STUDY OF KHARTOUM SINGLE FLOOR HOUSE LAYOUTS USING
GOOGLE SATELLITE HIGH RESOLUTION IMAGES

グーグルサテライト高解像度画像を用いたハルツーム平屋住宅の配置に関する研究

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This paper aims to determine the most common features of both the layout and the building materials of the single floor house in Khartoum –the capital of Sudan– using different methodologies. The results were then used to create a standard testing model to be utilized by researchers in all fields, especially, researches in the field of energy simulation, environmental design, etc. Google High resolution images were used to determine the layouts by studying the location of the visible roof parapets of each house. Three small neighborhoods were randomly chosen from the three cities of Khartoum state (Khartoum, Bahri, and Omdurman), each neighborhood contained around 350 houses. Additionally, one large neighborhood (about 15000 houses) was selected in an old third-class area in Khartoum state to test the various house layouts, in order to estimate the commonness of a specific uniform layout amongst the other layout patterns. Afterwards, the building materials and space dimensions were determined by surveying a random sample of 96 houses chosen from the large neighborhood. These 96 houses were built in accordance to the uniform pattern layout subject of this research. The results show that the uniform pattern layout is clear in about 39.75% of the total samples, and the common dimensions (length, width and height) of the room, hall, saloon, and the kitchen are (4.4m × 4.2m × 3.8m), (5.7m × 3m × 3.2m), (7.4m × 3.2m × 3.8m), and (4.4m × 4.2m × 3.8m) respectively. The most used materials are brick for the walls, local materials for the roofs, steel for doors, and steel frame and glass panels for the windows in 88%, 38%, 76%, and 82% of the cases respectively.

Keywords: *Single floor Houses, Khartoum, Google satellite images, Testing models,*

平屋住宅, ハルツーム, グーグルの衛星写真, テストモデル

1. Introduction

Standard testing models are very common all over the world. They are created depending on the most common features of the desired building type. Residential buildings are commonly studied and standardized and one of the best examples is the standard testing model for detached houses and apartments in Japan [1]. Single floor houses represent a huge sector of the residential buildings in Khartoum state. Although many studies have been carried out on houses in Khartoum such as studies on the environmental performance of a specific part of the house, for example, the courtyard [2], studies on materials [3], studies of the social use of the different spaces [4], and studies on the planning aspects of housing [5]. However, there are no studies that determine the most common features such as shapes, layouts, dimensions, and materials. The results of this research will serve as basis for future environmental studies, energy simulations, and all development studies of single floor houses in

Khartoum.

1.1. Satellite high resolution images

Google Satellite high resolution images have been used in many different ways to study various topics such as building detection [6], agriculture [7], archaeology [8], planning [9], and environmental effects [10]. However, they have never been used to study building layouts. In this research these images were used to study house layouts in Khartoum.

1.2. Aims and objectives

As observed from collected data, there is a limited number of layouts used in single floor houses in Khartoum. The most common pattern consists of two bed rooms and two halls built in opposite mirror of each other plus a Saloon (sometimes built in a second-stage), as the core of the house. Usually, the services are distributed around the edges of the plot. See figure 1.

The aim of this research is to study this uniform pattern layout in single floor houses in Khartoum by estimating its numbers in

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comparison to the other layout patterns and studying its materials in order to create a standard model that represents single floor houses in Khartoum. Furthermore, to demonstrate to other researchers the great potential of using Google satellite images to study single floor house layouts in Khartoum due to the visibility of the roof parapets in the satellite images.

Fig. 1 Single floor house components

1.3. Situation in Khartoum

Khartoum is the capital of Sudan and the biggest city [11]. According to government’s official estimates, the population of Khartoum is expected to reach 7.9 million by 2018 which represents about 19% of the total population of Sudan [12]. The city is inhabited by ethnicities form all over Sudan. About 81% of them live in 3rd class residential areas [13]. The weather in Khartoum is classified as desert climate (hot and dry), where the temperature reaches above 35 Degrees Celsius and the humidity is usually lower than 20% most of the year [14].

1.3.1. Features of the single floor house in Khartoum

Houses in Khartoum have common features that are very essential, these features are [4] ;

- The Fence wall: all houses have at least a 1.8 m wall all around for privacy.
- Courtyards: are usually used for daily outdoor activities, social gatherings, and sleeping during the night.
- Living areas (Halls/ Verandas): designed for indoor activities during the day. Usually, there are two or more halls; one or more for the females and one or more for the males.
- Rooms: are used for rest during the day and for more privacy. Mostly there are two or more rooms; one is used by the parents and the rest are used by female members of the family.
- Kitchen: usually used for cooking and storing equipment.
- Male living area (Saloon): in most of the houses, the saloon either already exists or is being planned to be built in the future.

The Saloon usually doubles as a male living area and a guest room for foreign males.

Figure 2 shows pictures of a typical house in Khartoum. The pictures are taken form the house’s yards.

Fig. 2 Images of a house example form the inner courtyard.

1.3.2. Planning pattern and regulations

In order to study the house layouts using google satellite images, an understanding of the general urban planning pattern is essential to determine the plot boundaries. In Khartoum State, the general pattern of all residential areas is a grid of plots where each plot has an elevation to the street and the plot connected to its backside has an elevation to the opposite street[15][16][17]. See Figure 3.

This pattern will be the main guideline for plot selection in this research.

Fig. 3 Urban planning pattern in Khartoum

In Khartoum, the residential areas are divided into three main categories: 1st, 2nd, and 3rd class areas. The regulations vary from one class to another [18]. Generally, the regulations for setbacks, over street extensions, and the maximum number of stories are different [19]. Generally, most of the single floor houses are found in the 3rd class residential areas [13] Therefore, all the selected samples for this research are from 3rd class residential areas.

1.3.3. Building regulations and social aspects

To further clarify the plot boundaries, reviewing Khartoum’s building regulations add an extra layer of identification. The regulations for residential areas classified as 3rd class, states that here must be at least 3m between the house’s main building and the north and south neighboring boundary walls.

Furthermore, the main building can only be attached to either the east or west boundary wall, and the maximum length of the building must not exceed half of the length of that wall. As for the service buildings (kitchen, toilets, stores, etc.), the regulations allows them to be attached to any of the neighboring boundary walls [18]. Therefore, the plot's buildings can be grouped into the "main building" in the middle of the plot and the "services buildings" around the plot's boundaries. Moreover, the social and cultural factors had an effect on house layouts in Khartoum and resulted in the creation of special patterns. This effect is illustrated by the separation of the house into two main zones: the zone near the street and it is considered the male area, and the zone far from the street (backyard) and it is considered the female area. In the middle and between the two zones are the common services (toilets and showers)[19].

2. Methodology

To carry out this research the following steps were taken:

2.1. Area selection

Three small neighborhoods were selected randomly from the three cities of Khartoum state (Khartoum, Bahri, and Omdurman). These small neighborhoods were chosen exclusively from residential areas classified as 3rd class where most of the single floor houses are concentrated. In addition, a large neighborhood was selected from an area that has a lot of diversity and history in order to cover a large variety of single floor house layouts.

2.2. Downloading and combining of satellite images

The Google Satellite images were downloaded for the selected areas using the program "Image and Map Downloader". Then, Photoshop was used to combine these images and to adjust brightness, contrast, levels, and colors.

2.3. Plot identification

After scaling the modified satellite images to a reference length, the shadows of the fence walls and the main buildings were used to create plot boundaries that matched the general urban planning pattern and the building regulations of Khartoum. This step was carried out in ArchiCAD

2.4. Layout categorization:

The shadows and the visible parapet walls were used to identify the plots and categorize them into the following:

- 1- plots that are vacant or under construction
- 2- Multi-story/ commercial Buildings
- 3- Not clear: this category consists of houses that have a general layout similar to the uniform pattern layout but the roof parapets cannot be clearly identified due to reflected sunlight from the metallic roof, trees covering the roof, and lastly, the roof parapets are not constructed.
- 4- Other patterns: the general building outline is very different

from the outline of the uniform pattern or the parapets show a different interior space layout.

5- The uniform pattern layout.

This step was created in the software ArchiCAD using the slab tool, and each category was assigned a different ID name. Figure 4 shows examples of the above mentioned categories.

Fig. 4 examples of different building types

2.5. Automatic counting

Using the ArchiCAD feature (List of Elements/ Slabs (Simple)), a list containing basic information such as ID, name, area, etc., was generated for each slab (plot) created. Then, this list was exported to MS Excel in order to calculate the total number of each building type.

2.6. The area verification test

To check the selection results and correct any errors, this paper adopted the following rule: the smallest plot area allowed is (150 m²), and any plots that were smaller than that were considered a mistake in the selection process.

2.7. Data analysis

All the data from the slab lists generated in ArchiCAD, in addition to the results of the space dimensions and the building material survey, were all analyzed. Then, the final results of the data analysis were illustrated in graphs and tables using MS Excel.

2.8. Material and dimension survey

A random sample of 96 houses that were built according to the uniform pattern layout, were selected from the large neighborhood. Space measurements and a building materials survey was conducted on these houses. As illustrated in Figure 5, 70 out of the 96 houses contain all spaces (2 Rooms, 2 Halls, Saloon, Kitchen and services buildings). The remaining 26 houses contain all previously mentioned spaces except saloons.

Fig. 5 The surveyed 96 houses form the large neighbourhood (houses were numbered and the houses that were marked by the symbol ♦ don't have a saloon)

The following Figure 6 illustrates the steps taken in this research. In step 1, the research areas were selected and the satellite images were downloaded and edited, followed by step 2, in which the individual plots were identified using ArchiCAD. In step 3, the plots were categorized based on the specified building types. Step 4 included the generation of the plots' raw data also in ArchiCAD, followed by steps 5 and 6 where the material survey and area the verification test took place respectively. Finally in step 7, the final analysis was conducted and the results were illustrated in the form of tables and graphs using MS Excel.

Fig. 6 Research steps diagram

3. Results

Three sample neighborhoods in Khartoum, Omdurman, and Khartoum north (Bahri) were selected form residential areas classified as 3rd class. Additionally, an entire neighborhood in Bahri was selected to be the main subject of this research. This full neighborhood was selected from an area that has a lot of diversity and history and first appeared in maps in 1955 but it has existed long before that as a cluster of small villages [20]. The name of the selected neighborhood is Alhaj-Yousif Almaygoma. Table 1 shows the detail geographical locations of the selected areas.

Table 1 Samples area locations

City	Top-Right Corner	Bottom-Left Corner	Images Date
1-Khartoum	15.458246° 32.502781°	15.455305° 32.497339°	Lat. Long. 1/25/2016
2-Omdurman	15.715599° 32.484523°	15.713028° 32.478640°	Lat. Long. 10/1/2016
3-Bahri	15.726956° 32.578290°	15.724095° 32.571083°	Lat. Long. 4/19/2016
4- Big Neighborhood	15.6529° 32.6258°	15.6102° 32.6028°	Lat. Long. 10/7/2016

The satellite Images of the selected sample neighborhoods are illustrated in Figure 7.

The plots in the images are coded as follows:

♣: vacant/ under construction, ♣: multi-story/ commercial buildings, ♥: not clear, ▲: other patterns, and ♦: the uniform pattern.

Fig. 7 Satellite images of the selected sample neighbourhoods.

The selected sample of the entire neighborhood (Alhaj-Yousif Almaygoma) is illustrated in Figure 8.

Fig. 8 The selected neighbourhood (Alhaj-Yousif Almaygoma)

3.1. Building type results

3.1.1. Building types

All plot samples were categorized as follows: (Vacant/ under construction, Multi-story/ commercial, not clear pattern, other patterns, and the uniform pattern). Shadows and visible parapet walls were used to identify the single floor houses and all other buildings types.

Fig. 9 Building types results

In Figure 9, the results show that the percentages of the vacant or under construction plots vary from 12% in the large neighborhood to an average of 5 % in the small neighborhood samples selected from the three cities. The percentages of the

multi-story and commercial plots averaged about x% in the small neighborhood samples combined, compared to around x% in the large neighborhood sample.

Fig. 10 Single floor houses patterns

The single floor houses are distributed as follows; the average percentage of the “not clear” pattern is around 32% of the total number of plots in all three small neighborhood samples, compared to 22% in the large neighborhood sample. The “other patterns” and the “uniform pattern layout” in the small neighborhood samples averaged around 28% and 38% compared to the large neighborhood were the percentages were 38% and 41% respectively. The results show that the percentage of houses in the “not clear” category is exceptionally high in the small neighborhood sample from Omdurman. This is due to either, the bad quality of the satellite images taken from Omdurman, or the absence of the roof parapets because of the different construction methods used in that area. Finally, the average percentage of the single floor houses built according to the uniform pattern layout is around 39.75% of the total single floor houses in all samples “see Figure 10”.

3.1.2. Area test verification

As a general observation, most plots in Khartoum are around 150 m² or more[19]. In order to check the reliability of the plot selection process, plots that have an area less than 150 m² were eliminated from all the previous results. In all the small neighborhood samples there were no plots that were under 150 m². However, in the large neighborhood sample, there were 57 plots that have an area less than 150 m². Table 2 shows the categorization of these plots according to the building types specified by this research.

Table 2 Plots which have an area less than 150m²

Building Type	No. of Plots	%
Vacant/Under Construction	11	19.3
Multi-Story/ Commercial	4	7.0
Not Obvious	7	12.3
Other Patterns	32	56.1
Uniform Pattern	3	5.3
Total	57	

After subtracting the numbers of these plots from the original results of the neighborhood of (Alhaj-Yousif Almaygoma), the final results are illustrated in Table 3.

Table 3 Final results of the big neighbourhood

Building Type	No. of Plots	%
Not Clear	2387	21.8
Other Patterns	3983	36.4
Uniform Pattern	4578	41.8

As Table 3 illustrates, even though plots that did not pass the area verification test were eliminated, the changes to the overall results of all the building types were still minimal.

The not clear pattern plots,

The final results show that the average percentage of the single floor houses that were built according to the uniform pattern is around 39.75% of all the single floor houses in Khartoum state. This percentage can increase remarkably if the not clear pattern houses were considered. The average percentage of the not clear pattern houses is around 26% in all samples, and they have great potential of being built according to the uniform pattern, but further research is needed for conformation.

Table 4 general survey information

Item	No.
Surveyed Houses	96
Number of Rooms	192
Number of Kitchens	96
Number of Saloons	70
Number of Halls	192

General observations made about the results in this part of the research are as follows;

- In 42% of the cases the rooms are square.
- In 100% of the cases the rooms and the saloon have the same height, in addition, the two halls have the same height but it is lower than the height of the rooms.
- 82% of the kitchens have the same height as the rooms and 85% of them have the rooms' same lengths and widths.

3.2.1. The dimension survey results

The results of this part of the research were illustrated in three graphs; these graphs are “length results” in figure 11/A, “width results” in figure 11/B, and “height results” in figure 11/C.

Figure 11/A shows three distinct length groups, the first group includes the rooms and the kitchens. In this group, the lengths vary from 4m to 5m and the most common length is 4.4m in

Fig. 11 A- Length results B- width results C- Height results

3.2. Building space dimensions and materials

Table 4 shows the number of spaces that were surveyed in all of the 96 randomly selected house samples previously described. The spaces were surveyed in order to derive the most common dimensions, study the building materials, and study door and window materials.

about 25% of the surveyed samples. The second group includes the halls and it shows that the lengths vary from 5.3m to 6m with the most common length being 5.7m in about 29% of the total samples. The last group is the saloons, and the lengths here vary from 6.6m to 8m, and the most common length is 7.4m in about 26% of the total samples of the saloons.

