Evaluation and Improvement Proposal of Sudan Building Codes to Solve Horizontal Expansion and Low-Population Density in Khartoum

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This research studies the effect of Sudan building codes on the Khartoum horizontal expansion problem and low-density population problem, which are among the main aims of all Khartoum master plans since 1960 until the most recent structural plan of 2007. The research curried out by Studying, analyzing, and categorizing Sudan building codes and determining its effects on Khartoum's horizontal expansions problem. The assessment of building codes takes into account environmental requirements for desert cities as main factor, in addition to social and cultural factors of Sudan. The results showed that; the setbacks regulations, maximum height regulations, and building extension over streets regulations need revisions. Because of these codes, the unused area in residential plots can reach over 35% of the total area. After testing the suggested modification, average of 13% of unused area (almost 37% of the unused area) can be available for residential functions. Moreover, the extension over street regulation and maximum height permitted regulations modified to improve city adaptation to desert climate and to increase building area by 4.4% of the total area for each 1m extension over streets.

Key Words: *Building Codes, Horizontal Expansion, Population Density, Desert Climate*

1. INTRODUCTION

(1) Historical Background

Khartoum is the capital of Sudan and the biggest city in the country. Its history goes back to the 16th century when it was just small three villages. During Turco-Egyptian occupation, it became the capital of Sudan. However, During Mahdiist era (1885-1899), the capital changed to Umm-Durman and changed back to Khartoum again during the Anglo-Egyptian occupation and it stayed the capital since then. The term Khartoum since the independence (1956) is referring to the three cities, which are, Khartoum the administrative city, Umm-Durman the national capital, and Khartoum north (also known as Khartoum Bahri) the industrial city [1)].

(2) Location, Climate, and Population

Khartoum city located at latitude 15.65 north, longitude 32.36 east and altitude of 380 meters above sea level. The city located in desert climate (Hot and dry), where the maximum average temperature reaches 42^{o} in May and the minimum relative humidity is 11% in March. The average annual precipitation in Khartoum is generally low reaching an average of 119 millimeters, most of which falls between July and September [2)]. See **Table 1**

Table 1 Khartoum climate data, maximum average temperature and minimum humidity are highlighted [2)].

Month	Average Sunlight hours	Temperature		Relative Humidity	
		Max.	Min.	Am.	Pm.
January	11	32	15	37	20
February	11	34	15	28	15
March	10	38	19	21	11
April	11	41	22	18	10
May	10	42	25	24	13
June	10	41	26	38	18
July	9	38	25	57	33
August	9	37	24	57	41
September	10	39	25	55	30
October	10	40	24	38	21
November	11	36	20	34	19
December	11	33	17	38	21

Khartoum population have grown rapidly from almost quarter million in 1956 at the independence time to more than six millions in 2007 official census. This number represents almost 19% of total Sudan population [3]. See **Fig. 1**

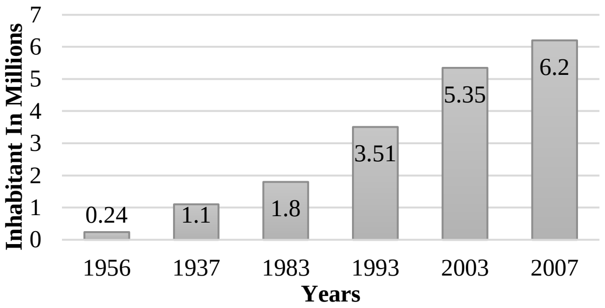

Figure 1 Khartoum population 1956-2007 [3]

The percentage of rural areas inhabitants to the total Khartoum population increased from 13.7% in 2000 to 33.1% in 2003 most of them live in very bad circumstances and living conditions in far part in the city [3].

(3) Horizontal Expansion and Density Problem

Since the first master plan of Khartoum in 1920 to the recent situation, the area expanded fast due to the immigration of people from all over the country to the capital seeking better opportunities, living conditions and safety from civil war in southern and western parts of Sudan. See **Fig. 2**.

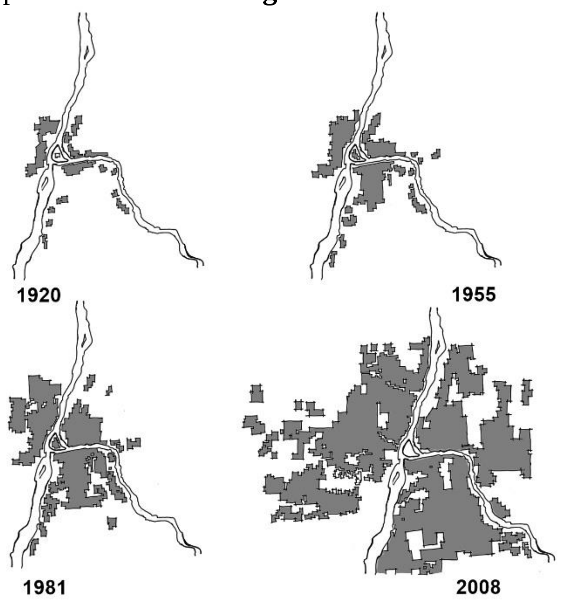

Figure 2 Edited version of the original map form the source for Khartoum horizontal expansion form 1920 to 2008 [2]

The density increased from 15 inhabitant per hectare in the first master plan after independence (Doxiadis 1960) to 42 inhabitant per hectare in current structural plan [3]. **Table 2** shows all Khartoum master plans and density objectives of each one. However, According to Acioly and Davidson, when densities increase from 50 to 200 inhabitants per hectare, infrastructure costs decrease spectacularly [4].

Table 2 Khartoum population density in all Khartoum master plans [3]

Paste plan	Population (M)	Area (Km^2)	Density (P/Hectare)
Mc Lean 1912	0.1	11.5	87
Doxiadis 1960 -1980	0.793	182	44 designed 15 altered
Mefit 1975-1990	2.5M	1,103	23
Doxiadis 1990-2000	5.3M	1,441	37
Current Structural Plan	7M	1,650	42

(4) Building Codes

a) History of Building Codes

The building codes know since early in human recorded history. Hammurabi the founder of Babylonian empire established written law called code of Hammurabi in 2000 BC. This was the first recorded building code in the history. The law stated the relation between client and engineer and the punishment if any engineering defect occurs.

According to the records, in Ancient Roman Empire, Building codes were also existed at about 450 BC. One of its roles stated the distance between building and the adjoining lot must not be less than 2.5 feet to achieve total distance of 5 feet between neighbors.

When Rome population increased, the height regulations established in Emperor Augustus era (27 BC. 14 AD). The maximum height was 70 feet and maximum floors numbers were 7 floors because of frequent collapses at tall buildings.

In Nero's era, there were also codes that decided the maximum height of building is not more than double street width. Roman building code also provided regulations on lighting, windows, drainage, and construction techniques. Therefore, various present regulations originated in the Roman's era.

England building codes developed based on customary Laws formed during period of the 11th to 12th century. These customary laws developed dramatically after London great fire.

In Queen, Victoria era the Metropolitan Building Act was established 1844. In this act the builds were categorized into three groups (1) Residential, (2) work spaces and (3) churches, universities, halls, hospitals, museums and other special buildings. This Act entirely revised in 1894 when London building act newly established [5].

In Sudan, the building laws and codes are existed since the first master plan of Khartoum city (Mc Lean 1912). However, the recent building codes did not developed since 1960 in the first mater plan after independence (Doxiadis 1960). As result of the global climate change, Khartoum weather has changed dramatically from savanna to semi-desert to desert climate in these 55 past years.

b) Purpose of Building Codes

The main purpose of building codes is to provide minimum requirements for safety included disaster prevention in disaster prone areas, health in terms of sufficient light and ventilation, welfare for individuals and for communities, and harmony of cities. Part of it is related to general planning and zoning regulations, and part of it is related to health and safety requirements. However, the building codes are varied from one place to another according to environmental, social, economic, cultural, and technological factors [5)].

(5) Research Aims and Objectives, and Methodology

a) Aims and Objectives

The main aim of this research is to study the building codes of ministry of urban planning in Sudan, in order to determine the codes that related to two main problems that facing the city which are; horizontal expansion of the city and low population density. Subsequently, study and evaluate these codes comparing to the environmental requirements of cities in hot and dry climates, taking in consideration the social and cultural factors. Finally, explore other possibilities to improve these codes by testing different scenarios.

b) Methodology

To achieve the objective of this research the following steps curried out.

- Study the Sudan building code and identify the codes that related to the research problem (Horizontal expansion and low population)
- Study the origin of these codes (Environmental, Social, and technical).
- Estimate the effect of these codes on area usage.
- Identify the main planning criteria of desert cities and environmental strategies that use to create better urban environment.
- Identify area of improvement on current building code and suggest alternatives.
- Test alternative codes and compare the results of current building codes with the alternatives.
- Identify the most effective alternatives.

2. RESULTS AND DESCUSSION

(1) Summary of Sudan Building Codes

Sudan building code provided orientations in all building areas starting from plot zoning area, setbacks, openings, and minimum required spaces in all functions, streets over hanged parts, parking, and maximum coverage areas of each building type[8)].

After studying the building codes, the codes that have direct impact on city horizontal expansion and low population problems classified to three groups, as follow;

a) Codes regulate buildings setbacks from neighbors

These codes designed to maintain adequate mount of ventilation and sun light for buildings (environmental), to provide privacy (social), and for safety in cases of fire and building collapsing (technical). The general rules for residential area is to set the building 3m or 1/3 the height from north and south neighbors and 1.5m or 1/6 from neighbors of east and west sides. However, for third class small plots there are other regulation that allowed building to be built attached to either east or west neighbor but building must not be more than half the length of the boundary length [8)].

b) Codes regulate building extension over streets

These codes designed to protect city street space to insure accessibility and provide space for infrastructure service (electricity, gas, internet, and water). The extension over street is allowed as 1.2, 1.5, and 1.8m for street widths of 10, 15, 20m and more respectively.

c) Codes regulate buildings heights

These regulations can be justified by safety measurements mainly for fire prevention and for master plan strategic objectives (technical and strategic requirements). The roles in this divided according to plot area and class. For the plot that are less than 1000 m^2 the maximum number of floors allowed are 3 stories and 4 stories for third class and first/second class residential plots respectively.

The first group of regulation is directly related to climate because it is mainly depends on sun angles and sky radiation levels to provide sun light and sufficient natural light for spaces. The ventilation depends mainly on wind speed [8)].

(2) Guidelines of Desert Cities Urban Planning

Desert climate cities general planning theme is compacted to prevent buildings form direct sun radiation and the streets are narrow to protect the city from desert hot dry wind as many studies illustrated [6)]. The most common technique that used in desert cities is shading technique. This technique depends mainly on building height and the street width to maximize the shaded area. **Fig. 3** illustrates the relation between the building height and street width and sun angles. As many studies show, the best cooling results come when vegetation is used because of the evaporative cooling effect. Moreover, the ratio of H (building height)/W (street width) is used as general guideline the bigger the number the better to reduce buildings direct heat gain [7]. See **Figure 3**.

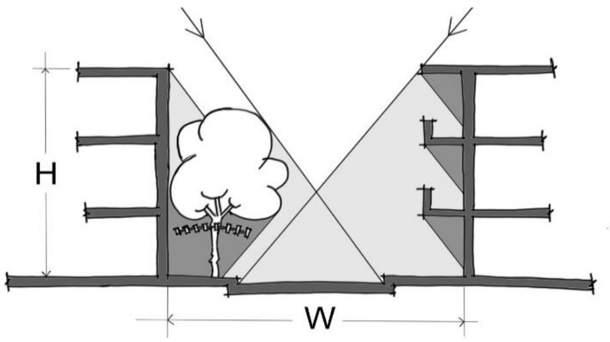

Figure 3 Shading strategy technique using building extensions, artificial shading devices, and vegetation

In case of Khartoum, the sun is very high in the sky almost all year (82.7^{o} on north façade in summer and 51^{o} on south façade in winter. **Fig. 4**) accordingly, minimum gap between buildings is sufficient to provide sun light. Moreover, the sky radiation level is very high.

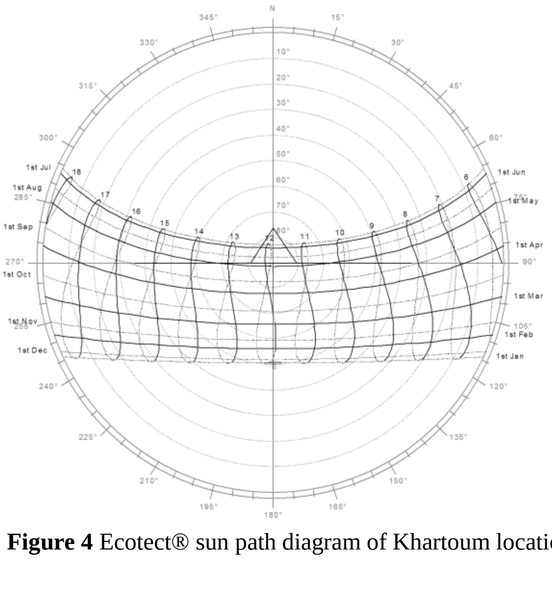

Figure 4 Ecotect® sun path diagram of Khartoum location

(3) Modification of regulations and comparison results

a) Setbacks regulations Modification

The main reason to modify these codes because in desert climate minimum space between buildings needed as mentioned previously. Also because of the dust and sand particles on air and desert air not recommended entering buildings directly from outside. Moreover, the wind is very hot and dry and it is recommended to reduce its temperature using vegetation and shaded areas [8]. Therefore, the setbacks regulations need revisions.

The setback regulations modified to be the half the recent values depending on the following:

The results of shadow rage of 12m building (the maximum number of floors allowed on private residential buildings in both first/second class and third class) in Khartoum and other recommendation for best planning options in desert climate.

Fig. 5 shows the results of Ecotect® simulation of shadow range (from 10:00 to 14:00 on 21 of May) for half of standard setback distance from north and south neighbors.

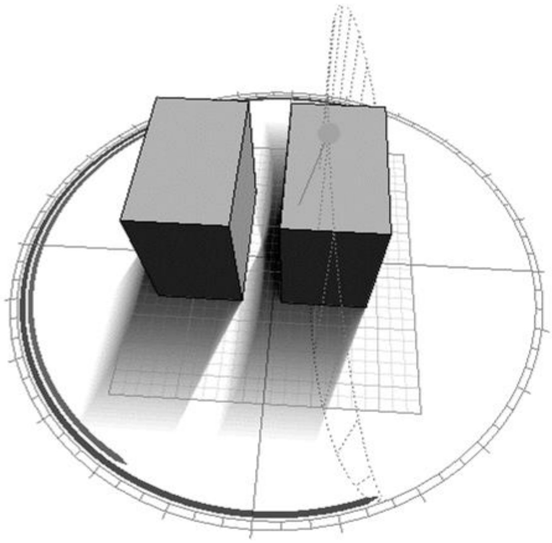

Figure 5 Ecotect® simulations of shadow rage of two 12m high buildings in Khartoum and the distance between the two buildings is have of the standard setback distance

According to the results of the simulation, the suggested setback from north and south neighbors will be reduced to (1.5m).

For the east and west setbacks, the minimum area for person accessibility for maintenance is used which is 0.75m (half of standard setback) to protect building from direct sun light from east and west façade.

After applying the modification, the unused area calculated for all scenarios and presented in one graph. The first values are percentages of unused area when standard setbacks regulation applied followed with the results of width (north and south) setbacks modification and then the length (east and west) setbacks modification and finally the combined effect of width and length modification.

There are three cases for setbacks regulation. The first discusses case of residential plots, which have area less than 400m^2 in all classes (first/second class and third class) followed by the second case, which illustrates the results of special case in third class plots when the area is less than 300m^2. And finally the results of plots, which have area more than 400m^2 and less than 600m^2.

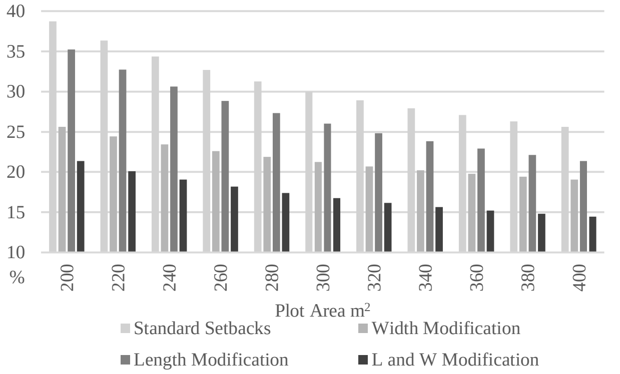

Figure 6 Unused area percentages comparisons between standard setbacks regulations and the modified setbacks in standard residential plots in all classes (first/second and third) which have area between 400 to 200 m^2

Fig. 6 shows the results of the first case. It shows the unused area when applying standard setbacks regulation goes over 30% of total area in plots smaller than 300m^2 and the unused area reaches slightly more than 25% in bigger than 400m^2 . However, with the new suggested modification, more than 13% of the total area can be recovered in plots smaller than 300m^2 and slightly more than 10% of area can be recovered in plots bigger than 300m^2.

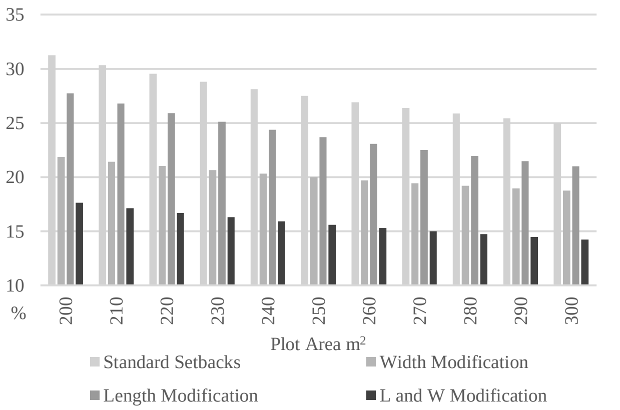

Figure 7 Unused area percentages comparisons between standard setbacks regulations and the modified setbacks in special third class residential plots (areas less than 300m^2)

Fig. 7 shows the results of the second case in which, standard setbacks regulations and the modification are applied on third class plots that less than 300 m^2 because they have special setbacks regulations. These set of setbacks regulation designed to maximize usage of area, however, the results show the smaller the plot the bigger the unused area. Unused area exceeded 30% of total plot area in plots that are less than 200m^2 and about 25% in plots that have area 300m^2 when the standard setbacks applied. However, more than 12% of the area can be

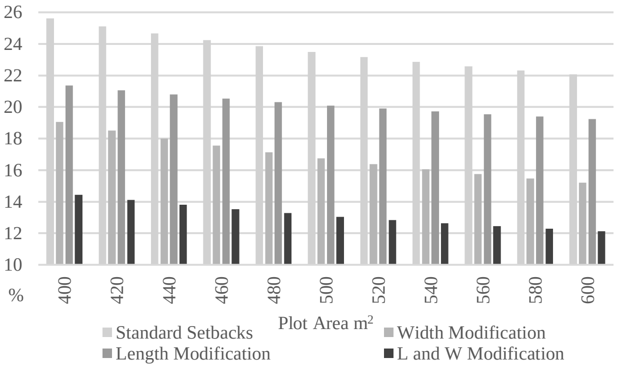

Figure 8 Unused area percentages comparisons between standard setbacks regulations and the modified setbacks in standard residential plots in all classes (first/second and third) which have area between 600 to 400 m^2

Fig. 8 shows the results of applying standard setbacks regulation comparing to the modified setbacks regulation on big residential area (bigger than 400 m^2). The same patterns continue here the bigger the plot size the lesser the unused area. However, as percentage, it is small, but as area, it goes form 104 m^2 in 400 m^2 plots to 132 m^2 in 600m^2 plots. On the other hand, the modified setbacks saved 10% of the area in plot area sizes.

b) Building Extension over Streets Codes and Maximum Height Codes Modifications

The guideline is to maximize shaded areas to avoid direct heat gain and to create narrow streets to protect buildings from the desert hot, dry, and dusty wind, and to maintain the humidity. For all this reasons these sets of code that regulate extensions over street and building heights are linked together to achieve the above environmental strategies. Increasing buildings height and the extensions over streets will increase shaded areas. To set regulations for street, there are many factors must be considered such as the importantce of the street, the numbers types of vehicles, and many other planning factor. However, the regulations must encourage extensions over street but over certain height to prevent accessibility problems.

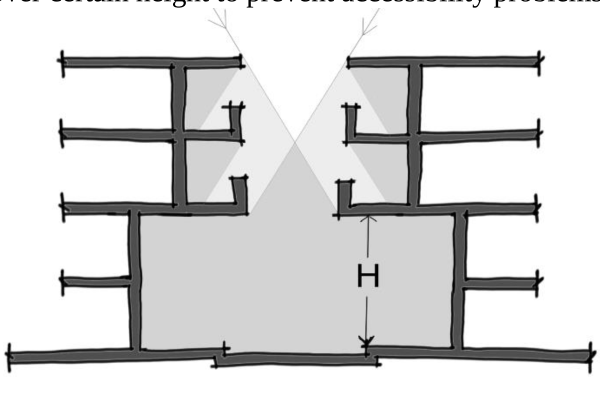

Figure 9 Proposed strategy to maximize the shading by using building heights and building extensions over street as shading devices. H is minimum clear height between

street and building extension

Fig. 9 illustrates the concept of new modification to building heights and over streets extension codes. As an alternative to prohibiting extensions over streets the research suggests determine effective height to allow infrastructure services (water, electricity, telephone line, etc.), and vehicles mobility and allow extensions over that height. Simultaneously, encourage the vertical extension of buildings.

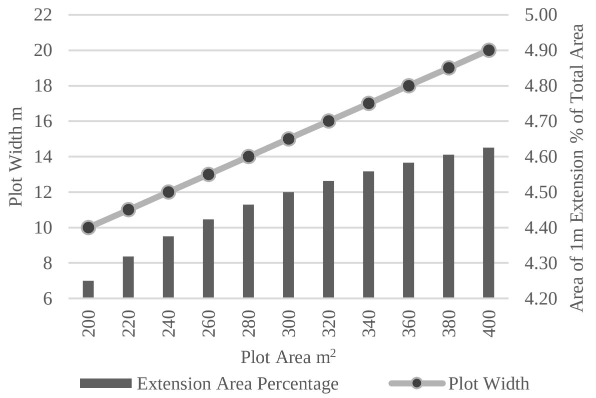

Figure 10 Percentages of 1m extension over street area to total plot area and the plot width

Fig. 10 shows area of 1m extension in one floor as percentage of total area with plot width and plot area. Extension area percentages of total area correspondingly follow with plot width from 4.2% to 4.6% for plot widths 10 and 20 respectively.

Permitting more extensions of buildings will increase useable area by almost 4.4% per floor for each 1m extension.

3. CONCLUSION

The building codes affect the city compactness and play role in the horizontal expansion problem and low-density problem that Khartoum is facing.

The modification of setbacks form neighbors regulation will save in average about 12% of plot land in all residential building class (first/second class and third class).

Modification of height regulations combined with modification of buildings extensions over streets regulations will increase the area by around 4.4% of total area on average for each 1m extension over streets per floor. Increase number of floors permitted will increase total usable area and subsequently will increase city density.

These improvements will increases the total built up area and help in shading city streets, reducing direct solar gain on buildings, protect city from desert hot, dry, and dusty wind.

The rage of applying these improvements will be on the new residential and housing proposals and on new the developments of existing areas.

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