions. The unique characteristics are a very high compactness of vertical towers built forms, a high built density, and sufficient solar potentials more than the modern urban forms despite of the narrow configuration of the road network. The vertical tower built forms were formed on small footprint sizes with high compactness and building density as well as a vertical arrangement of the functional spaces of the nuclear families. The unbuilt spaces are used as narrow-zigzag streets, private and semi-private open spaces (urban gardens and social squares) that help in controlling the thermal comfort and solar potential.

The complex fractional configuration characterizes the organic street pattern that has achieved very high accessibility and connectivity rates. It was formed by a very small block.
size, a very high block and intersection density, a very high connected node ratio and least angular changes creating more sustainable urban forms and providing the high possibilities for social interactions within its urban network. The traditional urban form is characterized by the vertical tower with a high building density; very high connectivity and walkability rates; and fractal complex pattern which significantly influence the solar potential in the urban texture as well as the energy efficiency of the urban forms and its built environments through forming an organic fabric with a complex pattern capable of adapting to the climatic and environmental surrounding.

Therefore, Sana'a traditional urban form and its design are more sustainable and more climate-efficient. This is more compatible with local socio-cultural features and less costly than the recent technological urban sustainability methods.

Analytical results of the comparison between the old traditional urban area of Sana'a with modern urban form and design in Haddah and Sawan reveal important and significant differences on the light of the three sustainable principles.

As for the first principle regarding form and density, the analysis showed that the multi-story extended family type of the traditional old part of the city, with its compactness and higher building and population density than modern layouts in Haddah and Sawan, stands closer, for its economic and social preferences of the principle of sustainable form and density.

The walkability and connectivity principle which is meant to be some measure of accessibility and permeability for each layout of the study area has been analyzed by parameters such as: average block length and size of the urban system; street and block density; and connected node and link – node ratios. The analysis reveals that the old traditional area in which these movement parameters are concerned has a high level of permeability and connectivity, although the other two modern layouts have generally showed also close results. The space syntax analysis with its two properties reassures integration, and choice shows that the integration measure in the traditional settlement with its small street segments is significantly closely-knit in different radius (200,800)

Fractional segments created a compact structure of paths and more 'closeness', which is composed mainly of a large number of nodes and intersections and shorter distances. The orthogonal grid in Haddah and Sawan has been formed of segments often with lengthy lines and therefore, configuration in these two modern layouts are not so integrated as it is in the old traditional layout. As for choice which reflects through-movement and betweenness, the vast majority of the segments in the old traditional layout have high values and are laid on each other in the shortest routes. High values are also produced by Haddah and the least values come from Sawan because of the small orthogonal grid in this modern layout which has formed fragmented geometrical properties.

Finally, the analysis of the third sustainable principle, namely solar energy, shows that the old traditional area produces sufficient shading on building surfaces due to its compactness layout, whereas the modern urban fabric in Sawan, with its dense buildings, has a relatively high percentage of unobstructed sky and daily average incident of solar radiation, and only a moderate percentage in the old-tradition layout. Most importantly, results show that the inside air temperature of the modern layout of Haddah and Sawan are outside of the comfort level, and only the traditional old Sanaa is within the comfort level due to its geometrical form and local building materials.
These findings have very important implications: that modern layout and design are not as compatible as the old traditional one, and that the lessons learnt from these findings is that the principles and characteristics of the old traditional layout, which is developed over a long time of urban practices, can be and should be utilized to establish and improve the modern urban form in the city.

REFERENCES:


