Creating Standard Testing Models for Residential and Office Buildings in Khartoum for Energy Simulations Purposes

February, 2018

Abdalmajeed Abdalla Mohamed Ahmed MOHAMMED

Creating Standard Testing Models for Residential and Office Buildings in Khartoum for Energy Simulations Purposes

ハルツームにおけるエネルギーシミュレーションのための標準住宅・オフィスモデルの開発

February, 2018

Waseda University
Graduate School of Creative Science and Engineering
Department of Architecture, Research on Environment media

Abdalmajeed Abdalla Mohamed Ahmed MOHAMMED

モハメド アブダラマジッド アブダラ モハメド アハメド

Acknowledgement

At the beginning, I would like to thank the Almighty god for his blessings and graces and for giving the strength and ability to do this research.

I would like to thank everyone who made this research possible on top of the list is the Ministry of Education, Culture, Sports, Science and Technology for the scholarship and it would be very difficult to carry out this research without it.

I would like express my heartfelt gratitude to Professor H. Takaguchi for his continuous help, encouragement, support and guidance. Nevertheless, I would like to thank my friends and colleagues in Prof. Takaguchi laboratory for their valuable friendship, help, support and feedback.

I also would like to express my sincere gratitude all my friends who have done most of the surveys in this research, and to all those who have responded to my questionnaires and to these who have provided me with examples of their projects whether they are individuals architects, companies or owners of real estate.

I should not forget to thank all my family members for their continuous support, encouragement and love.

Last not the least, I would like to thank my wife for her love, support, and encouragement.

Declaration of Authorship

I hereby certify that the thesis I am submitting is entirely my own original work and contains no materials that previously published or written by any person to the best of my knowledge and any use of the works of any other author, in any form, is properly acknowledged at their point of use.

Abdalmajeed A. M. A. Mohammed

November 2017

Table of Contents

List of Figures

List of Tables

Chapter-1

Introduction

1-Introduction

In this first chapter the author explains the importance of this research and its expected benefit whether it is for individual researchers, associations and organizations, or even for the national level. In addition, the first chapter also contains detailed explanation of the challenges that faced the author and the limitations of this this research. The scope or the specific field of this research was also explained. Finally, this chapter ends with the aims and objectives of this research and the structure of the thesis.

1.1. Research Importance

Sudan in general lacks the basic information in all fields especially in architecture, and as result of that gap there are difficulties to develop systematically any technology or research of architecture specifically and other fields of applied science in general (Sarzin & Mehta, 2011a). In the field of architecture, there are minimal researches about building types in Sudan and these studies are concentrating on just parts of the buildings. Some studies concentrate on the courtyard (Merghani, 2001), the social factors that affect house(a. M. Ahmed & Kurosawa, n.d.), building materials in general (Elkhalifa, 2011), residential areas planning(a. M. Ahmed & Kurosawa, n.d.), etc.

The importance of this research appears clearly in that it covers the lack and gap in the basic information about building types that has never been discussed before. This is the gap of information that will be experienced by each researcher in the areas of construction, architecture, sustainability research, energy consumption, building materials development, reduction of carbon dioxide emitted from buildings, research on indoor thermal comfort, etc. each researcher in these fields will feel the need for researches identifying the main characteristics of different types of buildings in Khartoum.

This research gives clear image of the types of buildings covered by the research and discusses all the details in numbers and comparisons, and this shows the current range of variations in that building type in Khartoum.

This research will also cover the large gap in the basic information on the main types of buildings in terms of dimensions, layouts, and construction materials in Khartoum. Also, it will give researchers the opportunity to study in depth these buildings and to develop them to be more efficient and more sustainable.

Finally, this research will be the basis for all researches in the above mentioned fields, and that makes it very important and necessary, especially the world is heading towards creating and developing more energy efficient buildings that produce less carbon dioxide.

1.2. Limitations and Challenges

This type of study requires huge data to be as accurate statistically as possible however, in Khartoum there is huge gap of information this area. The most basic information about the city is not scientifically measured or documented such as the population, cars numbers, energy consumptions rates of buildings, building materials, and so on (Pushak & Foster, 2011; Sullivan, Nasrallah, & Buvsbm, 2010). There are huge differences between the governmental estimations and non-governmental estimations. The first challenge is the total lack of information about building types in all governmental or non-governmental publications (Pushak & Foster, 2011) (Sullivan et al., 2010).

This type of research requires considerable financial and human resources so researchers can collect as large as possible number of samples as raw data of each building type. Then analyze this information and specify the most common features of each building type (Loga, Stein, & Diefenbach, 2016).

Therefore, the financial obstacle was one of the biggest challenges that faced this research, and it was a major reason for the lack of samples in this research.

The second challenge was the lack of basic information and often absence of information about buildings in Sudan in terms of number, energy consumption rates, number of residents, daily program of the users, construction materials, etc.

Finally, in many cases, a very few individuals were interested in the subject of this research, so that the chances of carrying this research out in collaboration with other researchers were nonexistent. Therefore, most of this research was carried out by only the author, and in some cases of the surveys and inspections assistants were hired to collect and inspect the selected samples.

1.3. Research Area

Due to the limitations of this research, it became obvious that it will be impossible to carry out this research on all building types using the available resources. Therefore, this research will cover only the two sectors that consume most of the energy according to the World Bank estimations (Sarzin & Mehta, 2011b) (Pushak & Foster, 2011), united states institute of peace (Sullivan et al., 2010), and the governmental estimations (Abdin, 2013) (State, 2013a) (Rabah, Nimer, Doud, & Ahmed, 2016), which are the residential sector and the office building sector. The residential buildings consume about 52% of the total energy of the city and the office buildings consume more than 18% of total energy. Therefore, the main focus of this research was on these two building types.

1.4. Aims and Objectives

This research is conducted to achieve the following aims and objectives;

1.4.1. Aims

As mentioned previously, the standard models of buildings in Khartoum have not been discussed before. Therefore, the objective of this research is to give a clear picture of the buildings that consume most of the energy in Khartoum. This clear image includes detailed description of each type of building in the following areas; the architectural spaces, general layouts, building materials, doors and windows for each building type. This research will provide researchers with a full model of each building type that is suitable for all types of specialized studies.

1.4.2. Objectives

To achieve the aims of this research, it was necessary to follow the following steps

- Understand the factors affecting each type of building in terms of environmental, legal, social, economic, and finally technical factors in order to utilize them all while making the standard testing model.
- A broad understanding is important for the required information to create standard testing models. Understanding of the basic information required in these model types.
- Collect as many samples as possible of each building type to obtain clear image of these building types and the current situation of each type.
- Analysis of these models is required to identify the most common features in terms of area, dimensions, general distribution of spaces, building materials, doors and windows.

- Use these most common features to create a standard model for each building type, a model that suitable for conducting experiments and computer simulation and other specialized research.

1.5. Thesis structure

This research was presented in the following chapters

Chapter -1- Introduction

In this first chapter the author explains the importance of this research and its expected benefit whether it is for individual researchers, associations and organizations, or even for the national level. In addition, the first chapter also contains detailed explanation of the challenges that faced the author and the limitations of this this research. The scope or the specific field of this research was also explained. Finally, this chapter ends with the aims and objectives of this research and the structure of the thesis.

Chapter-2- Literature Review and Background

In this chapter and in the first section, light was thrown on Khartoum generally in terms of history, geographic location, demographics, climate, and finally the importance of the city. Then followed by the second part in which the building types, regulations, and energy consumption were discussed in general and the residential and office buildings were discussed in depth. In the second section of this chapter, the standard testing models were discussed in terms of its background, requirements, and the basic information which it should provide.

Chapter-3- Single-floor House

The third chapter of this research is devoted to single-floor houses. This chapter divided into three sections. The first section was introductory to the single-floor houses in Khartoum in terms of distribution, energy consumption, the basic components of these buildings, and its share of the total population in Khartoum. In the second section of this chapter, the research methodology of this type of building was discussed in detail. The third section is devoted entirely to discussing the results of this part of the research. The residential neighborhood sample results were presented in the first part. In the second part, the results of the general layout of single-floor house which were collected from the high-resolution satellite images were presented. This is followed by the third part, where the survey results of the selected single-floor house samples were presented. These results were grouped into the results of the dimensions of the spaces, the building materials, and the final group was for the doors and windows.

Chapter-4- Apartment

The fourth chapter of this research has been fully allocated to the apartments. General information about apartments was presented in the first section of this chapter. The information contained in this section is general information about the spaces that apartment consist of, commonness of this building type, and finally its importance. In the second section of this chapter, the methodology used to examine this type of building was discussed in detail. In the third section of this chapter, the results of this research were presented in four parts. The first part presents the results of apartment type survey in general. This part was followed by the second part, which presents the results of spatial relations of spaces. Then followed by the third chapter, in which the dimensions survey results of the spaces were presented. Finally, the fourth part, which was devoted entirely to present the building materials survey results. This part includes the results of the structure materials, wall materials, door materials and windows.

Chapter-5- Office Building

The fifth chapter of the thesis was devoted entirely to the office buildings. It has been divided into three sections. The first section was general introduction to office buildings and their importance in Khartoum. In the second part, the research methodology was discussed in detail. In the third section was devoted to illustrate the results of office building research. The results were presented in four parts. The first part was dedicated to presenting the results of the general layout of the typical floor of the office buildings in Khartoum, followed by the second part which was designed to present the survey results of the typical floor area. In the third part, the results of the typical floor dimensions were presented and discussed in terms of the depth and the height. In the fourth and final part of this section, the survey results of the building materials were presented according to the materials of the main structural elements, the materials used in the sold parts and transparent parts, and finally the doors and windows.

Chapter-6- Summary, Recommendations and future studies

This chapter has been divided into two parts. In the first part, a summary of the results of the building types that were covered in the research was presented. Then in the second section of this chapter, the final recommendations of this research were illustrated.

Figure (1-1) shows the thesis structure.

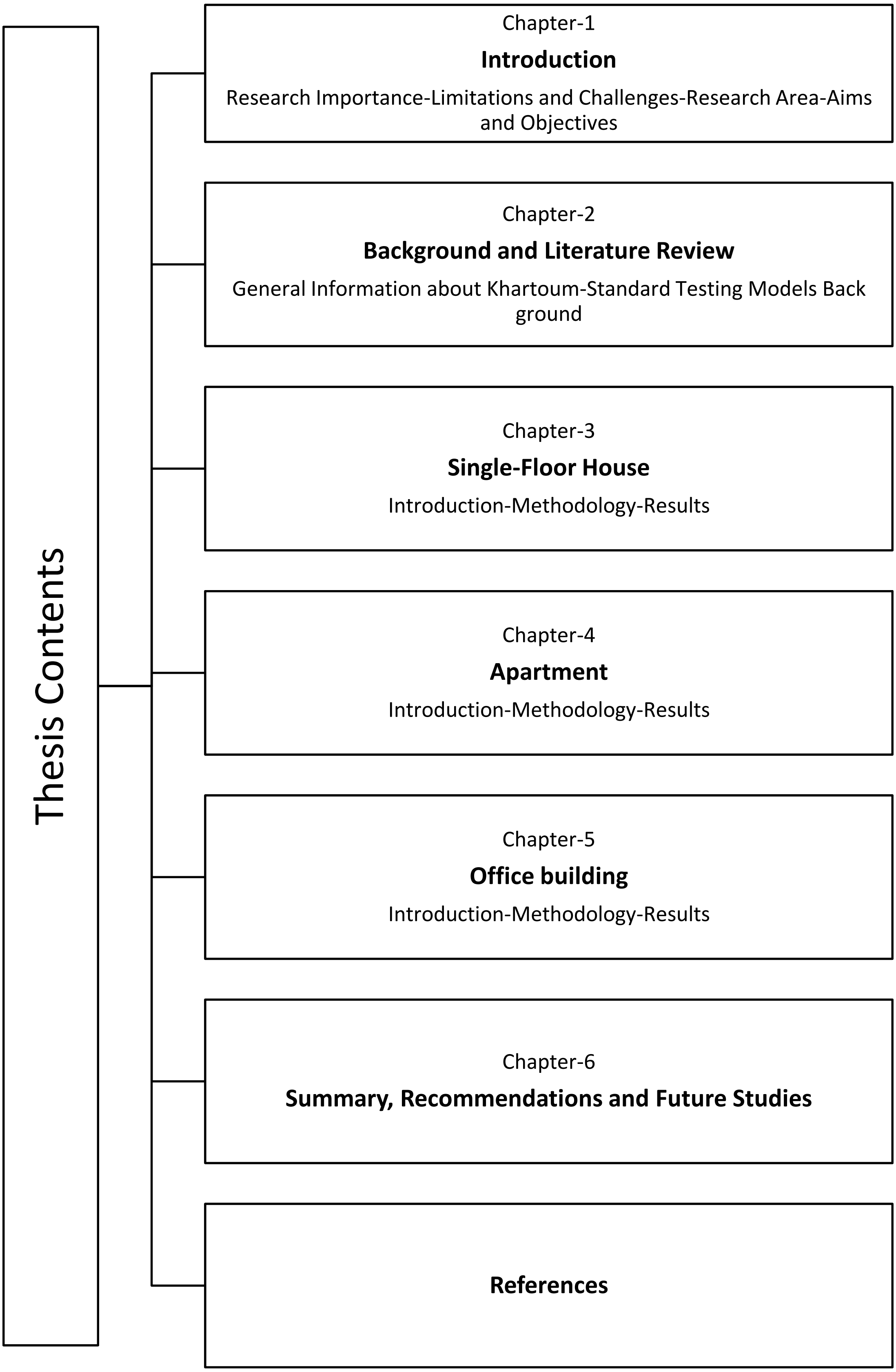


Figure 1-1: Thesis structure

Chapter-2

Literature Review and Background

2-Literature Review and Background

This chapter of the research was divided into two main sections. The first section is devoted to provide the reader with general information about Khartoum in terms of geographical location, history, population, and climate. This section also, gives information about building types and laws that govern them in terms of planning or building regulations. Finally, this section concludes with general information about the energy consumption of various sectors in Sudan.

After the first section comes the second section, which was devoted to give background information about the standard testing models, their use, examples and the basic information required to create standard testing model.

2.1. Khartoum, Image of the city

This first section is devoted to provide information about Khartoum in terms of geographical location, history, population, and climate. Then, this section provided information about the building types, regulations, and energy consumption.

2.1.1. Geography, history, population and climate

Khartoum is the capital of Sudan and it lies at the confluence of the Blue and the White Niles. It covers area of about 900 square Km. Greater Khartoum consist of three cities; Khartoum, Khartoum north (Bahri), and Omdurman. It is located at the longitude 32’5 east and latitude 15’5 north and at an elevation of 380 meters above sea level (Elhoweris, 2008). Khartoum map was illustrated in figure (2-1).

Khartoum history goes back to the Turco-Egyptian regime (1821 to 1885). At that time its location was strategic (Kuklick, 2008). By then it had an estimated population of 50,000 inhabitants (Elhoweris, 2008). The city was small villages on the river banks but in 1830 it was established as the capital of Sudan (Mustafa, 1993).

Archaeologist Anthony Arkell in 1944 dated settlements in Khartoum back to 4000 BC (Haywood, 1985).

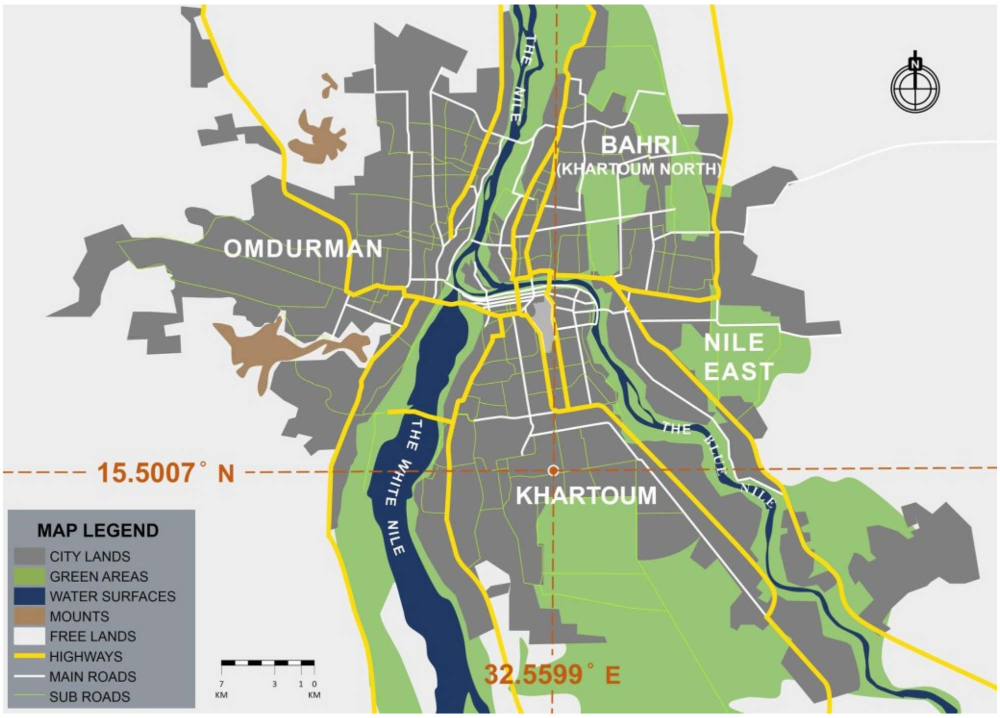


Figure 2-1: Khartoum Map

Khartoum population have grown rapidly from almost quarter million in 1956 at the independence time to more than six millions in 2007 official census (Berry, 2015). In 2017 the population estimated to reach 7.7 million and this number represents about 19% of the total number of Sudan population (State, 2013b). See figure (2-2).

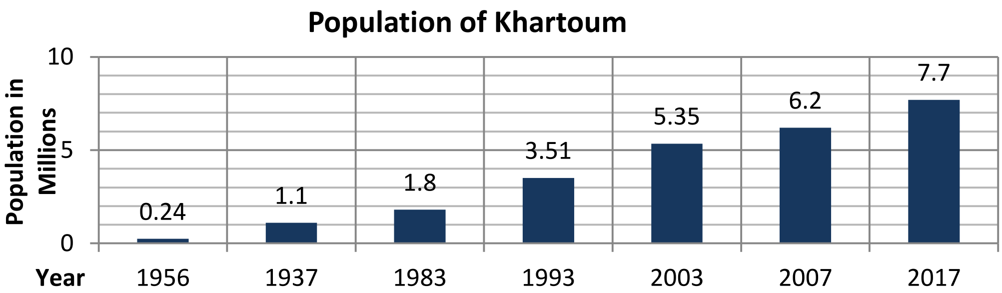


Figure 2-2: Population

Khartoum weather is classified as desert climate (hot and dry all the year) where the temperature is above 35 Degrees Celsius and the relative humidity is below 30% all the year (N. Ahmed & Elhag, 2011). The weather data is illustrated in figure (2-3).

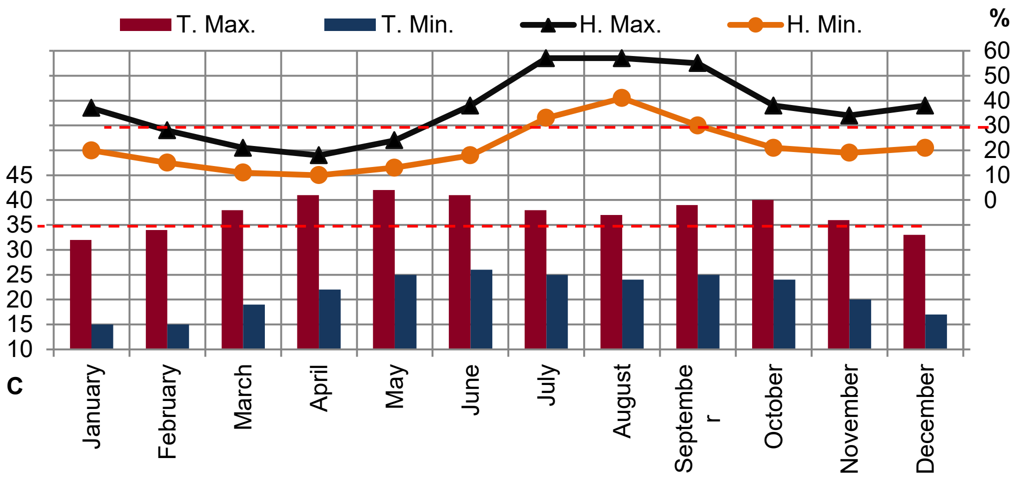


Figure 2-3: Weather in Khartoum (Omer, 2002)

The whole climate in Sudan has experienced clear rise of the drought level and lack of rain in the last three decades, according to specialized studies. In Khartoum, the climate has witnessed a clear shift to the dry, hot climate all the year and the sand storms which were never occur before 1990s in Khartoum now are very normal events see figure (2-4) ("Sand storm in Khartom," 2015) ("Huge snad storm in Khartoum," 2011) ("Scary Sand storm Khartoum," 2016) ("Big Sand storm Khartoum," 2014).

Figure 2-4: Sand storms in Khartoum

2.1.3. Khartoum Building Types, Regulations, Energy Consumption

2.1.3.1. Residential Buildings Spaces

Residential buildings in Khartoum consist of specific architectural spaces based on the social and cultural requirements of the community in Khartoum. These spaces differ slightly from one building to another in terms of building materials and finishes used depending on the income level of the owner (Ahmad, 2000). These architectural spaces are found in all residential buildings from single-floor houses to apartments as well as in private villas owned by high-income individuals (ELSAYED, 2015). The latter types of residential buildings are not included in this research due to the lack of preparation of this type and the lack of significant impact on the general energy consumption in the residential sector compared to the first and second types (single-floor houses and apartments, respectively) (State, 2013a).

The architectural spaces that required in all residential buildings are as follows:

- Rooms: The rooms are usually used for sleeping and they contain cupboards and sometimes they are also a study place for the children.
- Parents 'room: the parents' bedroom with their wardrobe and their objects.
- Hall: it is the living room in the residential buildings in Khartoum, where there the sitting room, TV and dining place.
- Saloon: is a place for non-relative male guests and sometimes used as a living room for mature male children.
- The kitchen: the place to cook and prepare the food and also the places to store various foodstuffs and equipment.
- Bathroom: There are always at least two bathrooms in the residential building in Khartoum. Sometimes the shower is separated from the toilet.
- Courtyards: There are always two or more courtyards and are used for night activities and for sleeping on summer nights. Usually, these courtyards are divided so that the internal courtyard is used for female members of the family

and the outer courtyard (closest to the street) for male members of the family. Finally, there is often another courtyard for the use of parents.

- Service buildings: include stores and sometimes a small shop on the side of the apartment overlooking the street.
- Fence wall: For cultural and religious reasons the people in Khartoum and Sudan in general putting great importance the fence wall. It has to surround the residential plot completely from all sides. This importance is concentrated in the fact that the fence preserves the privacy of the house. In addition, it provides security for the house and property.

These components are general components that exist in all residential buildings in Khartoum with few differences. In the case of apartments, the yards are replaced with balconies. The saloon is also replaced by a large hall reserved for this purpose and serves instead of the saloon (Osman, 2015).

2.1.5. Building regulations and planning patterns

Since 1906 in the strategic plan of Khartoum, three classifications of residential areas hve been adopted which are the 1^{st}, 2^{nd} and 3^{rd} class residential areas. In each class the regulations and laws are different from the other classes. In general, the 1^{st} and 2^{nd} classes have similar regulations and it is allocated for high-income housing plots while the 3^{rd} class residential areas have a slightly different laws and regulations and it is allocated for low-income housing. In general, residential plots in the 1^{st} and 2^{nd} class areas are larger in size where the smallest area of the residential plot is 500 square meters, while the area of residential plots in the 3^{rd} class areas might have an area 150 square meters (Elhoweris, 2008).

The regulations vary from one residential class to another. Generally, the regulations for setbacks, over street extensions, and the maximum number of stories are different (MOHAMMED & Takaguchi, 2016). Generally, most of the single floor houses are found in the 3^{rd} class residential areas. While the apartments spread in the 1^{st} and 2^{nd} class residential areas (State, 2013a).

As mentioned before, the planning laws for the residential plots in the 1^{st} and 2^{nd} class areas are slightly different from those of the 3^{rd} class residential areas. They are mainly two differences.

The first main difference in laws and regulations between the residential classes is the maximum number of floors allowed. While the maximum number of floors in the 3^{rd} class residential areas is three floors, in the 1^{st} and the 2^{nd} class residential areas the allowed numbers of floors are four floors.

While the second difference in the laws and regulations between these classes is the setback distances from the neighbors. In the 3^{rd} class residential areas, it is permitted to build the main building attached to the neighbor on the east or west side. While in the first and second degrees the main building is not allowed to be attached to any neighbor. Furthermore, a distance of 1/6 of the main building height or at least 1.5 m and 1/3 of the main building height or at least 3 m should exist between the main building and the east/ west and north/south respectively ("Khartoum Building Regulation Codes 2008," 2008). The regulation were explained in figure (2-5)

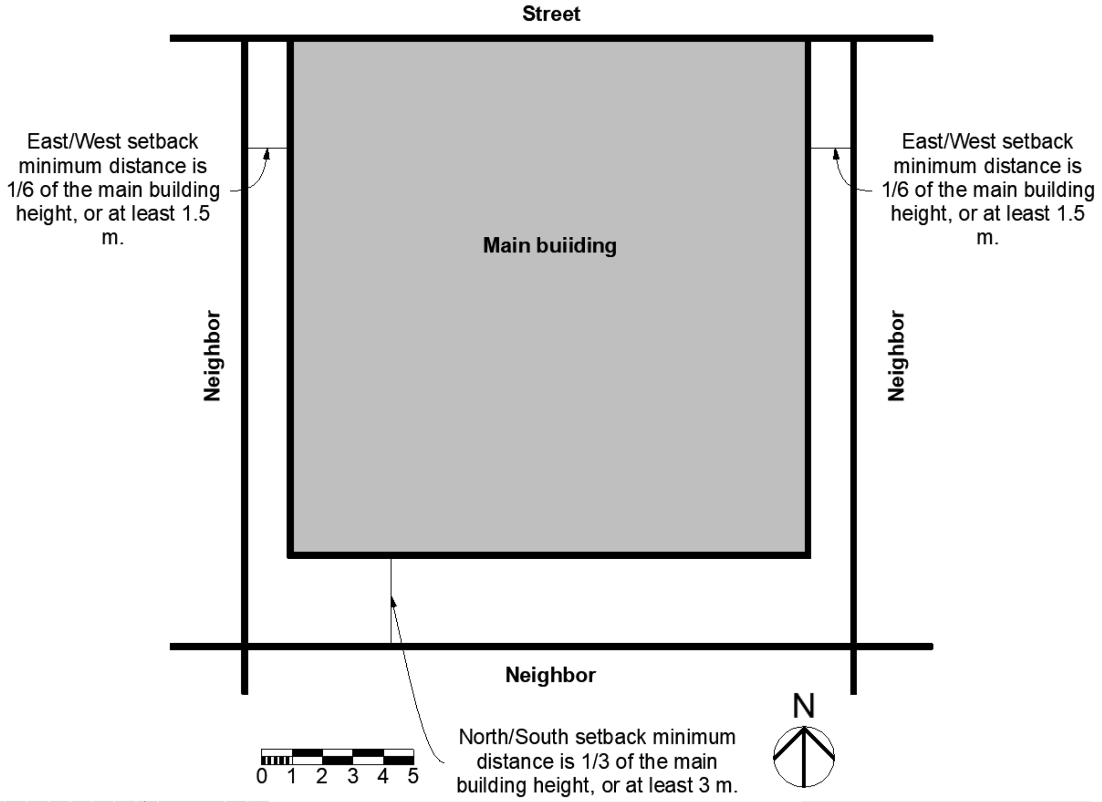


Figure 2-5: Summary of the setback regulations for the 1st and 2nd class residential areas

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 ("Khartoum Building Regulation Codes 2008," 2008). Figure (2-6) below explains the regulations.

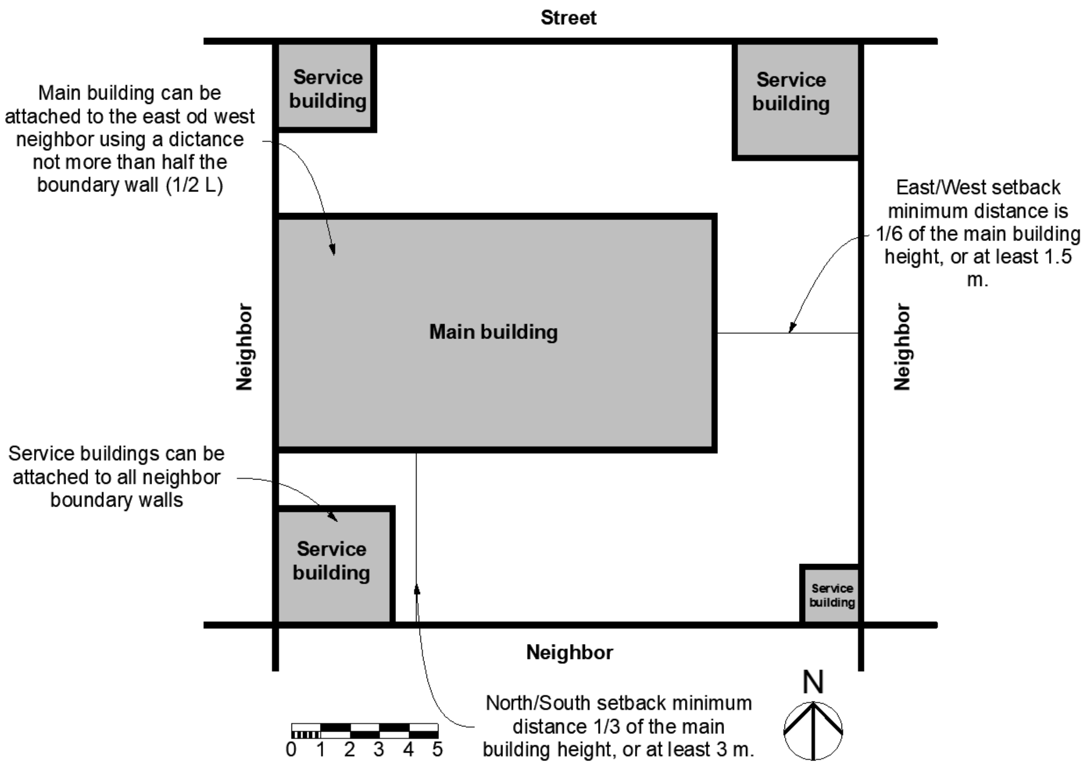


Figure 2-6: Summary of the setback regulations for the 3rd class residential areas

As a result of the regulations and laws in addition to the social factors, 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). The main building and the service buildings each has a different regulations according to the building code 2008 (MOHAMMED & Takaguchi, 2016).

In order to study the residential buildings in Khartoum, an understanding of the general urban planning pattern is essential to determine the plot boundaries and sizes. 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 (Mustafa, 1993) (Sara Pantuliano; others, 2011) (Fernando Murillo; and others, 2009). See figure (2-4).

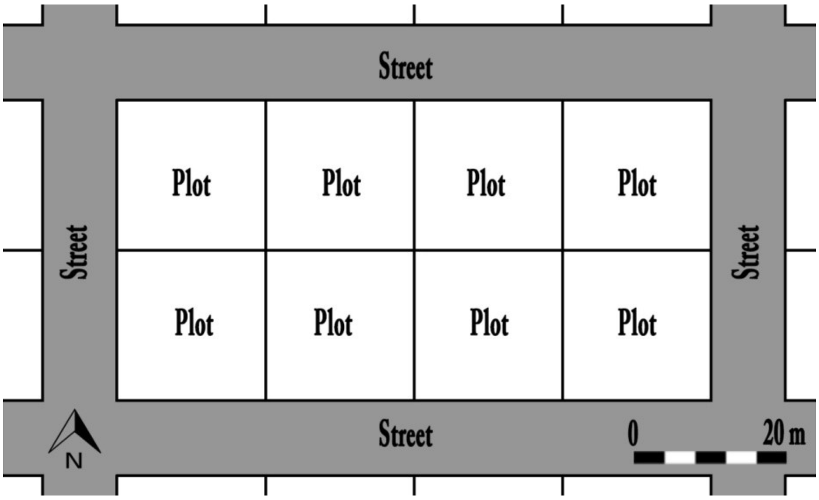


Figure 2-7: Planning patterns for residential areas

2.1.6. Building Energy Consumption in Sudan

In the developed countries, buildings consume between 20-40 percent of the total energy, and the rest is divided into industry, agriculture, transportation, and other sectors. The buildings that consume most energy are the office buildings and the residential buildings. About half of the energy consumed by these buildings goes to the heating and cooling HVAC systems in these buildings (Pérez-Lombard, Ortiz, & Pout, 2008).

In 2015, Sudan's electricity generation was about 13,133 GWh from all sources of electric energy production, including sustainable energy sources. More than 64% of this energy was produced by hydro-generating plants (five hydro power plants). The total capacity of these plants reaches 1,593 MW most of it was produced in Merowe dam, which has a maximum capacity of about 1250 megawatts. While thermal production plants produced most of the remaining energy. It is important to mention that, energy production from sustainable resources represents less than 3% of total energy production (Electricity, 2016).

In Sudan as a third world country and developing country, the energy consumption profile differs significantly from the global model. In Sudan, the industrial and agricultural sectors consume the smallest part of total energy while the residential, commercial and governmental sectors consume most of the energy (UNEP, 2017). As illustrated in the figure (2-5) below.

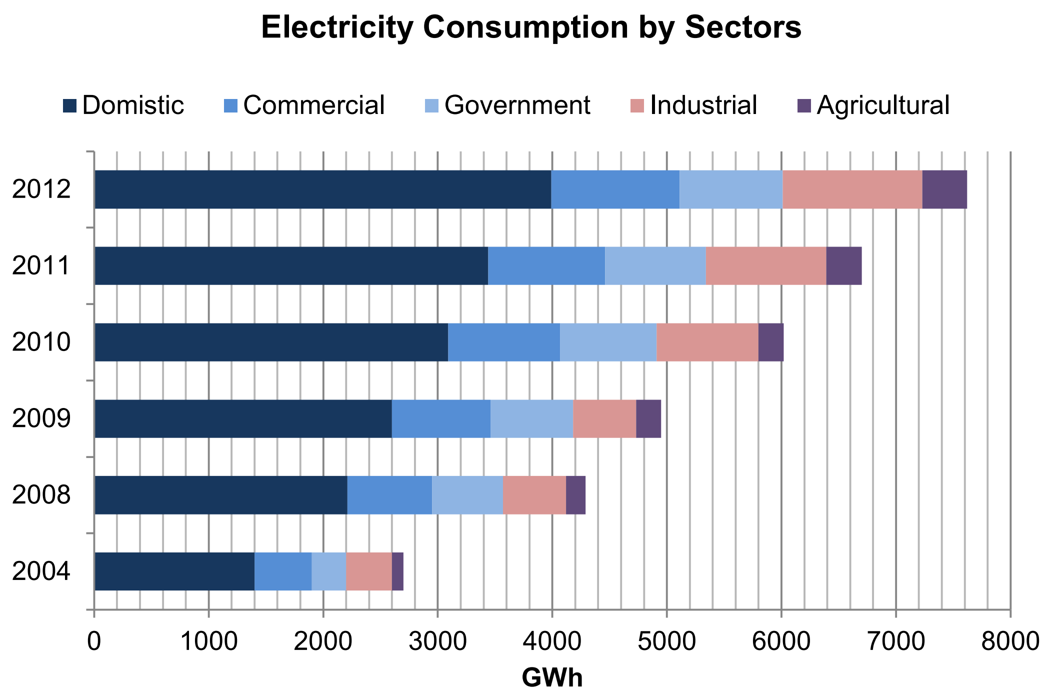


Figure 2-8: Electricity consumption profile by sectors 2004-2012 (Abdin, 2013) (Pushak & Foster, 2011)

The figure shows that residential buildings consume about 52% of the total energy and then the commercial sector is about 15% and therefore the government use is about 13%. The majority of the commercial and governmental energy is used by office buildings because of numbers of malls and big departmental stores in Khartoum and Sudan as general is very low comparing to the office buildings. The bulk of this energy is consumed by cooling systems because Sudan in general and Khartoum in particular is located in a desert climate where is it is very hot and dry all year (Abdin, 2013).

In a later study on the energy situation in Sudan, the study showed very close results in the energy consumption of the residential sector. The only difference is that this late study, carried out in 2016, took into account all the energy sources of the electric power, biomass energy, and oil. Also the second difference is the division of the sectors, which were different than the previous studies. In this research, the sectors were divided into residential, service, agricultural, and industrial sectors.

The results of this study were quite similar to the previous results in the consumption percentage of the residential sector, which was about 48% of the total energy. However it shows huge growth in the energy production and consumption. The total electrical energy consumption of all sectors is presented in figure (2-9) below (Rabah et al., 2016).

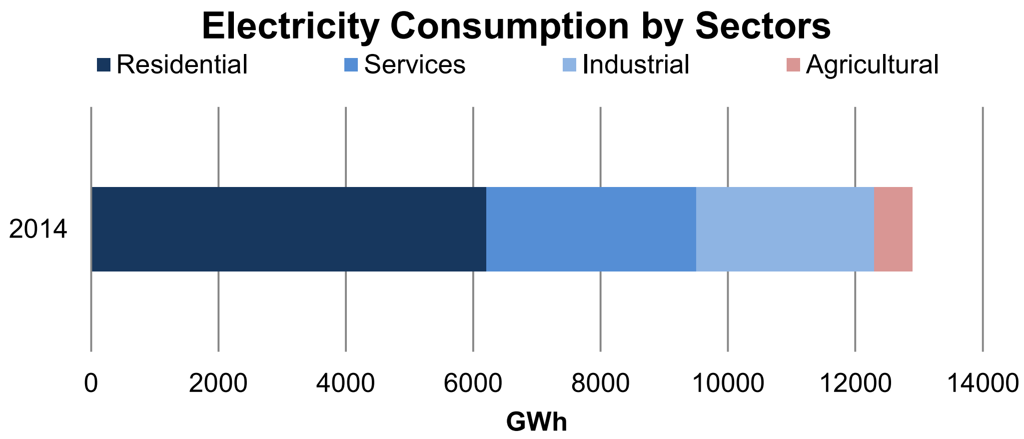


Figure 2-9: Energy consumption by sectors in 2014 (Rabah et al., 2016)

2.2. Standard Testing Models Back ground

This section is devoted for the standard testing models and provides general information about testing models, their uses, history, and the most important information required to create them.

2.2.1. Background

Standard testing model for a building type is a model consists of the most common features for that type of building (Loga et al., 2016). These standard testing models are used in the fields of environmental performance (Zhu & Chen, 2015), sustainability research (Adekunle & Nikolopoulou, 2016), energy consumption (Ruellan, Park, & Bennacer, 2016), indoor thermal comfort (Ioannou & Itard, 2015), building prefabrication technology (Roy & Roy, 2016), and building materials development. These models are also used in the study of strategic national plans to reduce carbon dioxide emissions or to reduce the energy consumption rates of different building types in cities, as well as waste the recycling researches (Érika Mata, Kalagasidis, & Johnsson, 2013). These standard models are of a vital importance to all different levels, the regional level, civil organizations level, international organizations level, and the individuals level because the results of that model can be generalized and give reliable results that describing the reality (Nemry et al., 2010).

The standard model for any type of building is a model that has the most characteristics of that building type (Loga et al., 2016). The standard testing model, in any computer simulation or calculation, can be a representor for all buildings in that building category and results of these simulations and calculations will still be close to reality (Ballarini & Corrado, 2017). As it is stated in more than one source, globally buildings consume about 40% of energy and produce about 50% of carbon dioxide. Therefore and based on the importance of buildings in terms of energy consumption and production of carbon dioxide, researchers, organization, and governments all around the world trying to reduce its consumption of energy and its production of Carbon Dioxide CO_2. So the attention to buildings was universal. Standard models have been proposed for buildings around the world (BPIE, 2011). Proposing of such models requires the existence of accurate monitoring and scientific documentation of the existing buildings, at the countries level, or at the cities level, to allow the researchers the opportunity to analyze as large number of models as possible in search of the most common features (UDAGAWA, 1985).

It is also known that each type of buildings includes large variations in the buildings inside. These variations are the result of the different characteristics of each building in terms of location, design, requirements, building materials, cost, etc. Accordingly, the definition of only one standard model for each type of building would not meet the exact accuracy required in calculations or computer simulations for the performance of that type of building. For all that, governments have devoted considerable support to monitoring and documenting buildings (Corrado, Ballarini, & Corgnati, 2012).

The European Union has collected analyzed a large raw information about buildings in 21 European countries, including Britain, to produce standard models of residential buildings in each country in TABULA project and EPISCOPE project in Figures (2-10 and 2-11). The European Union has set up an Internet website to present these results and to make these findings available to researchers since 2009 (Ballarini, Corgnati, & Corrado, 2014). In this site, the residential buildings were precisely divided according to the house size and construction date to a number of categories. Each category is fully described in terms of the used building materials and the doors and windows. Then, after the European Union published the study, the researchers developed a large number of computer models to improve the environmental performance of the residential buildings and to develop strategic plans to reduce its production of carbon dioxide, in addition to many other uses for these models. Then, modelling energy consumption of building stocks became the main tool to determine the policies of the countries towards any new regulations to develop the efficiency of energy consumption or the reduction of the CO_2 emission (Kavgic et al., 2010).

Figure 2-10: TABULA Project

Figure 2-11: EPISCOPE Project

Generally, these systems and models were introduced firstly in Britain. The first introduction was in a model that was developed to determine the residential buildings baseline of energy consumption. Then the models followed in countries all around the world and it varied in its calculations process. These systems are generally divided into two main directions. The first is the trend of working from the large level (national level) to the small level (the level of housing units) which called top-down models, and this is the origin and the beginnings. The second approach starts from the small level (the level of housing units) and ends with the large level (national level) and this type called bottom-up models, and this is the modern trend that was created because it solves many problems in the previous system. On the whole, each system has its strengths and weaknesses. What is important to us now is that the second system depends primarily on the identification of standard models of residential buildings (É Mata, Sasic Kalagasidis, & Johnsson, 2014).

Standard models are of great importance in all fields, starting from the micro-level of individual buildings and ending with the national or regional level.

At the micro-level, standard models help in computer simulations of building performance, and are used to develop building materials, thermal comfort studies, and air quality in place, as well as the development of prefabricated buildings and the building 3Ds printing.

On the Macro-level of building stocks, the standard models are very necessary to study any proposed developments or energy consumption estimation or prediction. As well as the computer simulation of the proposed development directions in this type of building. Standard models also assist in the development of building codes, and the plans for refurbishment of these buildings in the future.

All this will not be possible without standard building models. The higher the number of standard models in any building type the more accurate the results of any simulations or studies that carried out using these models. Figure (2-12) below illustrates the use of the testing models for individual buildings or for building stocks.

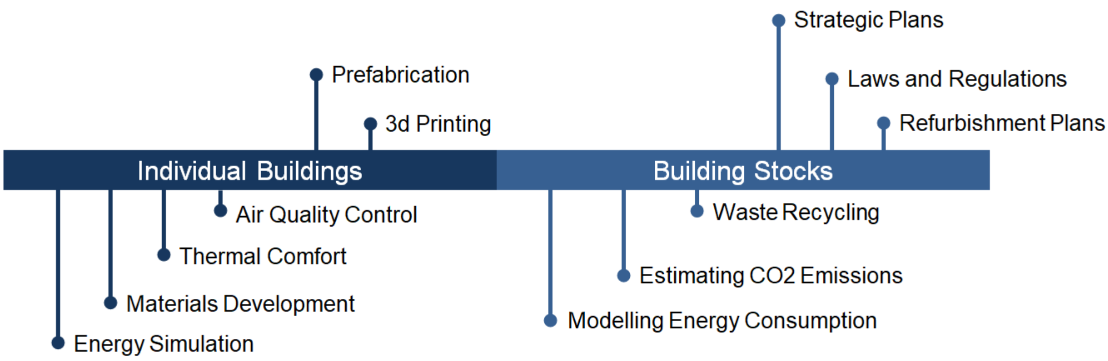


Figure 2-12: The uses of the standard testing models

2.2.2. Basic requirements in Testing Models

This part will throw light on the information that needed to carry out a simulation such as building structures, walls, roofs and floors, doors and windows, construction materials, equipment's, and users schedules etc.

Standard testing models should provide basic information according to the different needs. This basic information are summarized in the number of spaces in that building model, the dimensions of these spaces, used building materials, doors and windows. These are the required basic information for any researcher in all the different fields, in addition to other detailed information related to each field.

For example, in the environmental performance simulations, the researcher needs more information in addition to these which previously mentioned basic information. This information are regarding the electrical appliances used in each space, the number of people in each space in the model, and the operation schedules of electrical appliances and air conditioners. This detailed information is additional for the environmental performance simulation field (Calm et al., 2007).

However, in the construction materials or fire resistance cases, the researcher is interested in the basic information mentioned above, in addition to other information that is totally or partially different from the information required in the cases of simulation of environmental performance, for example. The same applies to other specialized research (Standard, 2013).

Therefore, the main objective of this research was to provide this basic information while opening the way for the following researches to modify and to increase the accuracy of these results.

Chapter-3

Single-Floor House

3-Single-Floor House

The third chapter of this research is devoted to single-floor houses. This chapter divided into three sections. The first section was introductory to the single-floor houses in Khartoum in terms of distribution, energy consumption, the basic components of these buildings, and its share of the total population in Khartoum. In the second section of this chapter, the research methodology of this type of building was discussed in detail. The third section is devoted entirely to discussing the results of this part of the research. The residential neighborhood sample results were presented in the first part. In the second part, the results of the general layout of single-floor house which were collected from the high-resolution satellite images were presented. This is followed by the third part, where the survey results of the selected single-floor house samples were presented. These results were grouped into the results of the dimensions of the spaces, the building materials, and the final group was for the doors and windows.

3.1. Introduction

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 (UDAGAWA, 1985) as mentioned before. Single floor houses represent about 77% of the residential buildings in Khartoum. 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 (Merghani, 2001), studies on materials (Elkhalifa, 2011), studies of the social use of the different spaces (a. M. Ahmed & Kurosawa, n.d.), and studies on the planning aspects of housing (Bahreldin, 2006). 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.

3.1.1. Satellite high resolution images

Google Satellite high resolution images have been used in many different ways to study various topics such as building detection (Ghaffarian & Ghaffarian, 2014), agriculture (Pulighe & Lupia, 2016), archaeology (Morehart & Millhauser, 2016), planning (Patela et al., 2015), and environmental effects (Malarvizhi, Kumar, & Porchelvan, 2016) . However, they have never been used to study building layouts. In this research these images were used to study house layouts in Khartoum.

3.1.2. Aims and objectives

As observed from collected data, there are limited numbers 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 (3-1).

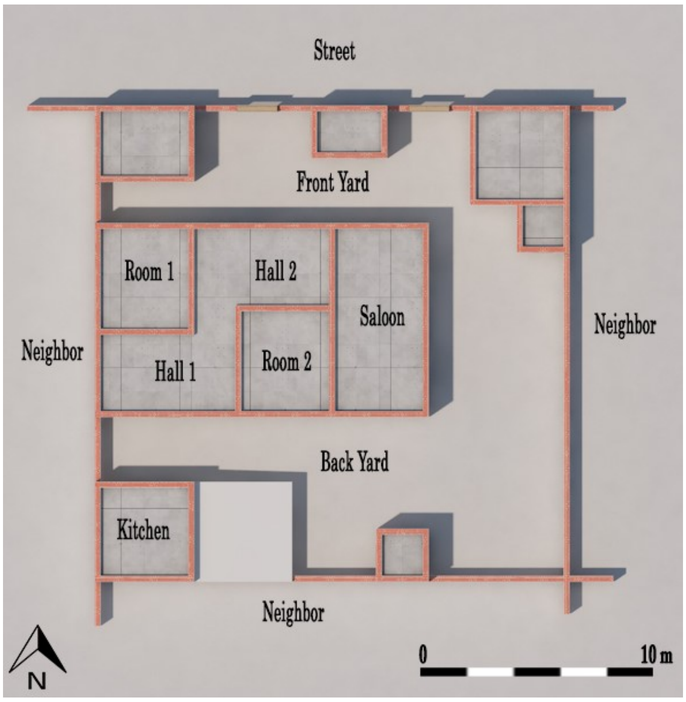


Figure 3-1: Single floor house components

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

3.1.3. Features of the single floor house in Khartoum

Houses in Khartoum have common features that are very essential, these features are (a. M. Ahmed & Kurosawa, n.d.) ;

- 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 (3-2) shows pictures of a typical house in Khartoum. The pictures are taken form the house’s yards.

Main building

Kitchen

Services

Figure 3-2: Images of house example in Khartoum

3.2. Methodology

The methodology of this research depended on working in two axes. The first axis was to identify the most common pattern of the general layout of the house. Therefore, in this axis has been relying on Google high resolution satellite images to ensure the largest possible range of samples with low cost and time efficient. This part has benefited from the fact that the walls rise above the roofs in the houses usually, and also the shadows of the buildings that show the heights.

After identifying the house layout, then the research moved to work in the second axis. This axis was the focus of a survey and direct inspection on selected samples of single-floor houses which were all built according to the most common layout pattern, to gather detailed information about the space dimensions and the building materials.

3.2.1. Layout Patterns

3.2.1.1. Area selection

To carry out the survey of the general layout pattern using the satellite images, 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.

3.2.1.2. 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.

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

3.2.1.3. **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 (3-3) shows examples of the above mentioned categories. In figure (3-4), the main building types were illustrated as they appear in the satellite images to illustrate the difference between them.

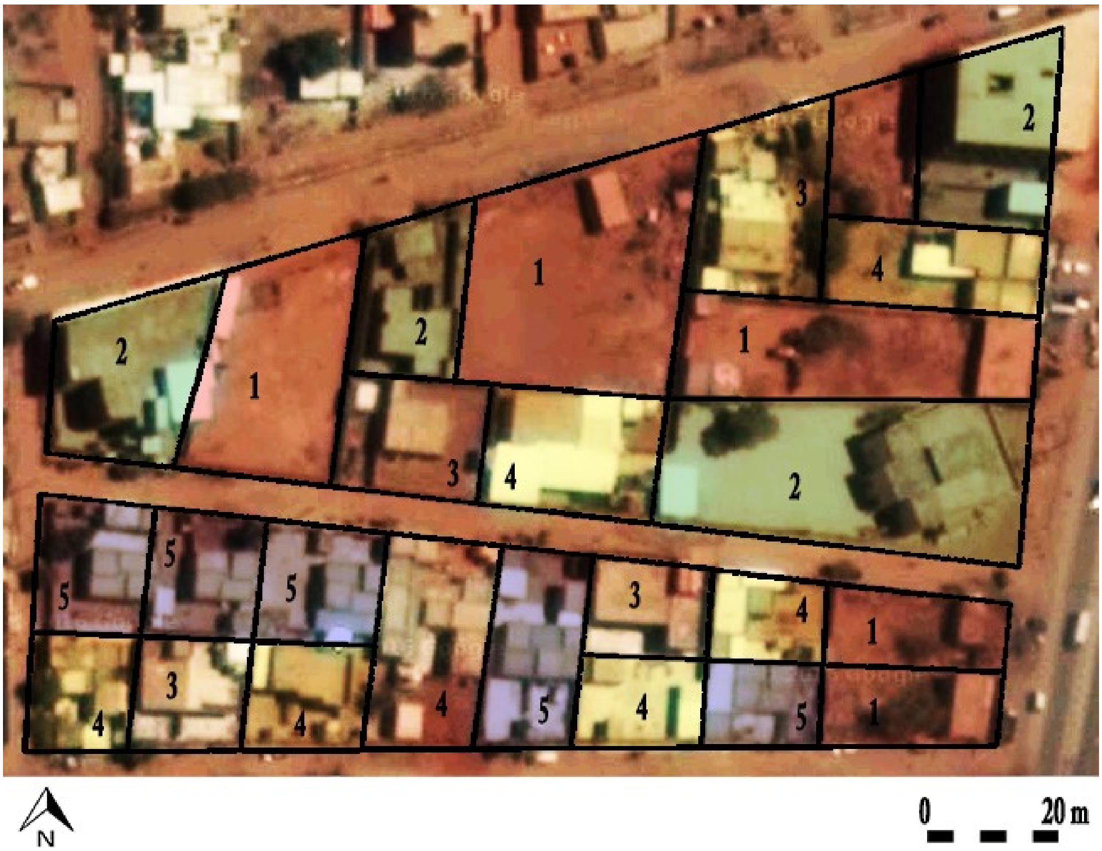


Figure 3-3: Examples of different building types

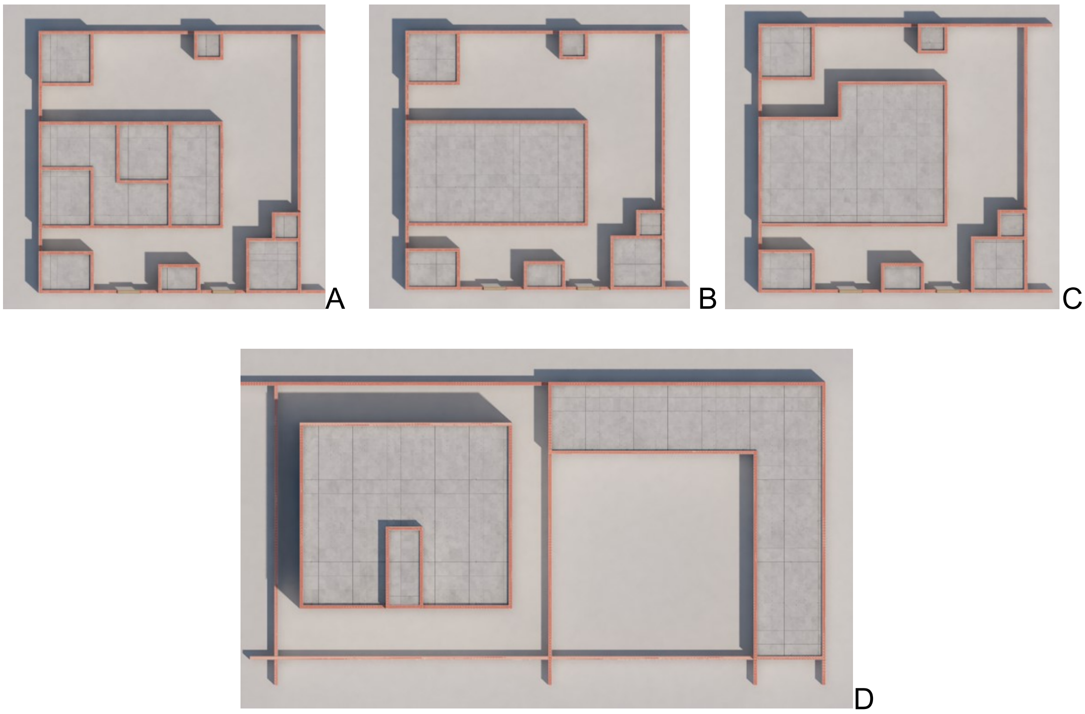


Figure 3-4: Examples of the different building types A- the uniform pattern B- Not clear Pattern C-Other Pattern, and D-Commercial and Multi-story buildings

3.2.1.4. 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.

3.2.1.5. 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 m^2), and any plots that were smaller than that were considered a mistake in the selection process.

3.2.1.6. 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.

3.2.2. Material and dimension survey and inspection

In this part of the methodology, it relied on direct inspection and survey of samples of houses built in general layout that matches the most common pattern from small geographical area to reduce the cost of the survey. In this survey, 100 houses were selected to survey the space dimensions and the building materials. The direct survey was conducted on 96 houses only and the residents of the other four houses were not present at the time of the survey which was form (15-21) of March 2017.

In the survey, a laser meter was used to measure the space dimensions. These measurements were taken for the internal dimensions of the space, and then the wall thickness was also measured at the openings (doors and windows). The doors and windows were also surveyed directly on all samples. While all the required information about the building materials was taken by asking the house residents about the construction materials that used in the walls and roofs. This data collection method was used because the walls in all cases were covered with plaster both sides (internal and external) and the material of the wall is not visible. In case the occupants was not aware of this information, either because they were only tenants of the property and not the owners, permission was taken to inspect the walls directly by digging a small hole in the wall to check the materials. This information has been collected using the form attached in Annex 1.

The surveyed random sample of 96 houses that were built according 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 (3-5), 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.

Figure 3-5: The surveyed 96 houses form the large neighborhood (houses were numbered and the houses that were marked by the symbol ♦ Yellow don't have a saloon)

The following Figure (3-6) 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 and 5 the area the verification test took place and the generation of the plots' raw data also in ArchiCAD respectively, followed by step 6 where the material and dimensions survey took place. Finally in step 7, the final analysis was conducted and the results were illustrated in the form of tables and graphs using MS Excel.

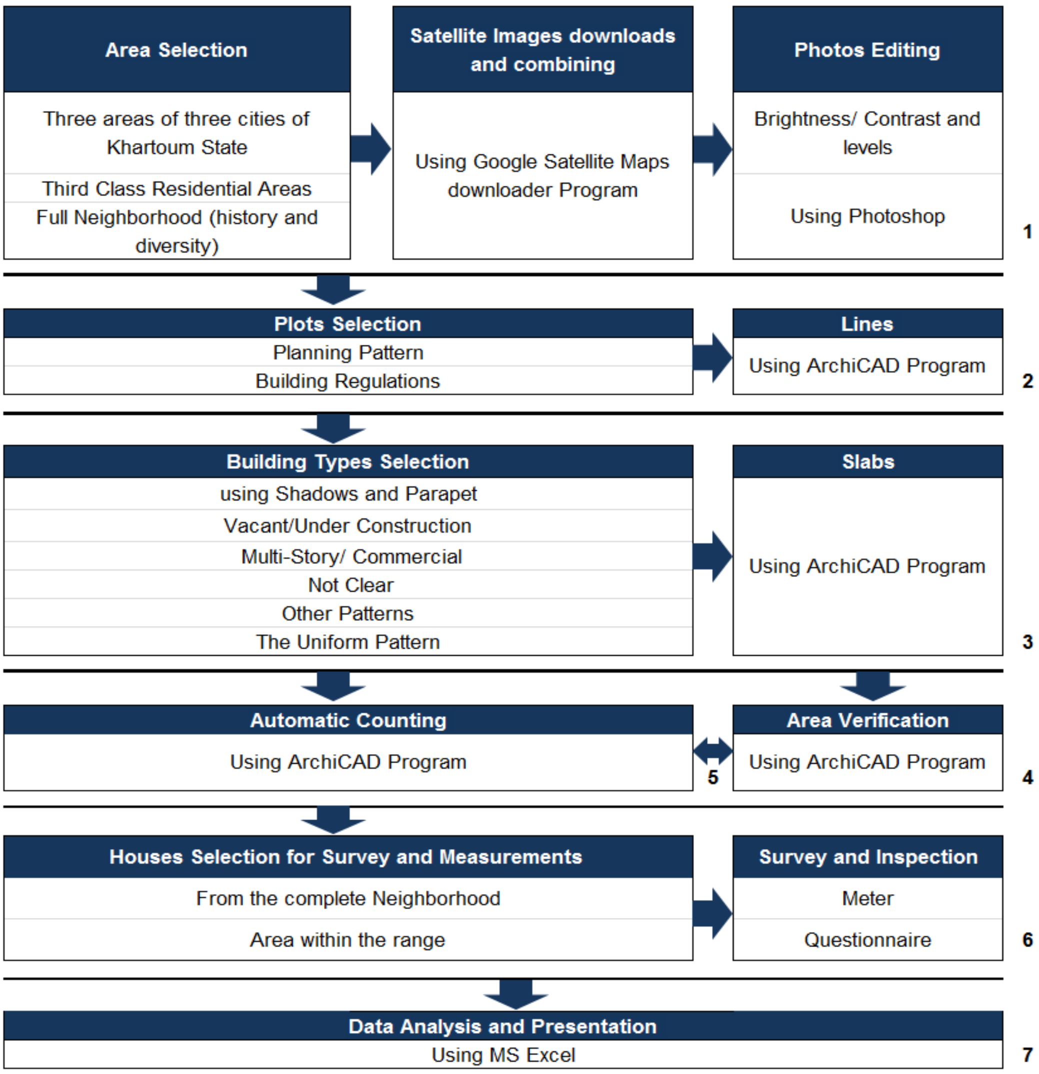


Figure 3-6: Methodology working diagram of single-floor house

3.3. 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 (Zakaria, 2012). The name of the selected neighborhood is Alhaj-Yousif Almaygoma.

Tables (3-1) show the detail geographical locations of the selected small partial neighborhoods in Khartoum, Bahri, and Omdurman.

Table 3-1: Samples area locations

City	Top-Right Corner	Bottom-Left Corner		Images Date
Khartoum	15.458246°	15.455305°	Latitude	1/25/2016
	32.502781°	32.497339°	Longitude	
Omdurman	15.715599°	15.713028°	Latitude	10/1/2016
	32.484523°	32.478640°	Longitude	
Bahri	15.726956°	15.724095°	Latitude	4/19/2016
	32.578290°	32.571083°	Longitude	

Table (3-2) shows the detailed longitude and latitude for the complete neighborhood of (Alhaj-Yousif Almaygoma).

Table 3-2: Location of the complete neighborhood

City	Top-Right Corner	Bottom-Left Corner		Images Date
Complete Neighborhood	15.6529°	15.6102°	Latitude	10/7/2016
	32.6258°	32.6028°	Longitude	

The satellite Images of the selected three small sample neighborhoods are illustrated in Figure (3-7).

The plots in the images are coded as follows:

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

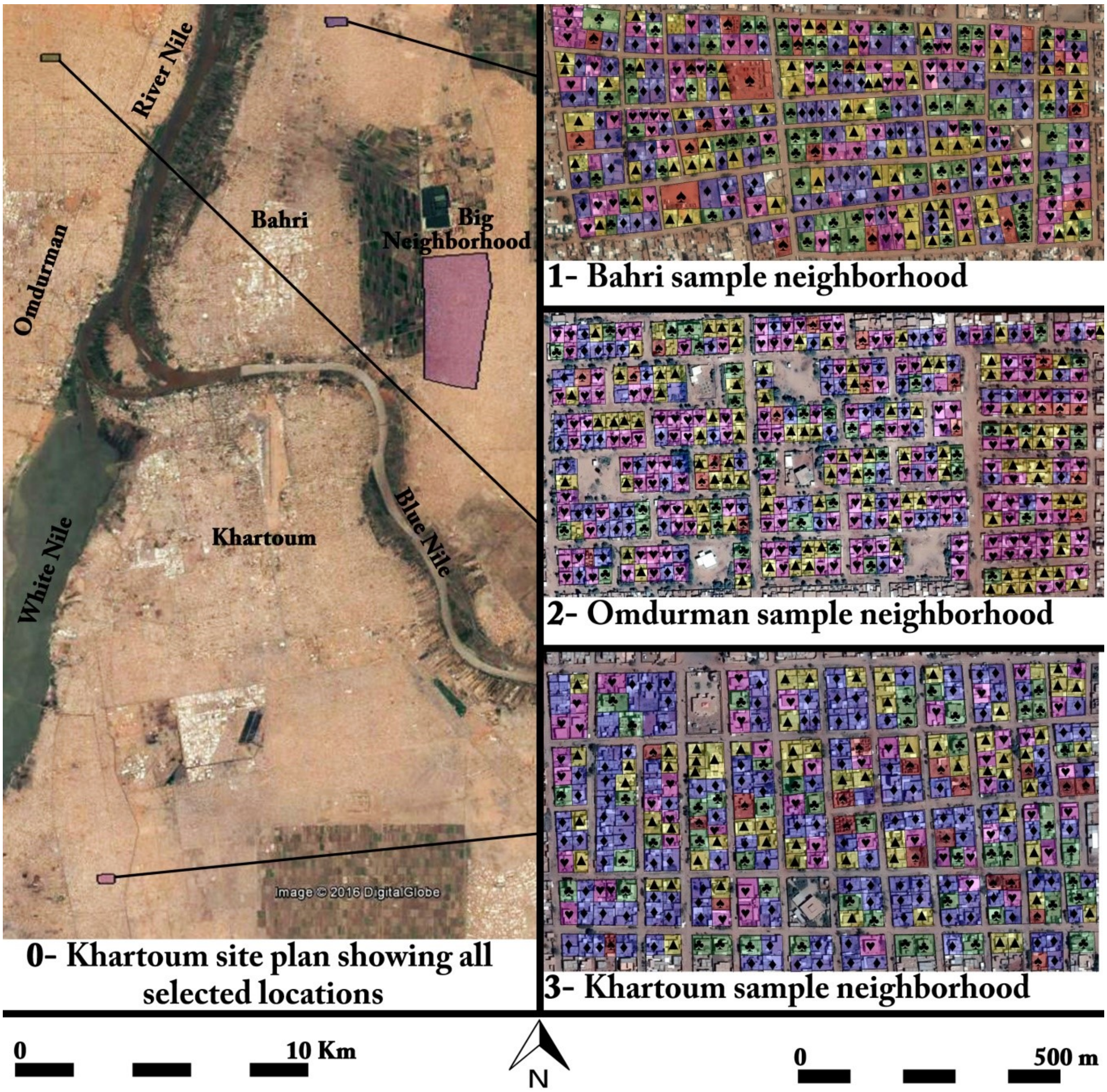


Figure 3-7: Satellite images of the selected sample neighbourhoods.

The selected sample of the entire neighborhood (Alhaj-Yousif Almaygoma) is illustrated in Figure (3-8).

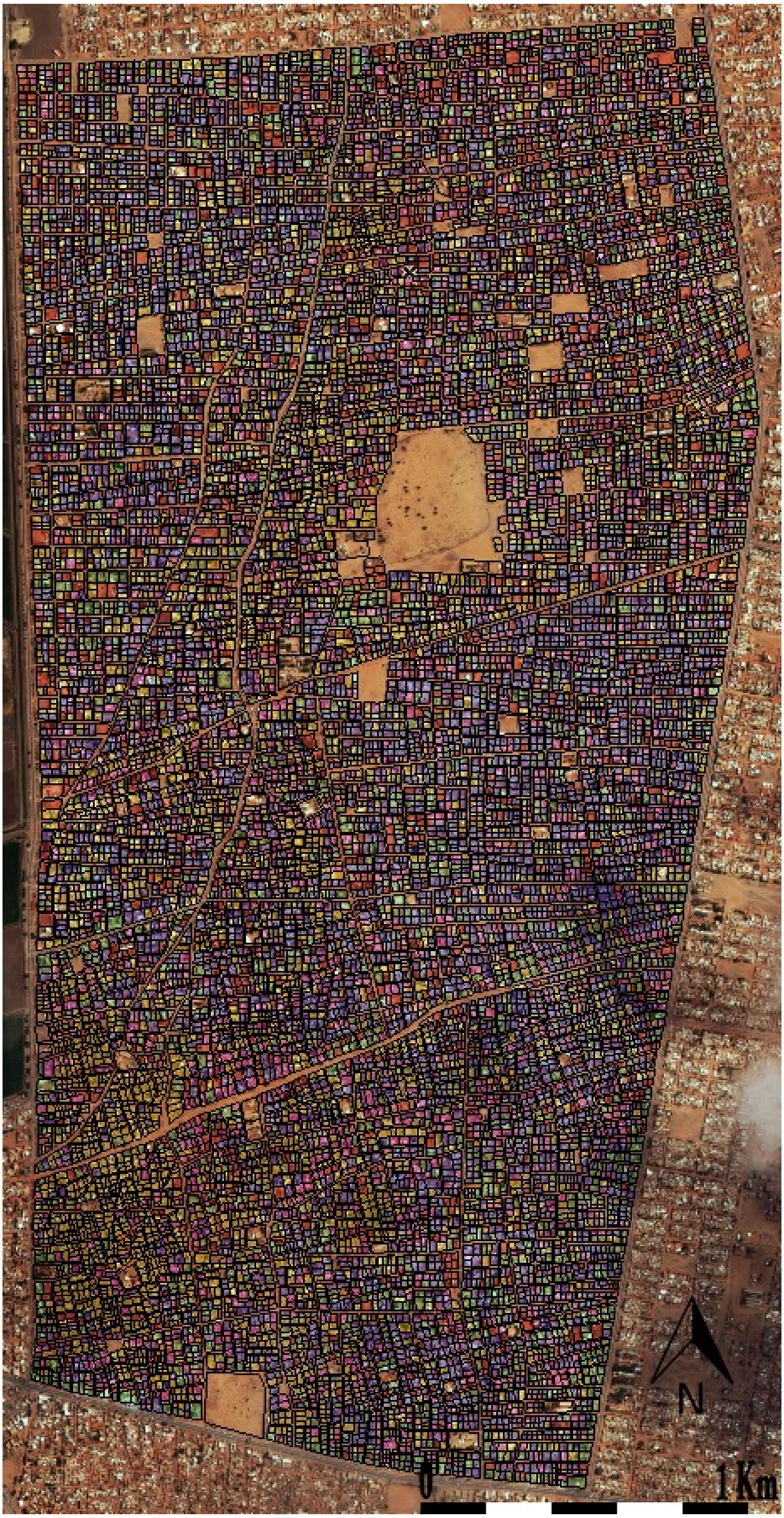


Figure 3-8: The selected neighbourhood (Alhaj-Yousif Almaygoma)

3.3.1. Building type and house layout pattern results

After completing the identification, selection and counting the total plots in all the selected samples either the partial neighborhood samples or the complete neighborhood sample, the results showed that the number of plots in the partial samples of the neighborhoods was 316 plots in Khartoum, 324 plots in Khartoum north (Bahri), and 384 plot in the partial neighborhood in Omdurman. While, in the complete neighborhood of Alhaj-Yousif Almaygoma the number of the plots was 14833 plots. These building types were distributed to all previously specified categories. In order to determine the accuracy of the plots section, area test must be carried out for all plots, and that what the next section was dedicated for.

3.3.1.1. **Area test verification**

This part of the methodology was designed to ensure that the selection of residential plots was correct. The residential plots that were selected in the previous steps were tested so that the residential plots with an area of less than 150 square meters will be excluded and then the types of buildings in each sample will be calculated and the most common building type will be determined (MOHAMMED & Takaguchi, 2016). The full histogram of the plots area was presented in figure (3-9) below.

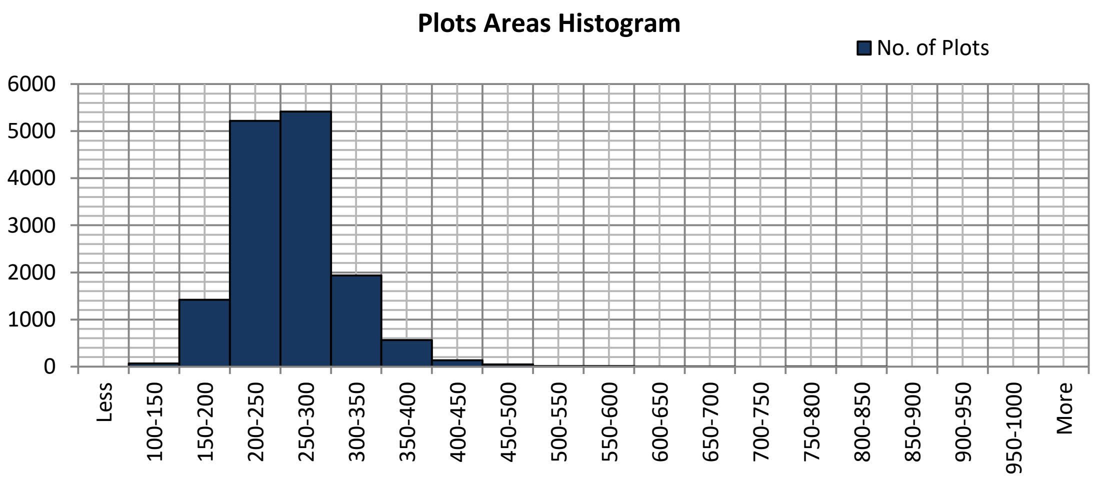


Figure 3-9: Area Histogram

The results showed that only 57 plots had an area of less than 150 square meters. These residential plots were distributed to all types of buildings in only the complete neighborhood as shown in table (3-3). It worth mentioning that, this test showed that, in the partial samples of neighborhoods all the plots was passed this test and all have area of 150 square meter or more.

Table 3-3: Plots which have an area less than $150m^2$

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**	100%

3.3.1.2. Building types

After ensuring the right plots selection, and running the area test verification, 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.

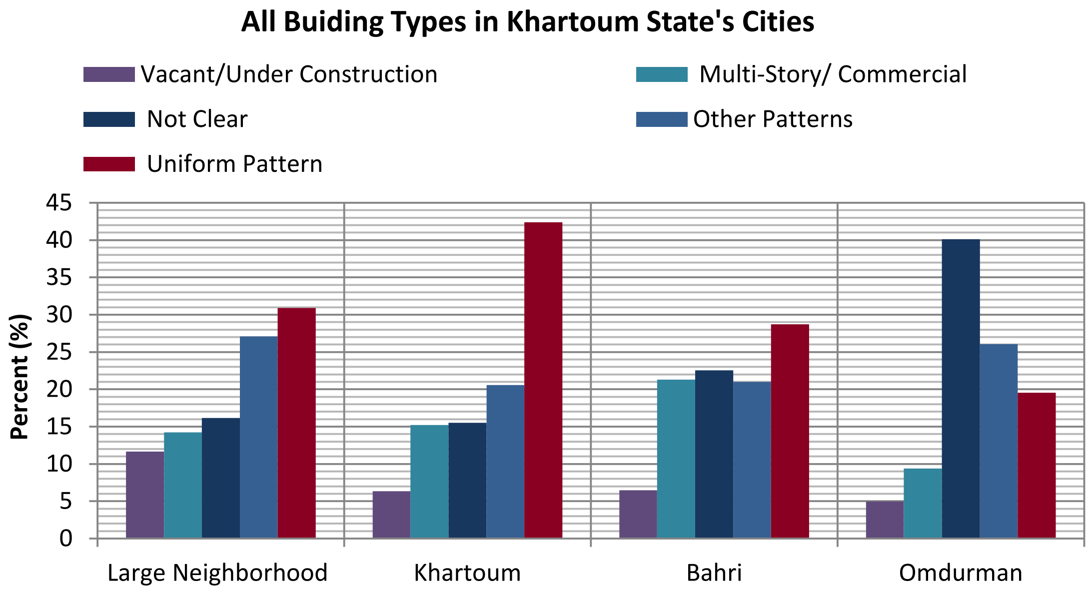


Figure 3-10: Building types results

In Figure (3-10), the results show that the percentages of the vacant or under construction plots vary from 12% in the large neighborhood to an average of 6 % in the small neighborhood samples selected from the three cities. The percentages of the multi-story and commercial plots averaged about 15% in the small neighborhood samples combined, compared to around 14% in the large neighborhood sample.

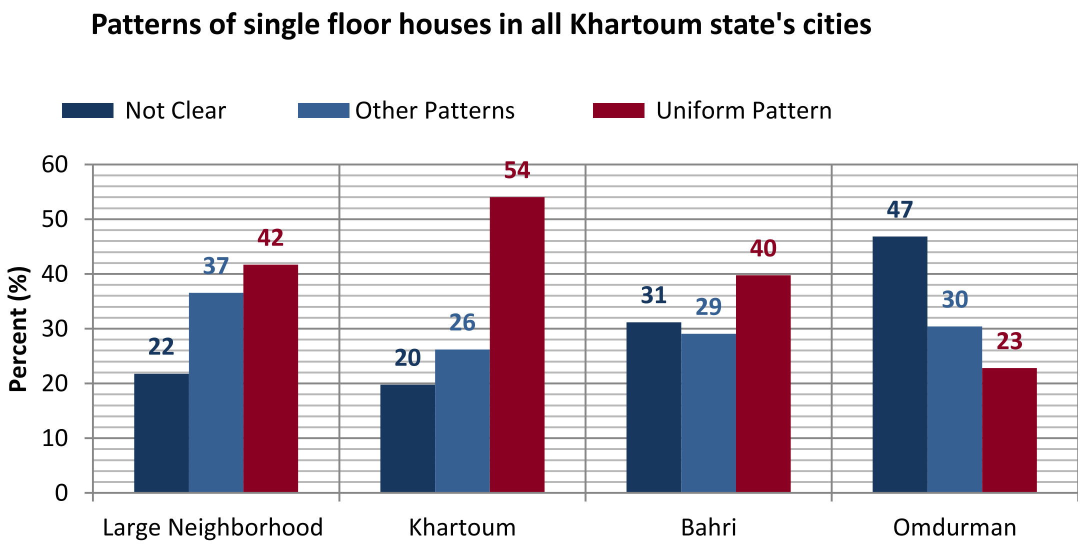


Figure 3-11: Single floor houses patterns

The single floor houses are distributed as follows; the average percentage of the category “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” layouts 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 (3-11)”.

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.

3.3.2. Building space dimensions and materials

Table (3-5) 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.

Table 3-4: 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.

***3.3.2.1.* The dimension survey results**

The results of this part of the research were illustrated in three graphs; these graphs are "length results" in figure (3-12), "width results" in figure (3-13), and "height results" in figure (3-14).

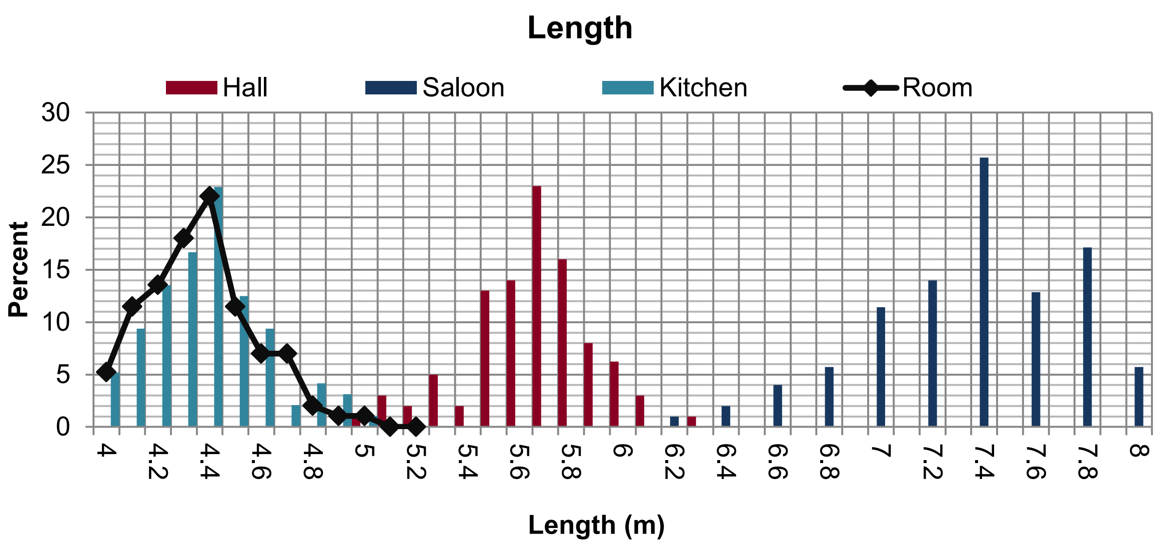


Figure 3-12: Length results

Figure (3-12) 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 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.

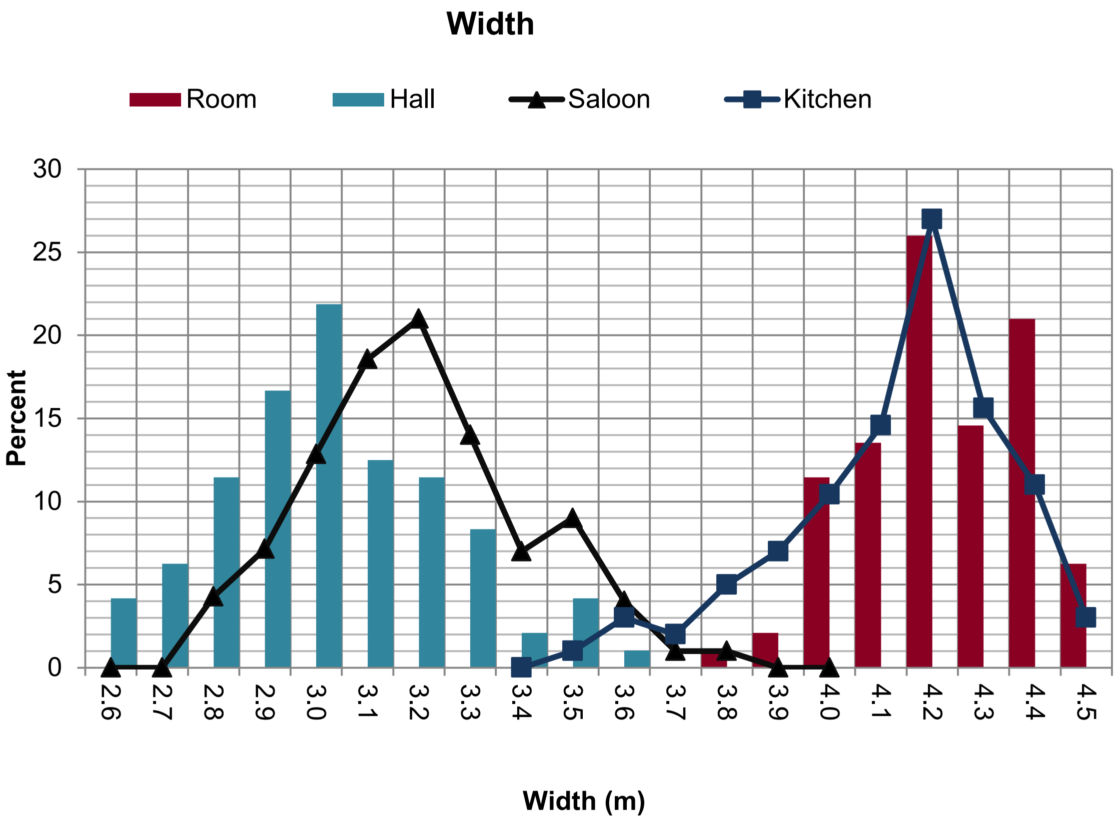


Figure 3-13: Width results

In Figure (3-13), 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.

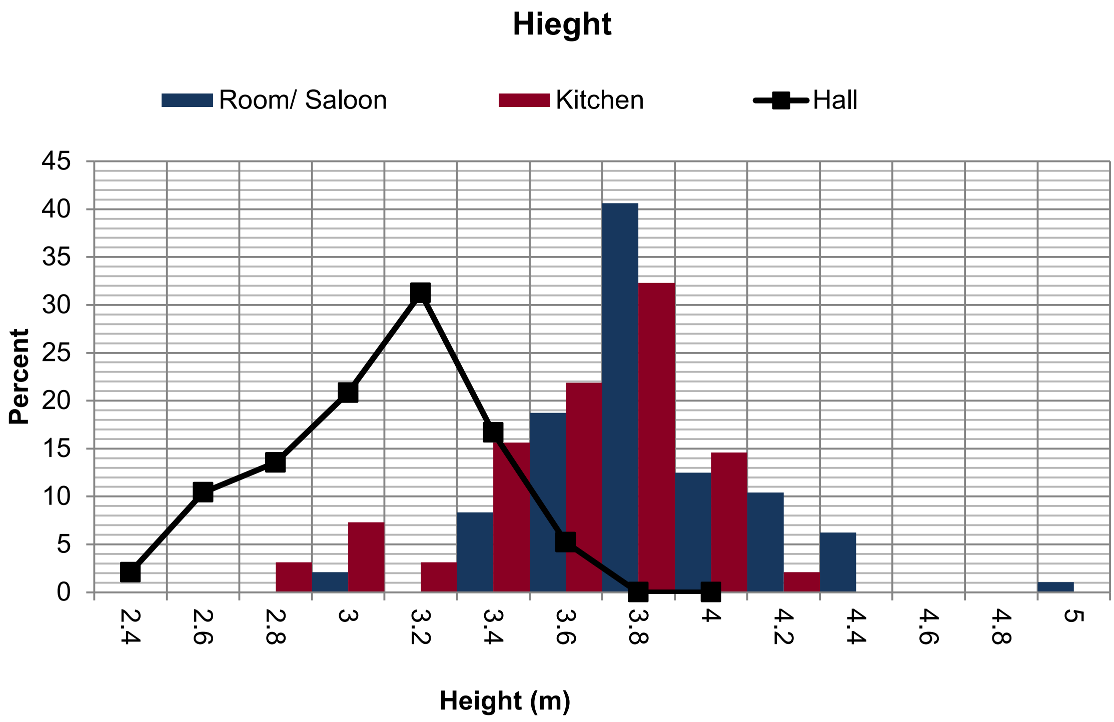


Figure 3-14: Height results

Figure (3-14) 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.

***3.3.2.2.* The building materials results**

There were general observations of this survey and inspection which were;

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 (3-6) illustrates, for the doors, the most common material is steel and it is used to create (76%) of the total samples.

Table 3-5: 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 (3-7) shows the total results of the windows' material survey.

Table 3-6: Windows materials

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

Figure (3-15) illustrates samples of the steel doors and windows that were the most common in the single floor houses in Khartoum.

Figure 3-15: Examples of the doors and windows

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 (3-8) below.

Table 3-7: 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%

Figure (3-16) below illustrates the layering of materials on the compacted earth roofs which were the most commonly used in roofs in houses in Khartoum.

Figure 3-16: Example of the roof materials and construction methods (NA, 2017)

The final results of this research are represented in the following plan “Figure (3-17)”, section “Figure (3-18)” constructional details “Figure (3-19)”, and perspective “Figure (3-20)”. These drawings represent the most common layout found in around 39.75% of the single floor houses in Khartoum.

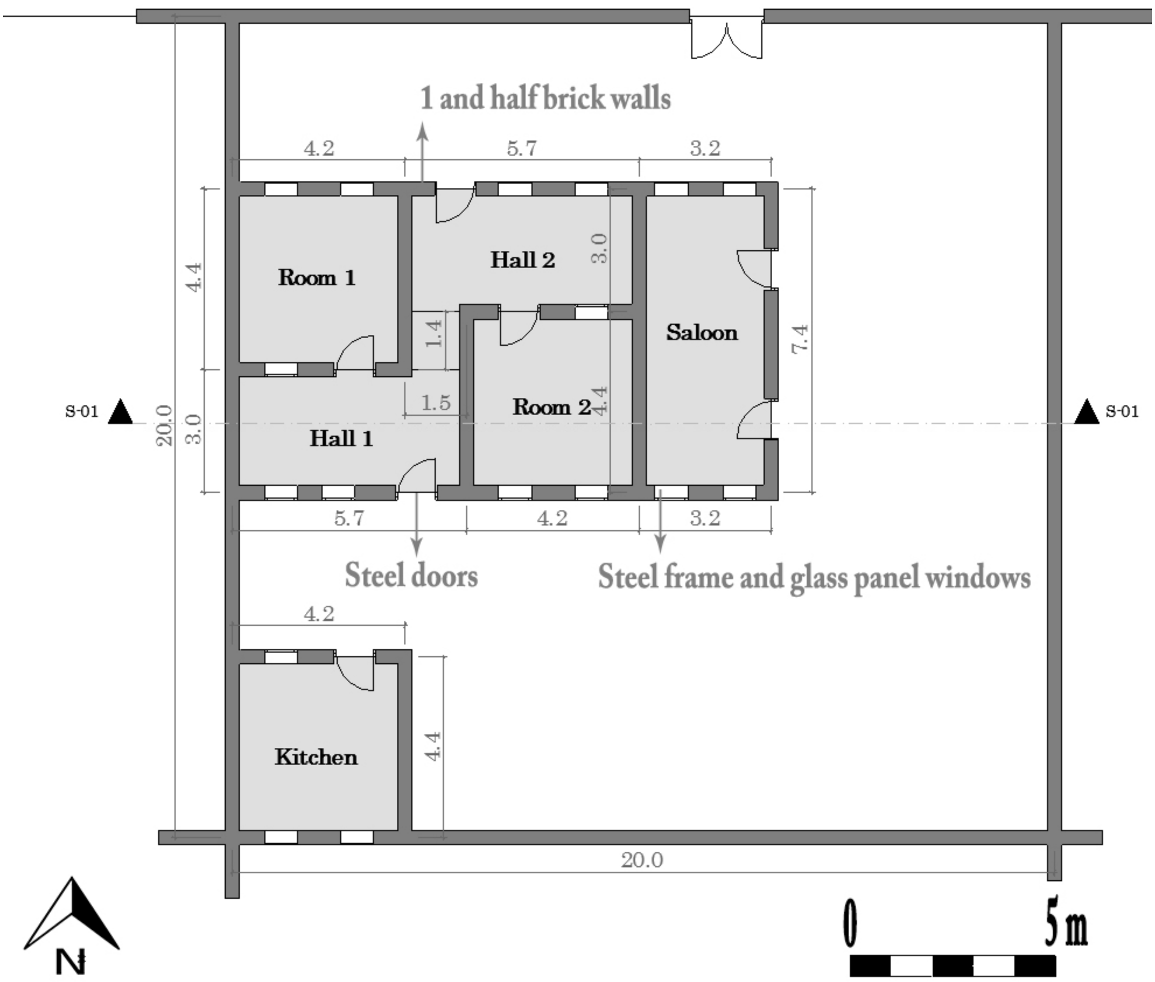


Figure 3-17: Single floor house plan shows the layout, the general spaces , and the most common dimensions for the main buildings.

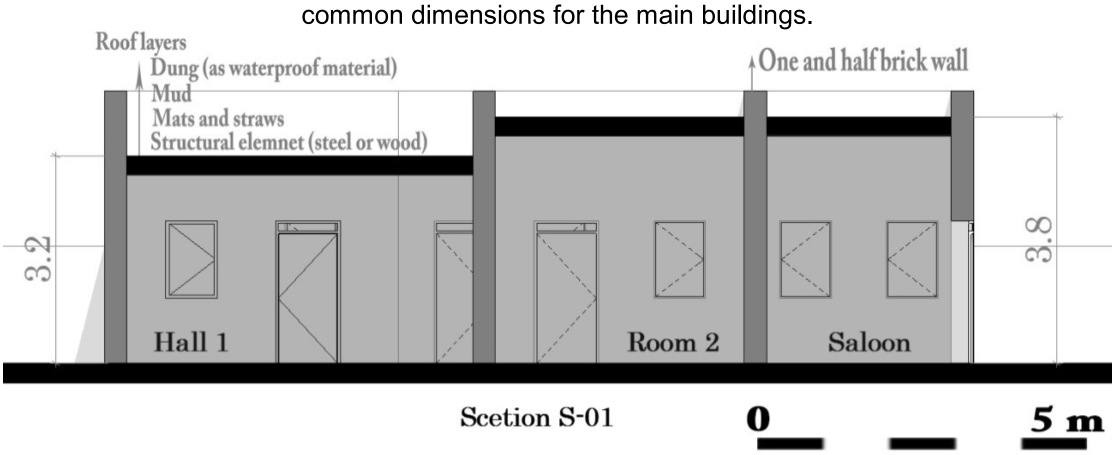


Figure 3-18: Single floor house section (S-01) shows the most common heights of the spaces

and the roof and wall materials.

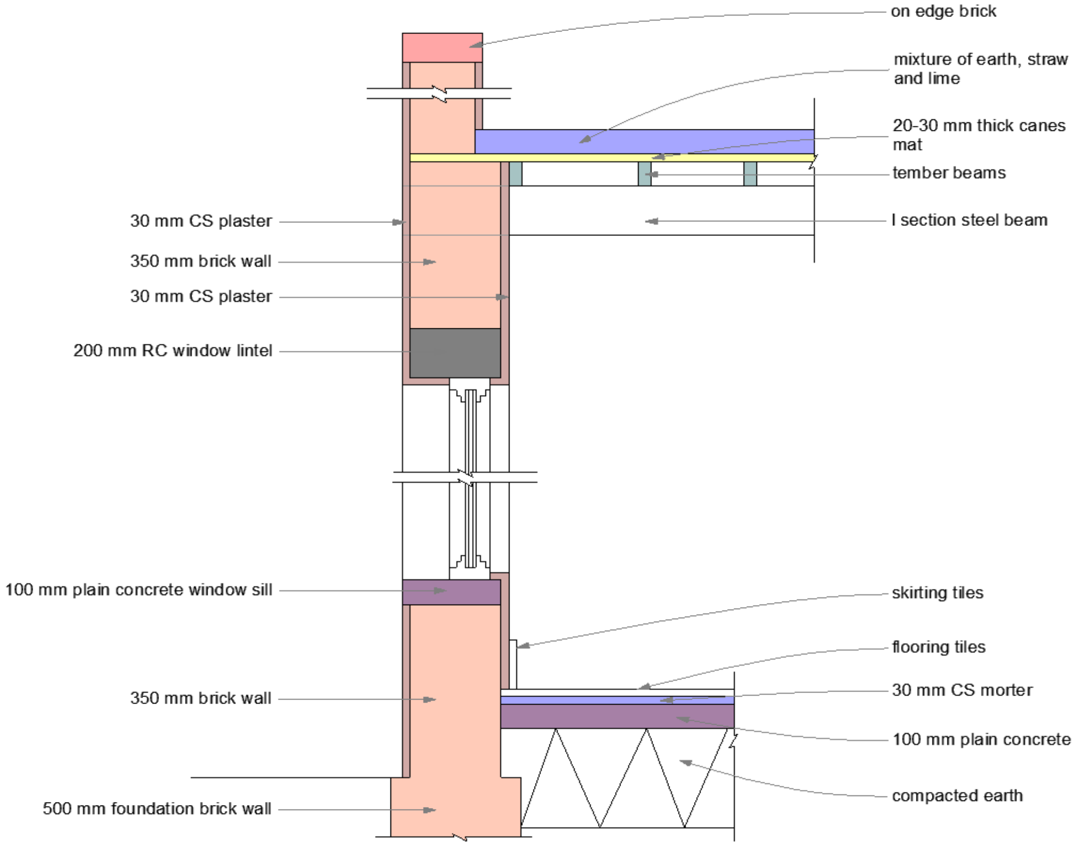


Figure 3-19: Construction details of the single-floor house

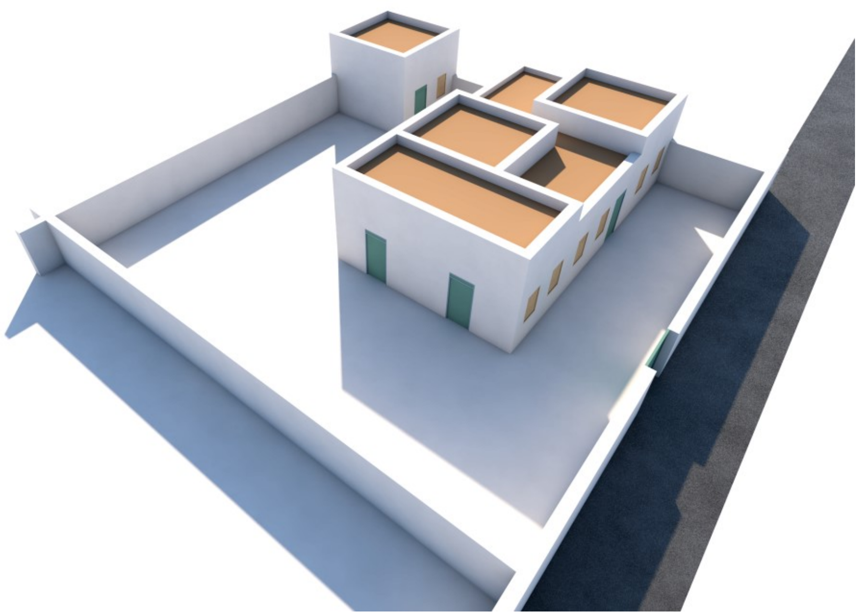


Figure 3-20: Perspective of the single-floor house standard testing model

3.4. 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 uninform 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' most common 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.

Chapter-4

Apartment

4-Apartment

The fourth chapter of this research has been fully allocated to the apartments. General information about apartments was presented in the first section of this chapter. The information contained in this section is general information about the spaces that apartment consist of, commonness of this building type, and finally its importance. In the second section of this chapter, the methodology used to examine this type of building was discussed in detail. In the third section of this chapter, the results of this research were presented in four parts. The first part presents the results of apartment type survey in general. This part was followed by the second part, which presents the results of spatial relations of spaces. Then followed by the third chapter, in which the dimensions survey results of the spaces were presented. Finally, the fourth part, which was devoted entirely to present the building materials survey results. This part includes the results of the structure materials, wall materials, door materials and windows.

4.1. Introduction

Residential apartments represent approximately 14% of residential buildings in Khartoum (State, 2013a). Moreover, apartments are the preferred choice for small families, according to a recent study. This type of building comes in second place in terms of spread after the single-floor residential buildings, which represent about 77% of residential buildings in Khartoum. It is common that this type of buildings builds in residential plots which have small to medium areas, but not in the large investment plots (Pushak & Foster, 2011). The owner house is usually located in the ground floor and the apartments on the upper floors designed to be rented to bring in additional income. But recently, as the demand for this type of building has increased, large real estate companies have begun to invest in this type of building. In the last five years, the companies have carried out many large residential projects. These projects have been built on large investment plots and they used architectural designs that were different from the usual designs that designed for small residential plots (ELSAYED, 2015).

This type of residential building is widely spread in the 1st class and 2nd class residential areas because these area are planned to accommodate these types of buildings in the last strategic master plan of Khartoum 2013. On the other hand, apartment buildings numbers are much lower in the 3rd class residential areas, and in there the most common residential building type is the single floor (Population, General, & Security, 2010).

For all what mentioned before, apartments should therefore have been carefully studied and standardized because this type of buildings is expected to grow more in the future. But in reality, apartments as well as all other building types in Khartoum have not been sufficiently studied, so it was necessary to study them extensively.

Residential apartments consist of the same architectural spaces that all residential buildings in Khartoum consist of. These spaces are used in the same way in all residential buildings because the cultural and social factors are almost the same in Khartoum. These spaces are:

- Master bedrooms: this room is part of each apartment. It has its own bathroom and normally inside the room.
- Bedroom: for the children and sometimes there is one bedroom dedicated to the guests. The room consist of the study desks, computers, wardrobes.
- Hall: in the apartment they can be more than one hall depending on the size of the apartment, but there is no apartment that does not consist of at least one hall. The hall is normally used as living room, sitting room, and reception. In the large apartments there will be a hall reserved for men, used for the same purposes earlier and sometimes called Saloon.

Each apartment consists of these spaces in addition to the kitchen and bathrooms.

In all apartments there is a very necessary architectural element, which is the balcony. It is normally used as an alternative to the courtyards in the traditional houses.

Residential buildings in Khartoum have two main types in terms of size and in terms of ownership. The first type is the apartments built by the owner of the residential plot on the upper floors of his own home for additional income. This type is the most widespread and in most cases the apartment floor consists of two apartments and staircase in between. The exterior shape of this type of apartment clearly illustrates this building division. Examples of apartment were illustrated in figure (4-1).

Figure 4-1: Examples of the first apartment building type in Khartoum

While the second type is not widespread, but in recent years there has been a trend for this type. The second residential apartment type is the large investment apartments that are built by large investment real states companies. This type is very different from the first type, which is built in the normal areas of residential plots. The latter is built in large areas and building size is large which makes the number of apartment per floor are more than the usual apartments that owned by individuals. Example of this type of apartments is illustrated in figure (4-1).

Figure 4-2: Example of new large investment apartment building type in Khartoum

4.2. Methodology

The research methodology was based mainly on collecting architectural projects for this type of building, from architectural companies, architects, and owners of these buildings. These projects were certified by the authorities to comply with all the legal requirements specified in the Building Code of Khartoum, and the structural and architectural design was fully approved. These conditions were adopted to insure that all selected projects represent the real requirements of this type of buildings in terms of functional requirements, environmental requirements, social and cultural requirements, financial requirements, and finally legal requirements.

To insure the diversity of the projects, the samples were collected from hugely varied companies, architects, and owners. They were varied on the ages, experiences, and size of the company and so on.

After collecting the samples, and because the apartments consist of typical floors in which the same floor layout and apartments were repeated, the first step after collecting the samples was to study all projects and to select one sample of each repeated apartment for the farther steps.

After identifying the different apartments in all the projects, the apartments were classified according to the classification used in the field. The classification of apartments is usually based on the number of rooms they contain. This initial monitoring of projects determined the most common apartment type.

Then, using a special form, all the dimensions of architectural spaces were fully surveyed in all projects.

The construction materials used in the projects were then surveyed. The survey was carried out on the structure, walls, doors and windows using a form that designed for this purpose.

In order to know the relationship of the spaces in the most common apartment type after surveying the space dimensions, a special matrix was used to survey the relations between the spaces after these spatial relations were categorized to four main relations.

In Microsoft Excel, all of this information was inputted, analyzed and displayed in tables and graphs illustrating the most common features of this building type.

In the final step, using ArchiCAD, these common features were used to create the standard testing model for this type of building.

Figure (4-3) illustrates the working diagram of the methodology.

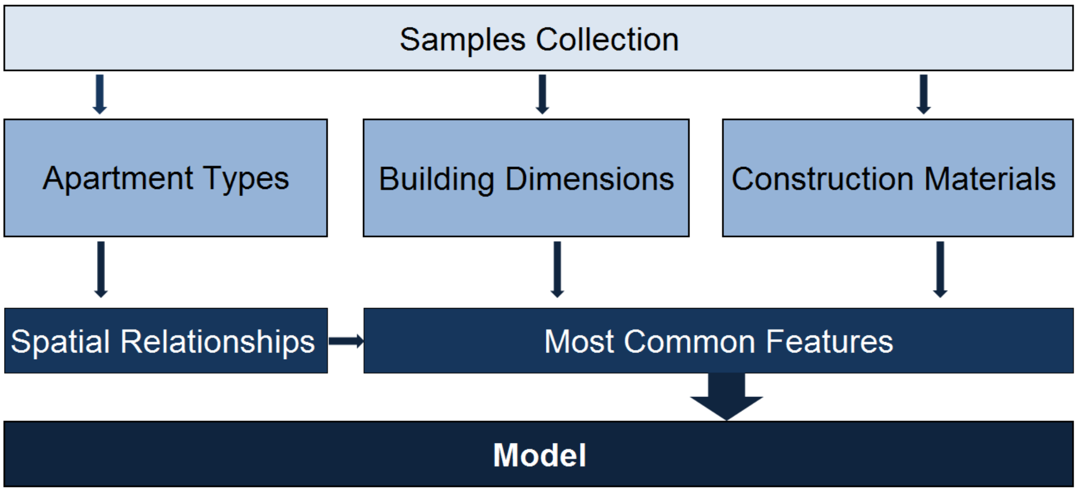


Figure 4-3: Methodology working diagram of the apartment

4.3. Results

4.3.1. Samples

To collect as much projects samples as possible 20 companies, 40 individual architect, and 30 residential apartment owners were contacted to participate in the research with samples of their projects in the period from July 2015 to March 2017. 4 companies, 23 architects and 24 owners were responded to the communications and provided this research with 85 project samples. Then in March 2017 the analyzation of the received projects was started. The results of these analyses were summarized in the following table (4-1).

Table 4-1: Sample project sources

Source of Projects	No. of sources	No. Projects
Companies	4	19
Individual Architects	23	42
Owners	24	24

These 85 projects included 163 different residential apartment designs. These different types of apartments were divided into 24 projects that contained only one apartment design, 44 projects that contained two different apartment designs, and 17 projects in which there were three different apartment architectural designs. These results illustrated in Table (4-2) below.

Table 4-2: Number of different apartment designs

No. of Different Apartments in one Project	**1**	**2**	**3**
No. of Projects	24	44	17
Total No. of Projects	**85**		
Total No. of Different Apartments	**163**		

In total, 163 different apartment designs gave this research required diversity in the projects and designs.

In this part of the research, 85 complete architectural projects were collected from a number of architects, companies and real estate owners. After that, they were analyzed to identify the most common features of apartment in terms of their type, dimensions, building materials and general layout. All the information about each apartment was then surveyed using Form (2) in the appendixes.

4.3.2. Apartment type

The results of the first analysis of the types of apartments to show that the most common type of apartments is the two-bedroom apartments which counted 68 different design. Within this number, there were 41 two-bedroom apartments containing only one hall while there were 27 apartment containing two halls. Therefore, the two-bedroom apartment with one hall was adopted as the standard apartment for this research. Figure (4-4) illustrates all the results of the apartment type.

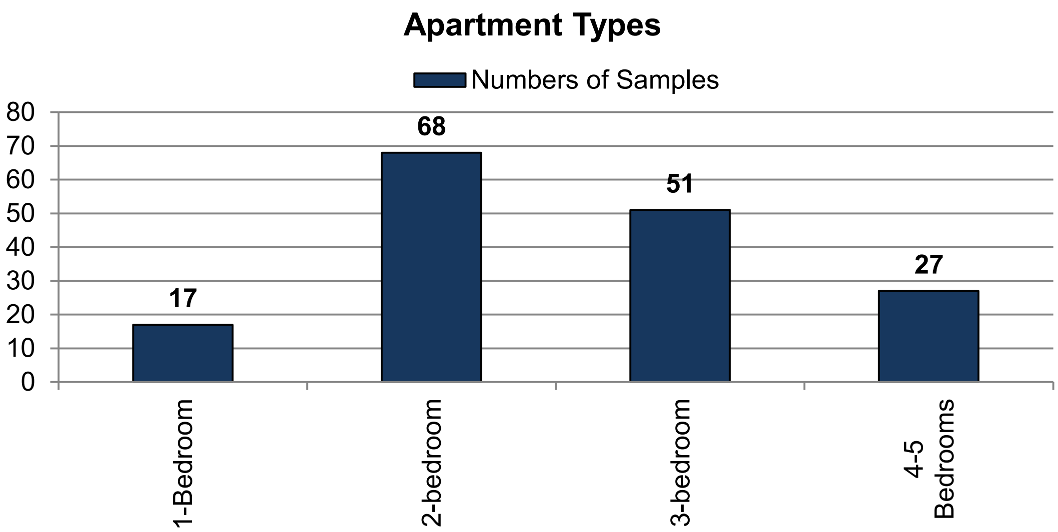


Figure 4-4: Apartment type results

After identifying the most common apartment type which was the tow-bedroom apartment, the architectural spaces were surveyed for the space dimensions and the following figure (4-5) shows the number of spaces that were surveyed.

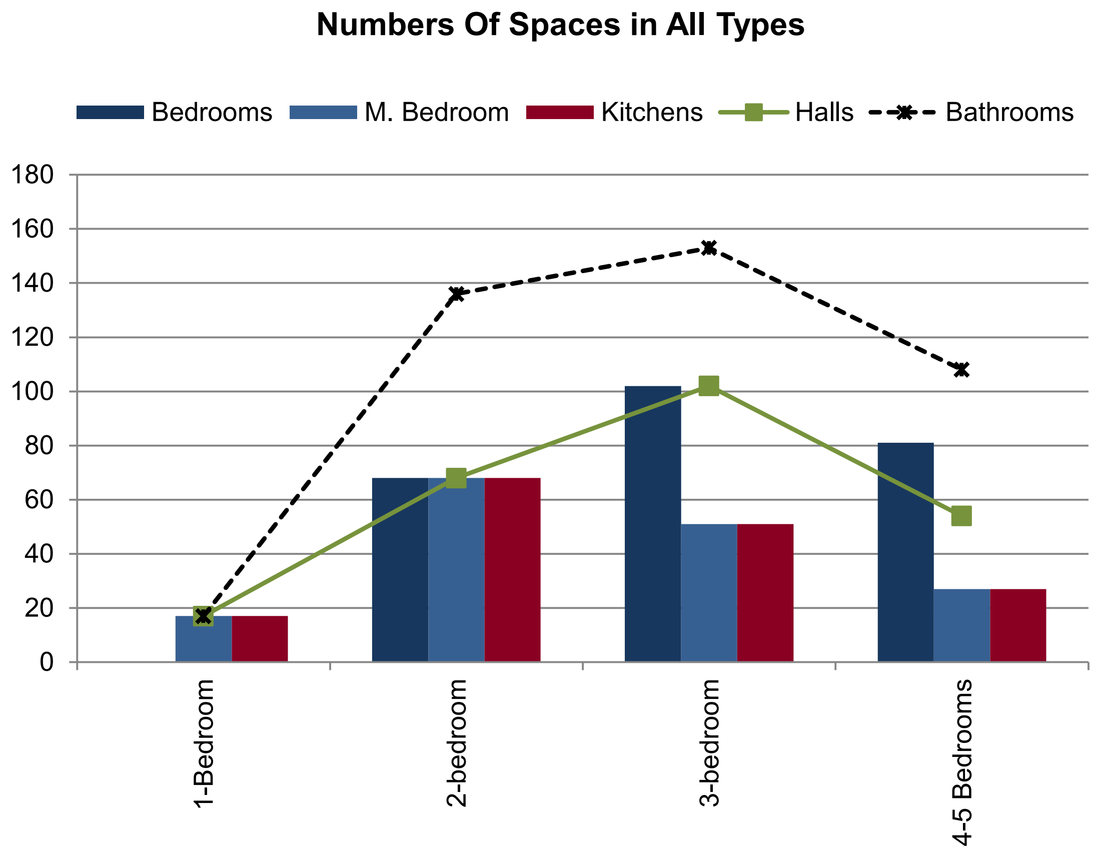


Figure 4-5: Number of surveyed spaces

4.3.3. Space Dimensions

After surveying and inputting all the data that concerns the dimensions of architectural spaces in Microsoft Excel and analyzed this raw data. The results of each dimension were combined together for all spaces and presented as graphs. These results explained in detail in the following parts of this research.

4.3.3.1. **Length**

The results showed that the length of the kitchen and the room varying in close range to one another, as well as the length of the hall and the length of the master-bedroom. As illustrated in figure (4-6).

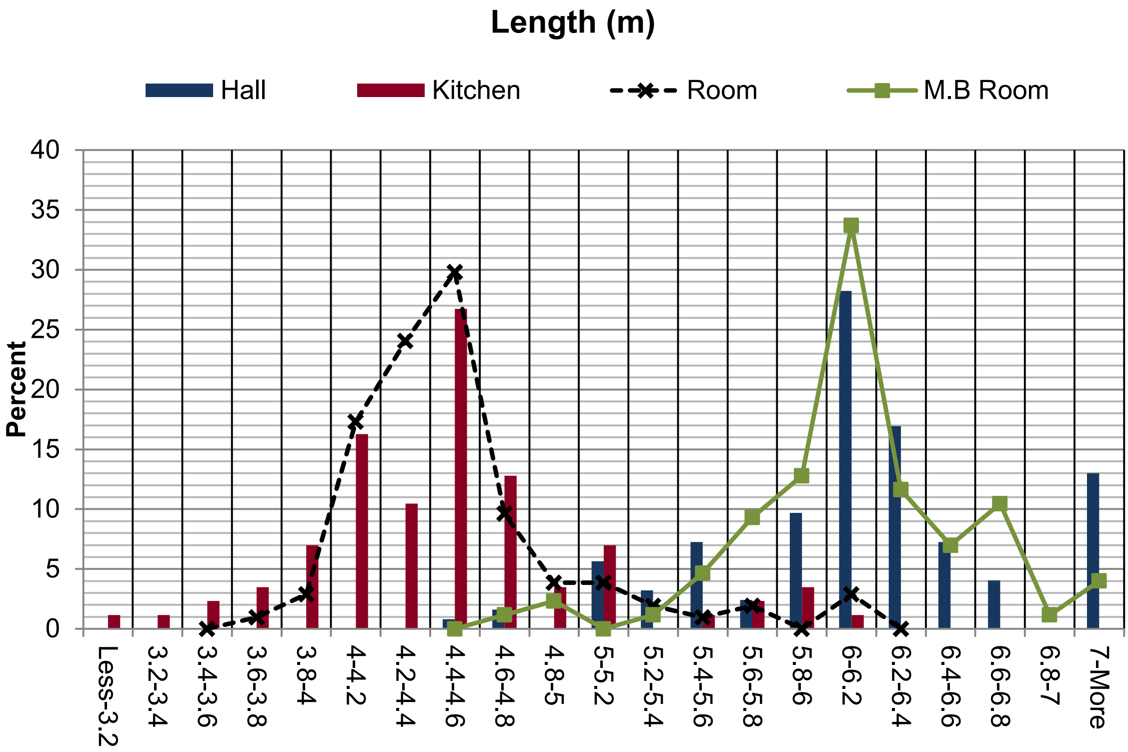


Figure 4-6: Length results

The most common length for the kitchen and the bedroom was between 4.4 meters and 4.6 meters for nearly 25% of the total samples. While the most frequent length in the master-bedroom and the hall in the range between 6 meters and 6.2 meters for approximately 35% and 30% of samples, respectively.

4.3.3.2. Width

The results of the analysis showed that the most frequent width for all spaces excluding the bathroom (Master-bedroom, Bedroom, Hall, and Kitchen) was between 4 to 4.2 meters for nearly 25% 30% of the samples. Figure (4-7) showed all the results of the width of all spaces.

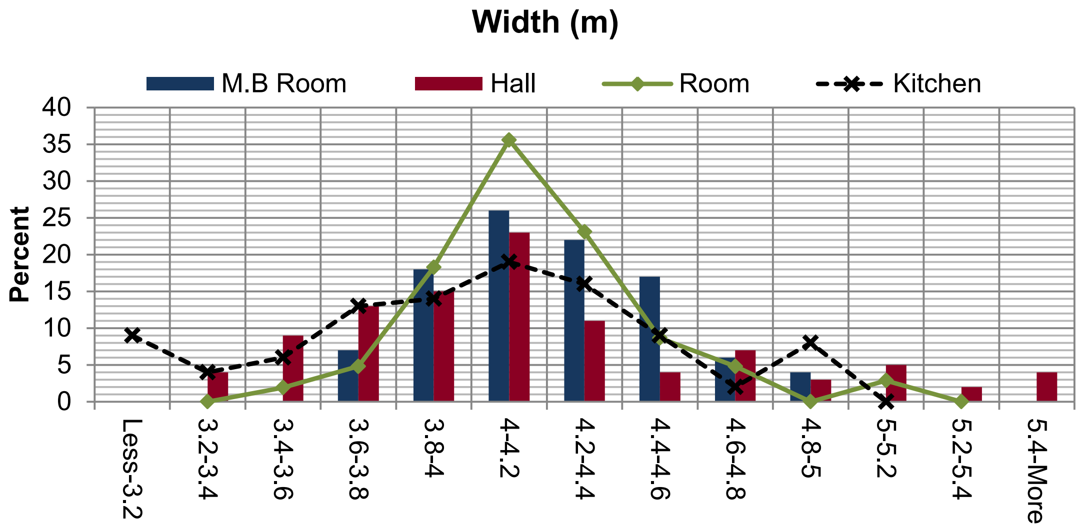


Figure 4-7: Width results

4.3.3.3. Bathrooms

For the bathroom, the results showed that the most common length and width of the bath was in the rage between 2 meters to 2.2 meters for more than 50% of the samples in width and approximately 31% of the samples in length. All the results of this part were illustrated in figure (4-8).

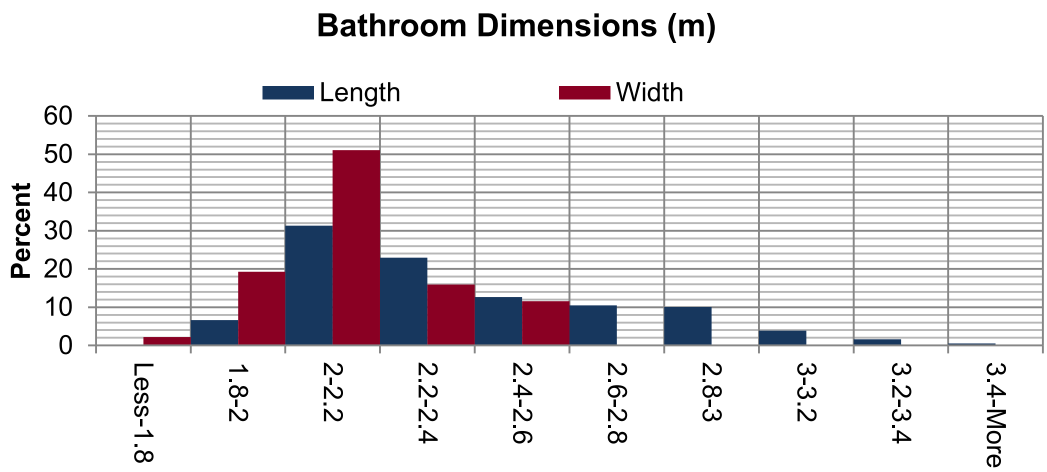


Figure 4-8: Bathroom dimensions results

4.3.3.4. Floor Height

The analysis results of floor heights showed that the height of the floors was varying in narrow range. The height of the floor ranged from 3 meters to 3.3 meters in all projects samples. The most commonly used height is 3 meters, and has been used in more than 60% of samples. Figure (4-9) below, illustrates the results.

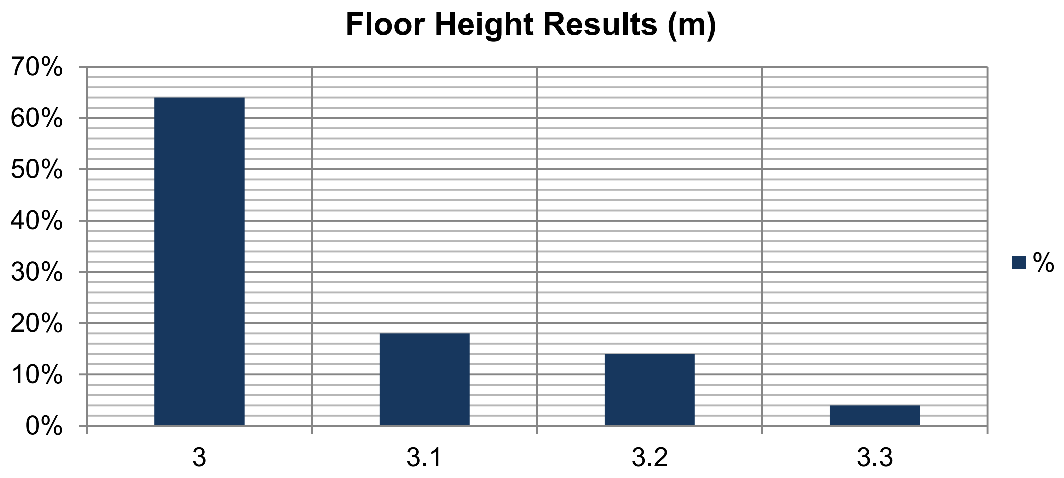


Figure 4-9: Floor height results

4.3.3.5. **Balconies**

The balcony as mentioned before played very important role in the apartments because they are used as an alternative to traditional house courtyards. The analysis showed that the master-bedroom, the bedroom and the hall have balcony attached to these spaces in 92%, 73% and 58% of the cases respectively. The kitchen in 65 of the cases did not have balcony attached to it. As shown in the following table (4-3).

Table 4-3: Balcony in spaces

Space	Balcony	No Balcony
Bedroom	**73%**	27%
M. Bedroom	**92%**	8%
Hall	**58%**	42%
Kitchen	35%	**65%**

After the identification of which space contain balcony and which not, in the following part the balcony with results were illustrated.

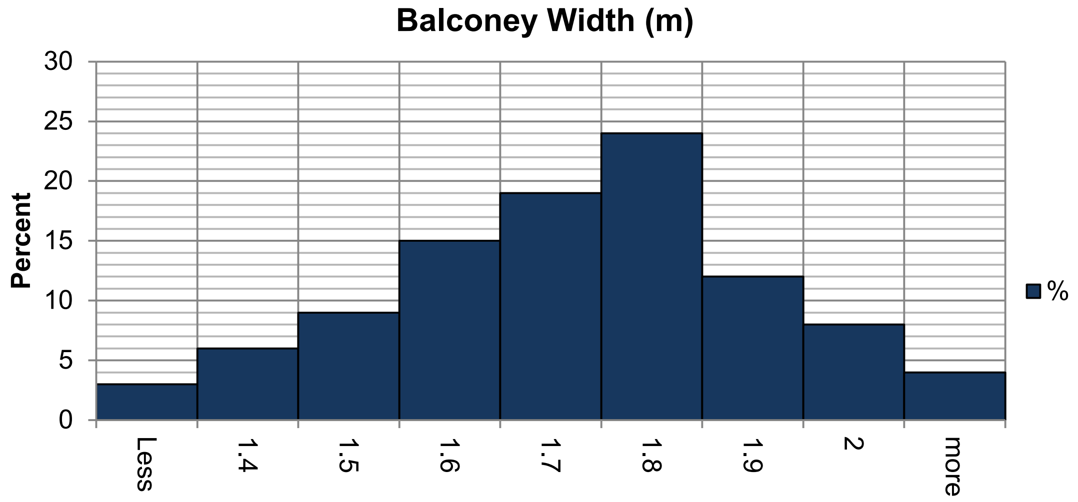


Figure 4-10: Balcony width results

Figure (4-10) above illustrates that, the width of the balcony ranged from less than 1.4 meters to more than 2 meters, but the most frequent width of the balcony registered was 1.8 meters for about 25% of samples.

4.3.4. Construction Materials

The following section shows the results of the building materials survey. The results were divided into the results of the structure, walls, doors, windows

4.3.4.1. Structure

The results showed that the structure was made of reinforced concrete in all the tested samples. Table (4-4) below illustrates all results.

Table 4-4: Structure construction materials

Structures Material	%
Concrete	**100**
Steel	0
Others	0

4.3.4.2. **Walls**

The results of the wall building materials showed that the most commonly used material for the built of walls in these samples was the brick in 56% of the cases. The complete results of this part of the research were illustrated in table (4-5) below.

Table 4-5: Wall construction materials

Walls	%
Brick Wall	56
Hollow Brick	25
C/S Hollow Blocks	19

4.3.4.3. **Doors and Windows**

The most commonly used doors were the wooden doors and have been used in 45% of samples. The full survey results of the door materials were illustrated in the following table (4-6).

Table 4-6: Doors materials

Doors Material	%
Wood	**45**
Aluminum	31
Metal	24

The windows results were divided according to the farm and panel materials. The most commonly used material in the frame was the wood and has been used in 53% of the cases. The panel was double glazed glass in 68% of the cases. The following table (4-7) explains the full results of this survey.

Table 4-7: Windows materials

Windows Material			
Frame	**%**	**Panel**	**%**
Wood	**53**	Single-Glazed	32
Aluminum	29	Double-Glazing	**68**
Metal	18		

4.3.5. Spatial Relations

To study the relationships between spaces, all types of relations between spaces were analyzed in all samples. Only four relationships were found, either that the space is connected to the other space through a wall. Or through wall and door (one space is opened in the other). Or the space is completely open to the other space without any barriers. And the last relationship is that the two spaces are not connected at all. Figure (4-11) shows the types of relationships.

Figure 4-11: Examples of the different spatial relationships

Based on these four relationships, the relationship matrix shown in the following figure (4-12) was designed to register relationships between spaces in projects using the same numbering system for each relationship.

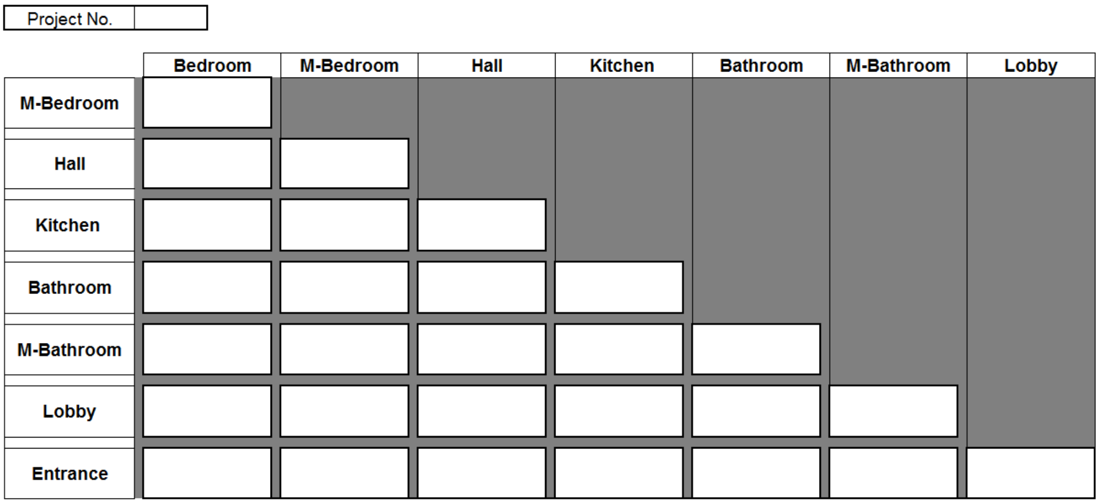


Figure 4-12: Relationship data collection form for each project

By registering all the relations between spaces in all projects using only numbers, the first step was completed. Then, and because every cell had 4 different possible relations, each cell divided into four cells and each cell was addressed for one relation types. Finally all the relations in all projects were collected together to create the matrix in figure (4-13).

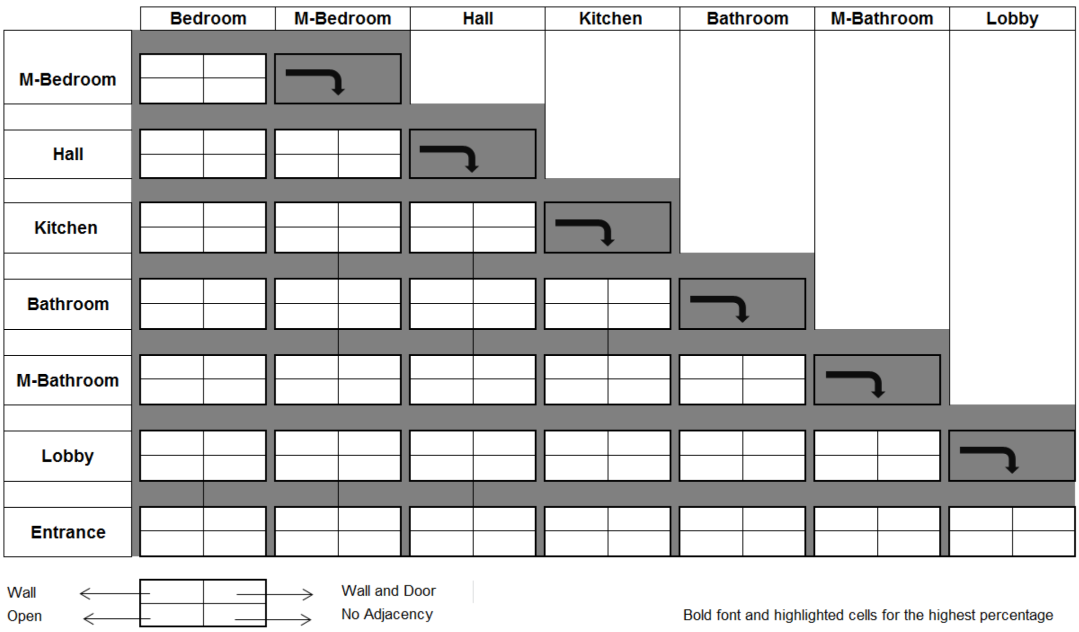


Figure 4-13: All relations in all projects data collection matrix

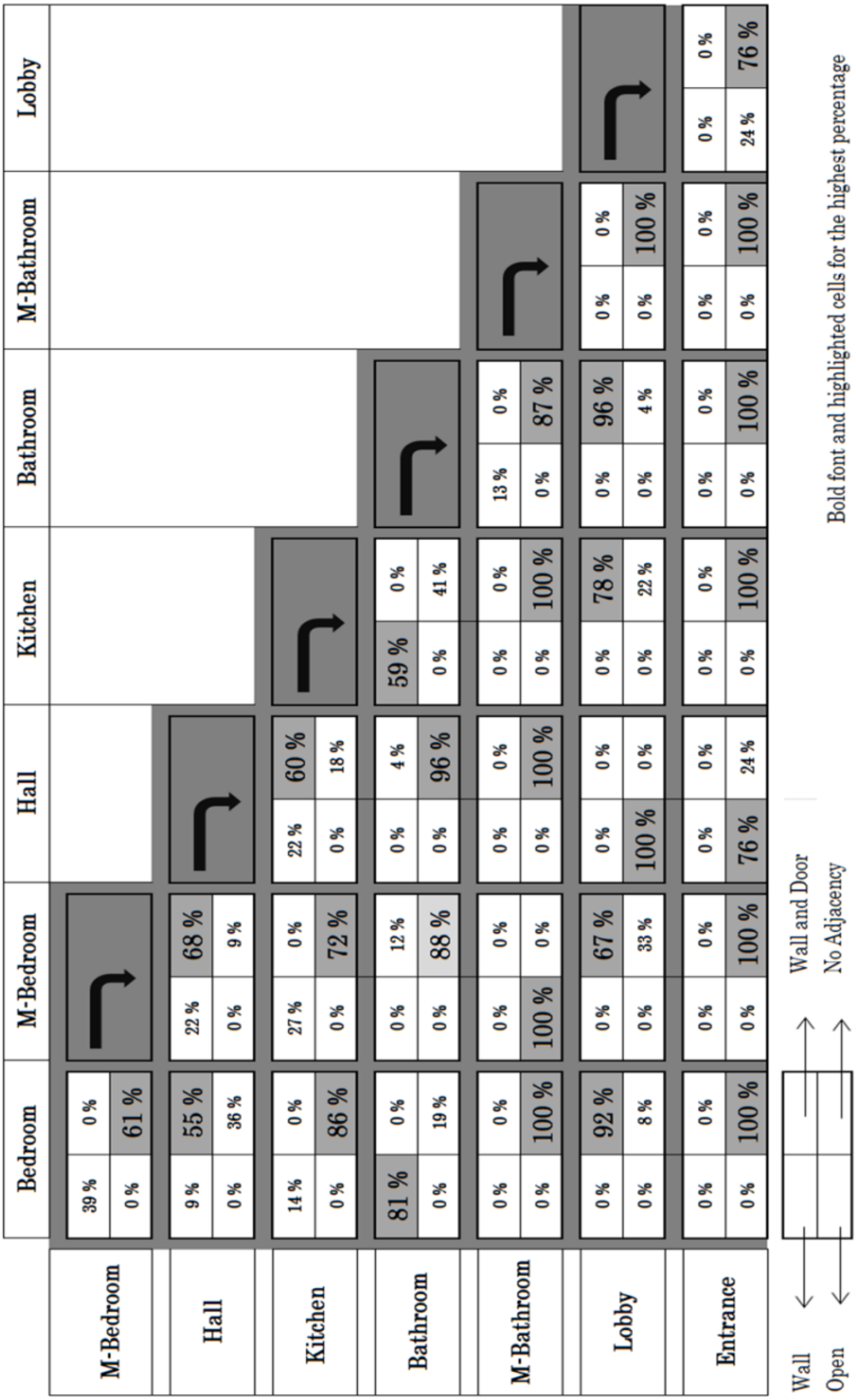


Figure 4-14: Spatial relationship final results

As the mentioned before figure (4-13) shows, this matrix was designed to register the relationships between spaces for all projects as first step towards identifying the most common relationship between spaces. The relations were registered as percentage of total number of projects. For example, the spatial relationship between bedroom and master bedroom are as following in 39% of the total 163 project it found to be a wall separate the two spaces. Furthermore, in 61% of the samples the two spaces are away from one another. While the two spaces never in all projects were opened in one another neither by wall and door nor by just opening.

The results were as follows: The room and the kitchen were always opened in the inner lobby and so was the bathroom in 91%, 77%, and 96% of the samples respectively. While the apartment door opened directly in the hall in 77% of the cases. As expected, the master-bedrooms bathroom was completely isolated from all other spaces. The complete results were illustrated in figure (4-14).

4.3.6. Results Summary and the Model

Based on all previous results, the following model was proposed after using all the most common properties in the apartments, in terms of apartment type, the number of architectural spaces, the dimensions of these spaces, and spatial relations between spaces. Figure (4-15) shows the proposed apartment floor plan showing all the previous results.

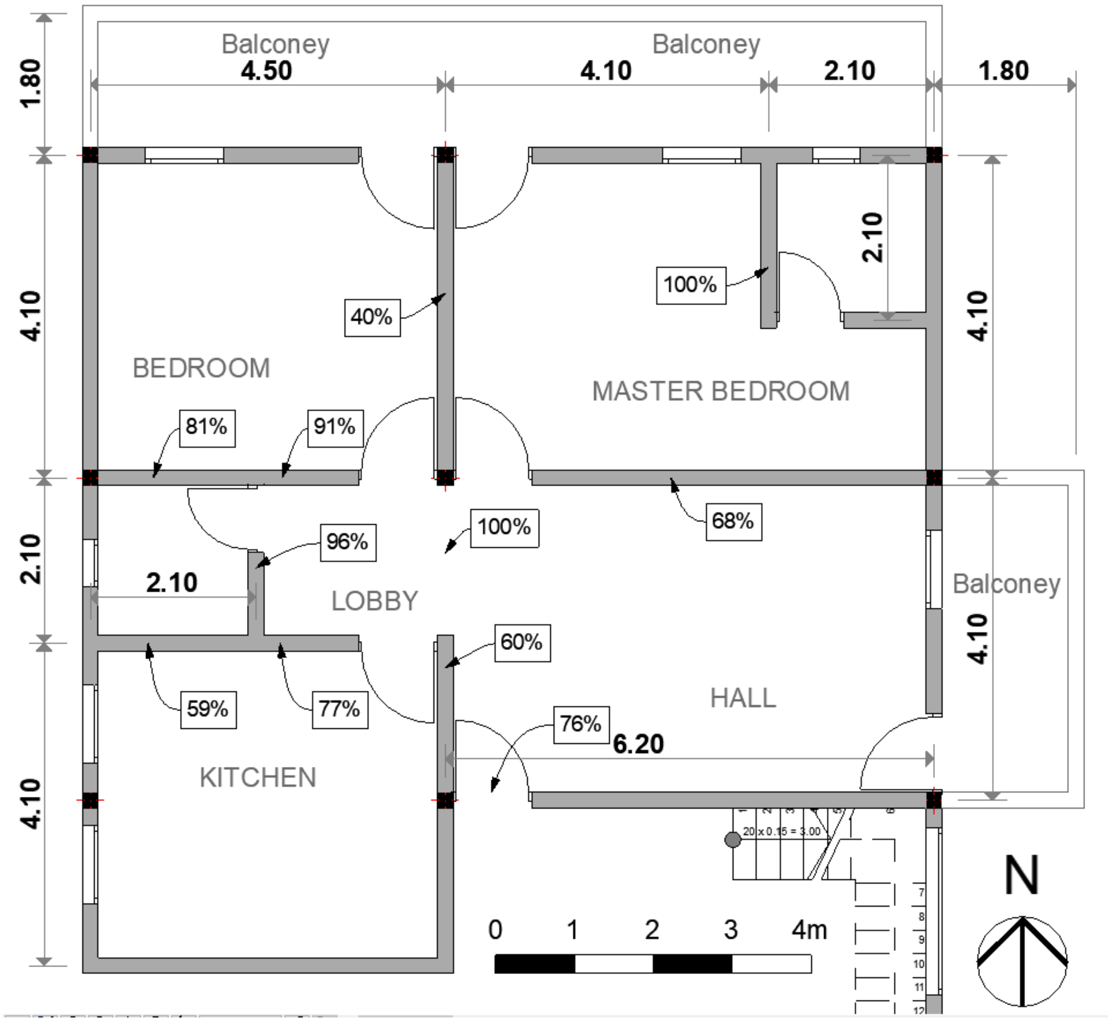
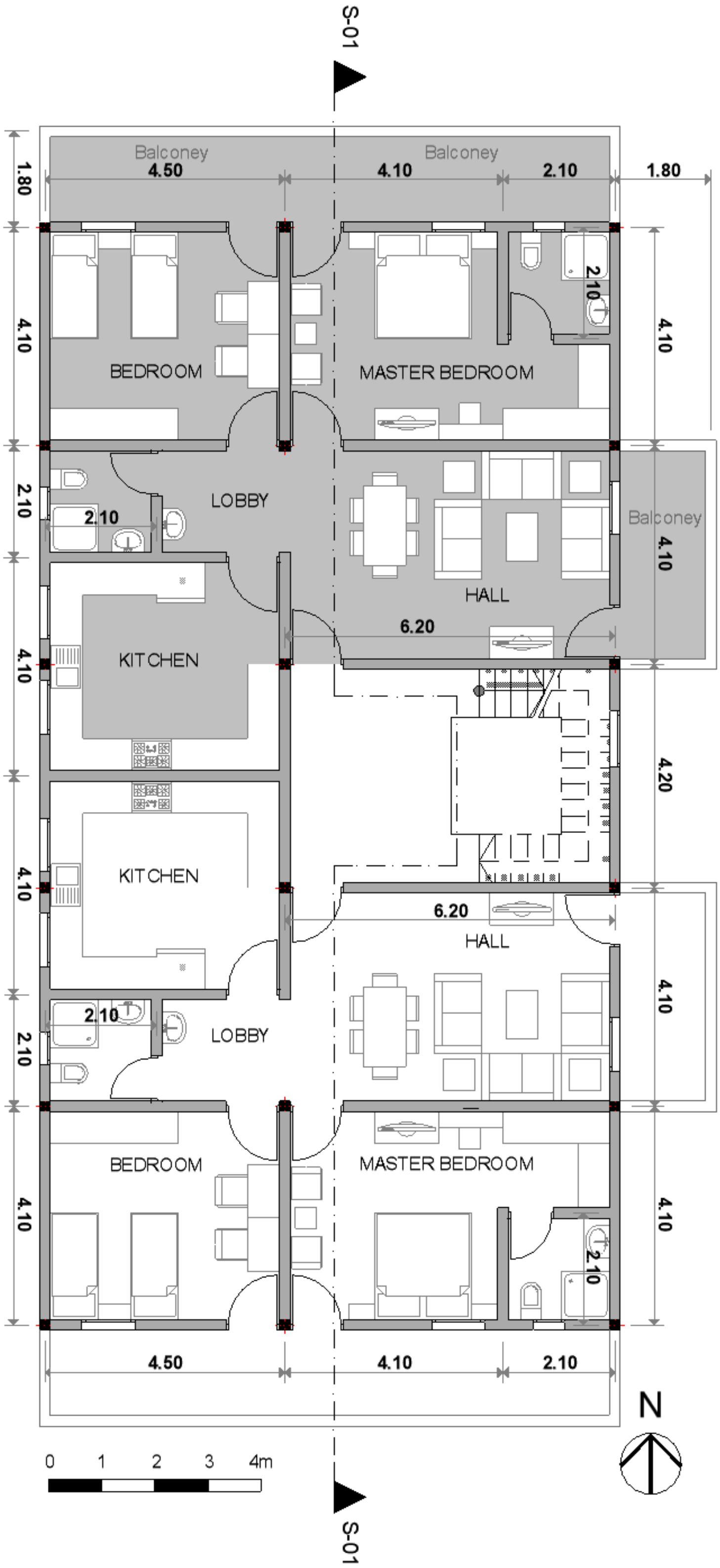


Figure 4-15: The final arrangement of space and the most common relations are highlighted

The following figures (4-16) and (4-17) show the architectural plan and section respectively of the apartment when it is duplicated to create a typical apartment building. The building has been designed to act fully in accordance with all laws in terms of the setback regulations or the spaces minimum dimensions. Moreover, the building was designed to fit in the smallest 1st or 2nd class residential area, which is 25 meters by 20 meters plot.



.

Figure 4-16: Typical floor of apartment building testing model

Figure 4-17: Typical section of apartment building testing model and the most common features are highlighted

The vertical section shown in figure (4-18) below explains the typical construction details of this type of building.