In Figure 11/B, the space widths are divided to two main groups; the first group includes the halls and saloons, and the second group includes the kitchens and rooms. In the halls and

saloons group, the widths vary from 2.6m to 3.6m, and the most common widths are 3m and 3.2m found in 22% and 28% of the samples respectively. In the kitchens and rooms group, the widths vary form 3.2m to 4.5m with the most common width for both being 4.2m in about 28% and 32% of the samples respectively.

Figure 11/C shows that the common height for the rooms and the saloons (both in all cases have the same heights) is 3.8m in 40% of the samples. The common height for the kitchens is also 3.8m in about 32% of the samples. In the case of the halls, the most common height is 3.2m in about 32% of the samples.

3.2.2. The building materials results

General observations;

- All the doors and windows in all of the surveyed houses are locally made in local workshops. The doors are made from steel frames and steel panels and the windows are made from steel frames and glass panels.
- The walls are usually made using bricks, and plastered on both sides with cement and a sand plaster.
- The roofs are usually made from local materials (wood, adobe) and also from Corrugated Iron Sheets C. I. S.

As Table 5 illustrates, for the doors, the most common material is steel and it is used to create (76%) of the total samples.

Table 5 Door materials

Doors Materials	%
Steel	76
Aluminum	0
Wood	24
Total	100%

Windows are more complicated and a variety of materials are used depending on the design. However, they can be grouped according to the material of the frame and the material of the panels. The most common material for the frame is steel (82%) and the most common material for the panel is glass (53%). Table 6 shows the total results of the windows' material survey.

Table 6 Windows materials

Windows Materials			
Frame	%	Panel	%
Steel	82%	Glass	53%
Wood	18%	Metal	36%
Aluminum	0%	wood	11%
Total	100%		100%

As for the walls and the roofs, the materials used in their construction are not always clear, and the information had to be gathered from the houses' owners. The most common material used for the walls is brick in around 88% of the cases, and in around 85% of the cases it was plastered on both sides using a mixture of cement and sand plaster. The roofs are usually built

using compacted earth. Steel I section beams or wood beams are used for structure in order to carry the weight of straw mats covered with compacted earth and dung for waterproofing in 38% of the cases. Survey results for the materials used in roof and wall construction are illustrated in Table 7 below.

Table 7 Roof and wall materials

Roofs		Walls	
Material	%	Material	%
Concrete	10	Brick	88
C.I.S.	24	Adobe	12
Brick	28		
Compacted earth	38		
Total	100%	Total	100%

The final results of this research are represented in the following plan “Figure 12” and section “Figure 13”. These drawings represent the most common layout found in around 39.75% of the single floor houses in Khartoum.

Fig. 12 Single floor house plan shows the layout, the general spaces , and the most common dimensions for the main buildings.

Fig. 13 Single floor house section (S-01) shows the most common heights of the spaces and the roof and wall materials.

4. Conclusions

- The two bed rooms and two halls built in opposite mirror of each other plus a Saloon and a kitchen layout is the most common layout in single floor houses, and found in around (39.75%) of the total number of house samples used for this research.

- The uninformed pattern layout is approximately present in at least 50% of the “not clear” house category, but further research is needed to determine the percentage more accurately.
- The rooms’ dimensions are (4.2m × 4.4m × 3.8m), the halls’ dimensions are (3m × 5.7m × 3.2m), the Saloon’s dimensions are (3.2m × 7.4m × 3.8m), and lastly the kitchens’ dimensions are (4.2 × 4.4 × 3.8m). These dimensions represent about 40% of the surveyed samples.
- The doors are mostly made from steel in 82% of the surveyed samples. The window frames are steel in 82% of the cases and the panels are glass in 53% of the cases.
- The walls are load bearing walls made of brick in 88% of the surveyed samples.
- The roofs are made of steel I section beams or wood beams as the main structure in order to carry the loads of the straw mats covered with mud and dung for waterproofing in 38% of the cases.
- Further research is needed and larger number of the single floor house samples must be analyzed to fully verify the results of the space dimensions and the construction materials of this research.

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和文要約

パリ協定が発効し、発展途上国や新興国においてもエネルギー消費の抑制が求められるようになった。しかしインフラ整備が遅れ、依然として室内環境等の環境の質が低いこれらの国々では、生活の質の改善とエネルギー消費の抑制という両面に取り組まなければならない。そのためには建築物や住宅の質をどのように改善していけば、この二つを両立できるかを慎重に検討する必要がある。この課題に対する基本的なアプローチとして、日本を含む先進国では、現在使用されている標準的な建築物を同定して標準モデルとし、対策の効果を数値計算で求めることで多様な対策の検討を効率的に行ってきた。

本研究の目的は、アフリカ北部に位置するスーダン、特に人口が集中する首都ハルツームにおける標準住宅モデルを提案することにある。スーダンはエジプトの南側に位置し、中央部をナイル川が縦貫する。北部は砂漠気候に属し、南部には草原地帯であるステップ気候が広がる。ハルツームは7月8月が雨期となるステップ気候に属し、世界の主要都市で最も熱い都市として知られている。和平と経済発展に伴い、エアコンの普及やヒートアイランド現象が顕著になると考えられ、エネルギー消費の急増を抑制できる建築物の開発が強く求められている。しかし現時点において、スーダンにおいては、建築物を用途別に分類して研究する試みや、その分類に応じた対策試験用の標準モデルを作成する試みは全く行われていない。

本研究では、エネルギーシミュレーションやLCA分析、室内空気質改善など研究に使用されることを想定し、首都ハルツームにおける標準的な平屋住宅の平面計画と使用材料を明らかにする。現時点においてハルツームの戸建住宅はほぼ平屋が占める。作成にあたっては、Googleの高解像度の衛星写真を用いるなど新しい手法を用いた。衛星写真から建築物のパラペットを読み取り、平面計画を推定する。ここではハルツーム州の3都市（Khartoum, Omdurman, Khartoum North）から無作為に350軒の住宅を選びその平面計画を分析した。また、低層住宅が多いハルツームの都市計画区分（third-class residential areas）である Alhaj-Yousif Almaygoma から1500軒の住宅が連なった地区を抽出し平面計画の多様性を確認した。Alhaj-Yousif Almaygomaは1955年以前は小さな村だったところで、それ以降に開発が進んだ地区である。最も平均的な平面計画をこれらの統計的な解析から導き出した。その計画を概約するとそれぞれの住宅は居室2室にホールが2室、サロン1室を有し、屋外に台所を持つ。部屋の配置はほぼ同じで、道路との関係から配置が鏡面状に反転する場合もある。調査した住宅の約39.75%がこの平均的な平面計画と同様の計画に分類される。さらに使用材料と実際の寸法、高さを確定するため、調査した1500軒から96軒を選び、現地にて実測、目視にて材料を確定した。本調査から、最も一般的な居室、ホール、サロン、台所の寸法はそれぞれ、4.4m×4.2m、5.7m×3.0m、7.4m×3.2m、4.4m×4.2m、天井までの高さはそれぞれ3.8m、3.2m、3.8mであることが分かった。

住宅の壁はレンガが一般的で、88%が地元で調達可能な材料を使用している。また屋根の38%も地元で調達可能な材料を使用している。最も一般的なドアは鉄製のガラス窓付きのドアで76%の住宅が有していた。また、窓ガラスは82%が鉄製のサッシで、シングルガラスが53%を占めた。ドアや窓はいずれも地元の工場で製造されて

いた。

最後にこれらの調査をもとに、スーダン・ハルツームにおける標準住宅モデルを提案した。このモデルは一般的な平屋住宅の平面計画や高さ、材料を代表している。このモデルは関係研究者や設計者に提供し、エネルギーシミュレーションや環境に配慮した設計や計画に活かされることを期待している。

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