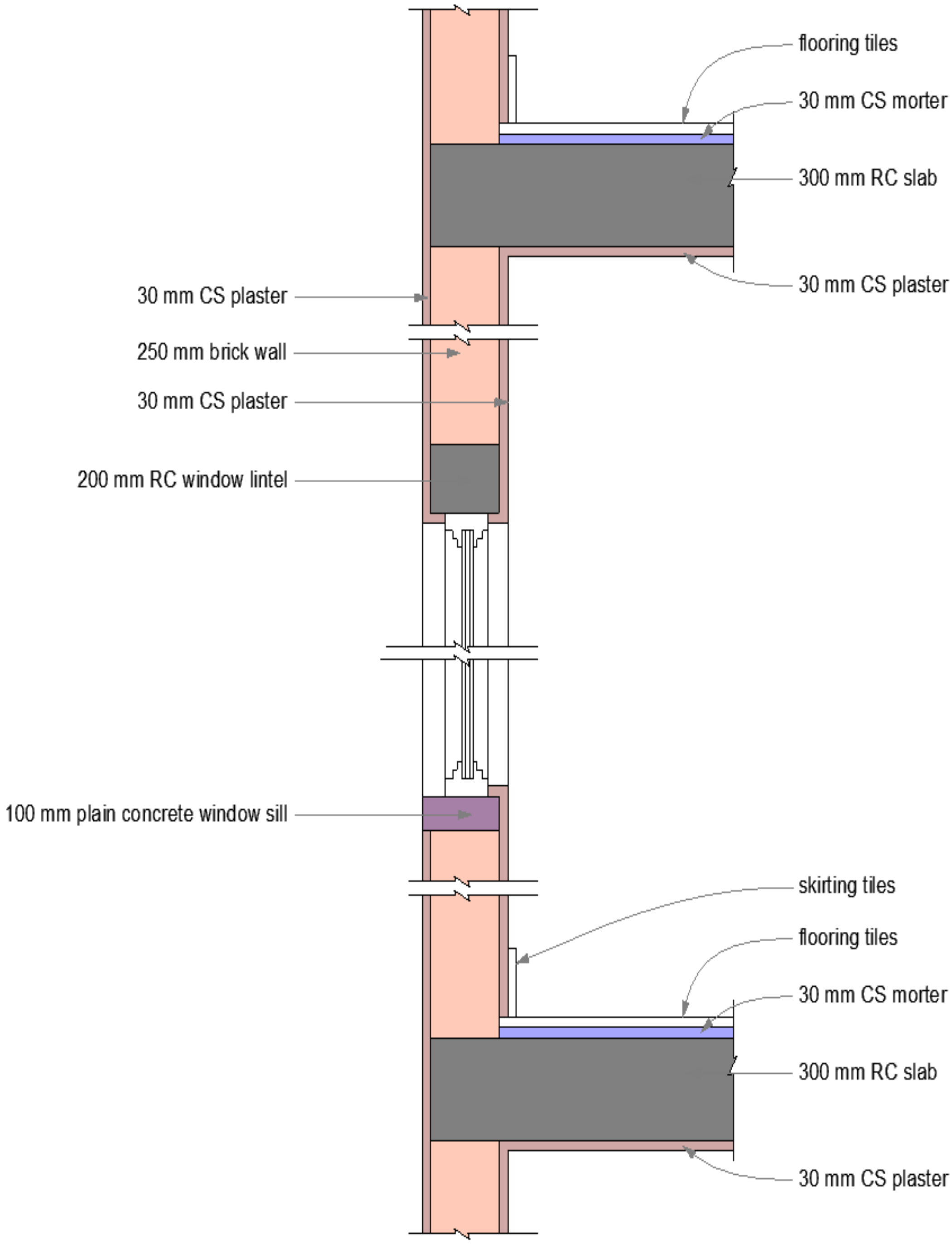


Figure 4-18: Construction details

Figure (4-19) below shows the perspective of the suggested apartments testing model with an illustration of the most common Features.

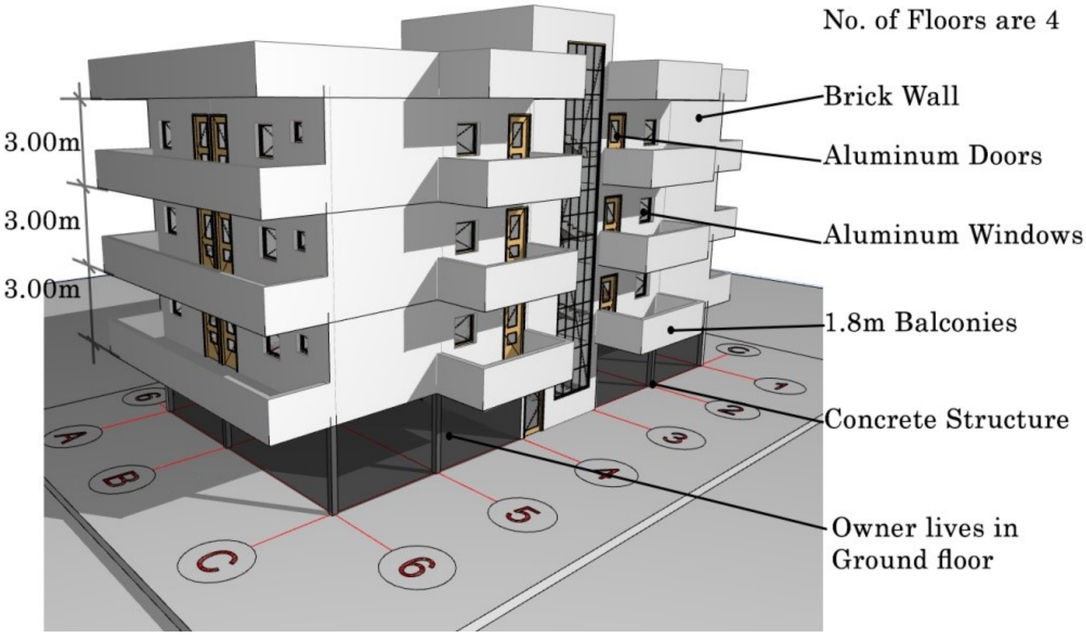


Figure 4-19: Perspective of the model

4.4. Conclusions

- The results of the survey analysis on apartment samples showed that the most common type of apartments was the Two-Bedroom Apartment type.

- The results of the space dimensions survey were as follows: Bedroom was (4.5m × 4.1m), Master Bedroom was (6.2 m × 4.1m), Hall was (6.2 m × 4.1m), Kitchen was (4.5 m × 4.1m) and finally the Bathroom was (2.1 m × 2.1m).

- The survey also showed that structural elements of the buildings (columns, beams, and slabs) were made of reinforced concrete in 100% of the cases.
- And floor height in about 65% of cases was 3 meters.

- A 25-cm-thick brick wall plastered with 3 cm of cement and sand on both sides was used in about 56% of the cases.

- The doors were made of wood in 45% of cases and windows were made of wooden frame and double glazing in 68% of the cases.

Chapter-5

Office Buildings

5-Office Building

The fifth chapter of the thesis was devoted entirely to the office buildings. It has been divided into three sections. The first section was general introduction to office buildings and their importance in Khartoum. In the second part, the research methodology was discussed in detail. In the third section was dedicated to illustrate the results of office building research. The results were presented in four parts. The first part was dedicated to presenting the results of the general layout of the typical floor of the office buildings in Khartoum, followed by the second part which was designed to present the survey results of the typical floor area. In the third part, the results of the typical floor dimensions were presented and discussed in terms of the depth and the height. In the fourth and final part of this section, the survey results of the building materials were presented according to the materials of the main structural elements, the materials used in the sold parts and transparent parts, and finally the doors and windows.

5.1. Introduction

The office buildings have a very significant importance among the other building types. The office buildings energy consumption is very high due to the use of heating, ventilation, and air conditioning (HVAC) systems, high levels for lighting, and the other electric and electronic appliances (Pérez-Lombard et al., 2008). The importance of the office buildings originated from the fact that they contain the headquarters of major companies, banks, telecommunications companies, government offices, headquarters of organizations, etc. for all these reasons, the office building were investigated all over the world in very comprehensive studies to determine its energy consumption and its Carbone-Dioxide foot print (Huang & Franconi, 1999).

Office buildings in Khartoum have not been adequately studied, and studies relating to office buildings are very few. Some of these studies have taken one office building as sample to conduct some simulation study on thermal comfort in office buildings (Mohamed & Abdalla, 2010). Also there are some studies that documented examples of office buildings as part of the documentation for the influential architect Abdel Moneim Mustafa (Omer S. Osman, , Amira O. S. Osman, 2011). Nevertheless, the structural studies on tall buildings are (office building) available (E. M. A. Ahmed, Osman, & Ali, 2016). However, this study was concentrating mainly on his architectural style, and did not provide any data that can help to understand the general features of the office buildings in Khartoum.

In Khartoum these buildings are geographically concentrated in the cities center. In Khartoum there are three types of these buildings.

The first type is residential buildings that were not designed to be office buildings, but have been transformed in response to the challenges of changes in city center over time. Over time the city center has acquired commercial and investment importance. Land prices and rents are rising, the number of workers in the city center is increasing, traffic is increasing, crime rates are raising, and the living environment is polluted with the high levels of population and noise. All these factors force the people to immigrate to the sub-urban areas. Then, these residential buildings were converted to serve as office buildings.

The second type of office building is a multi-purpose building. It is always built so that the lower floors were been used in commercial activities and the upper floors are designed for offices (Abdin, 2013).

The third type is a prober office buildings and this type is originally designed to be the company headquarters, banks, or just offices for rent.

This research will focus on the second and third types, multi-use buildings and office buildings, because they were originally designed to serve this purpose. Figure (5-1) illustrates examples of office buildings in Khartoum.

Figure 5-1: Examples of office building in Khartoum

The office buildings in Khartoum have special rules to have official permission for the construction work. As general planning regulations, the total floor areas of all floors must not be less than the total area of the plot. In addition, the car parking also have special regulation must be met for the design to have the official permission. In case the number of floors of the building exceeds six floors, a special design is required for fire protection and the emergency staircases and exits. The building also needs special permission for the structural design.

This research will give a clear picture of the office buildings and the parts that must be developed to increase their energy efficiency and also to reduce their production of carbon dioxide. Also, there are a lot of office buildings in Khartoum have been over 25 years, and in the near future they will need to be rehabilitated, and it is necessary to think in advance in the laws to insure the optimum environmental performances of these buildings. Moreover, this research will provide the decision makers detailed standard testing model for this building type to test any suggested modifications and examine their results on the building level or in the city level before making these decisions.

5.2. Methodology

To understand and identify the most common features in the office buildings in Khartoum and to create a standard model, factors that influence the design of this type of buildings were studied comprehensively, these factors were the legal factors, social, cultural and technical factors.

After that, samples were collected for the survey. The diversity of these samples was prerequisite to insure that the research covered all possibilities. Diversity in the buildings age, size, and types was taken into consideration.

Basic information about buildings was collected by direct survey for the buildings or by the questioning maintenance department in each building for the required information. A special form designed mainly for this reason was used to collect this information.

The general layout of the typical floor in terms of the core location on the floor was the first collected information. After the core layouts were categorized into two scenarios, the central core and the end core.

Using the same form, the basic information was collected about the typical floor dimensions. The surveyed characteristics were the area, the depth, and the height of the typical floor.

There was special form for the building materials used to survey the materials of the structural elements, the solid parts and transparent parts, and finally the basic information about the doors and windows.

In Microsoft Excel, all of the data was inputted, analyzed and displayed in graphs and tables that identify the most common features in office buildings.

Using the results of the previous, the standard testing model for the office buildings in Khartoum was created using ArchiCAD program for the architectural presentation.

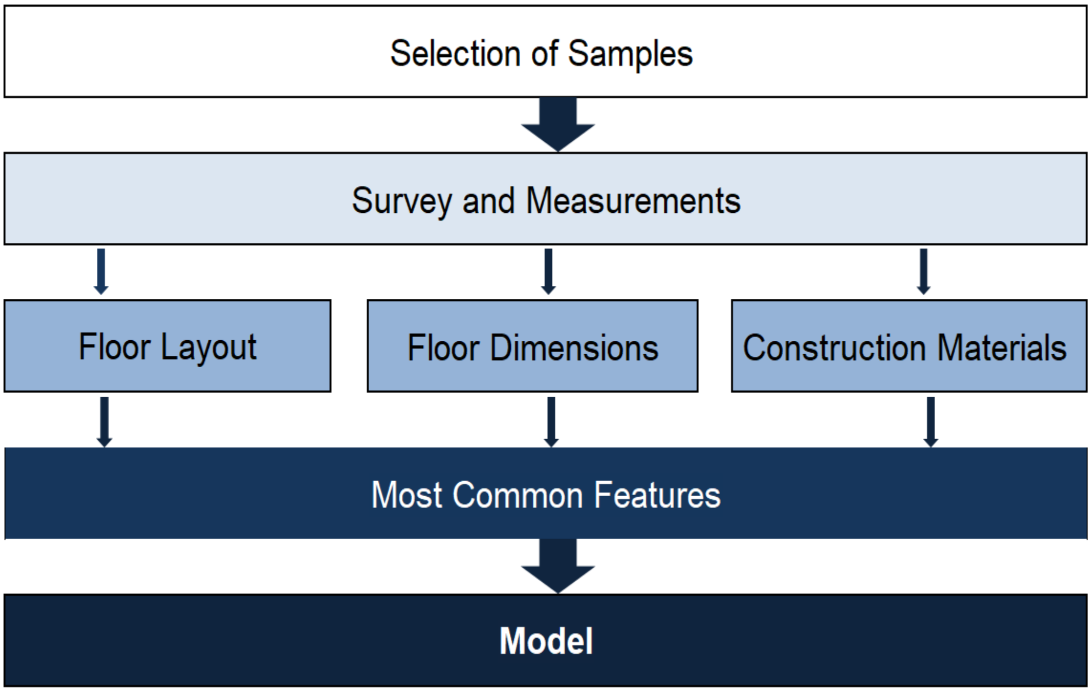


Figure 5-2: Methodology working diagram of the office buildings

5.3. The results

5.3.1. Samples Selection

The office buildings were selected in the Central Business District (CBD) of Khartoum to be the samples for this research. This selection was made due to the wide diversity of office buildings and their widespread presence in the CBD. In the center there is a great diversity of office buildings in terms of the architectural styles, Building sizes, and the building ages. There are buildings constructed in the seventies of the last century and there are buildings that have been completed in the last two years. There are also buildings designed to be fully office building and there are multi-purpose buildings, where the lower floors are used in commercial activities, while the upper floors were designed to be rent as offices. The buildings that are more than 6 stories high have been chosen to meet all the legal requirements specified by the laws to insure that the samples are truly reflects the real characteristics of office buildings in Khartoum.

A total of 146 office buildings have been selected including headquarters of telecommunications companies, banks, and investment office buildings. Then these 146 office building were surveyed. The survey was conducted on February of 2017 by two assistances. The program of work has been prepared so that researchers have an hour to access the maintenance department in each building and collect the required information using the form (3) attached in the appendences. The survey was expected to take about 14 working days, but what has been done on the ground was that the researchers have collected all the information in 10 working days only. This survey took place from Sunday (12 February) to Thursday (23 February). All the required information was taken directly from the maintenance department in the buildings and in few cases direct measurements were taken.

The attached map in figure (5-3) shows the geographical area of these buildings. And figure (5-4) shows the selected office buildings in that area.

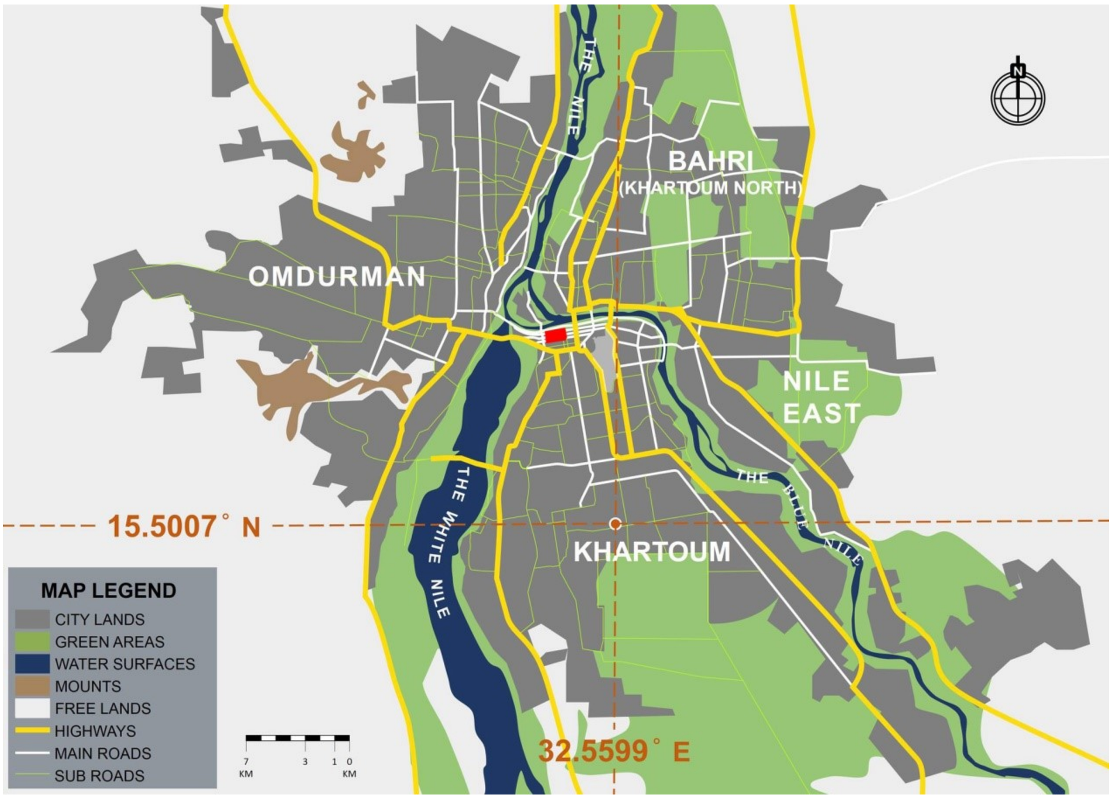


Figure 5-3: Location of the selected area (CBD of Khartoum)

Figure 5-4: Google satellite image and the sample buildings are highlighted

5.3.2. Layout Results

After the selection of the area, the samples of the buildings were selected. Then the all the samples were surveyed searching for the most common features in office buildings in Khartoum. The results showed that the general layout of the typical floor showed that, central core layout was the most common layouts and it have been used in 98% of the cases. Figure (5-5) illustrates the classifications of the core location that used in this study.

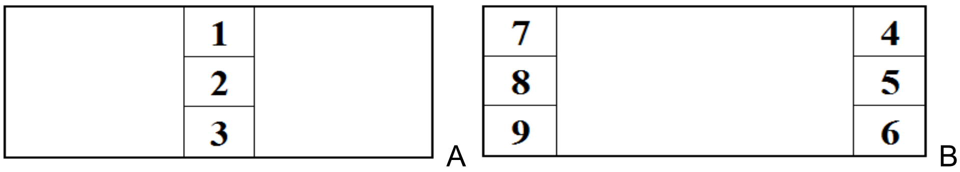


Figure 5-5: Core layouts (A) cases are central core layout, (B) cases are the end core cases

5.3.3. Dimensions Results

For the dimensions of the repeated floor, the results were categorized into three groups. The first group was for the area, the second group was dedicated to the floor depth, and the final group was to illustrate the results of the floor height.

5.3.3.1. Typical Floor Area

For the first group, the following diagram shows the full monitoring of the floor area in all the studied samples. The results were illustrated in figure (5-6).

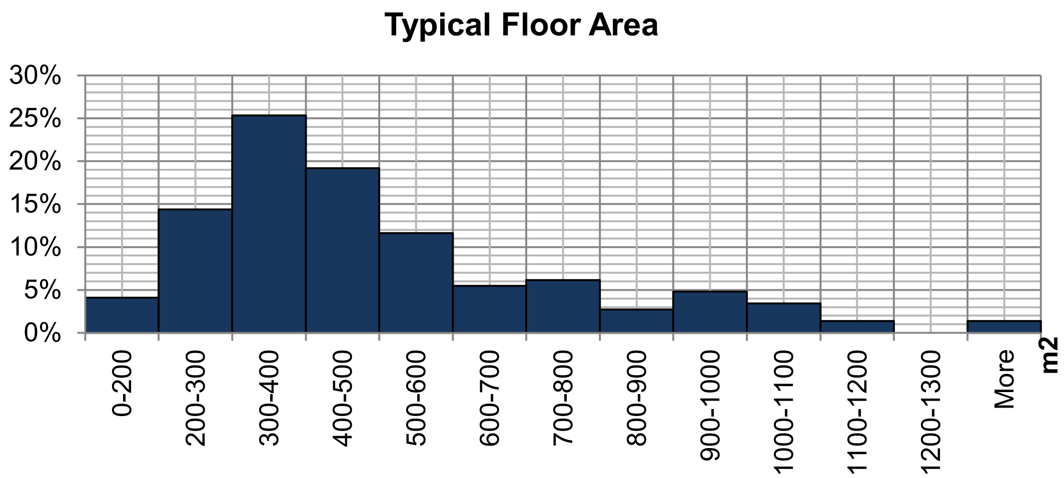


Figure 5-6: Floor area results

The floor area ranged from 200 square meters or less to more than 1,300 square meters. And that was very large range. However, more than 65% of the projects were located in a range from 200 square meters to 500 square meters. The most frequent area was the area between 300 square meters to 400 square meters and this area range was used in more than 25% of the surveyed buildings.

5.3.3.2. **Typical Floor Depth**

The following figure (5-7) shows the analysis results of the typical floor depth in all samples. The depth as the area was also varied in large range from 10 meters to more than 30 meters. However, same as the area, about 51% of the samples floor depth was in the range between 12 meters and 18 meters.

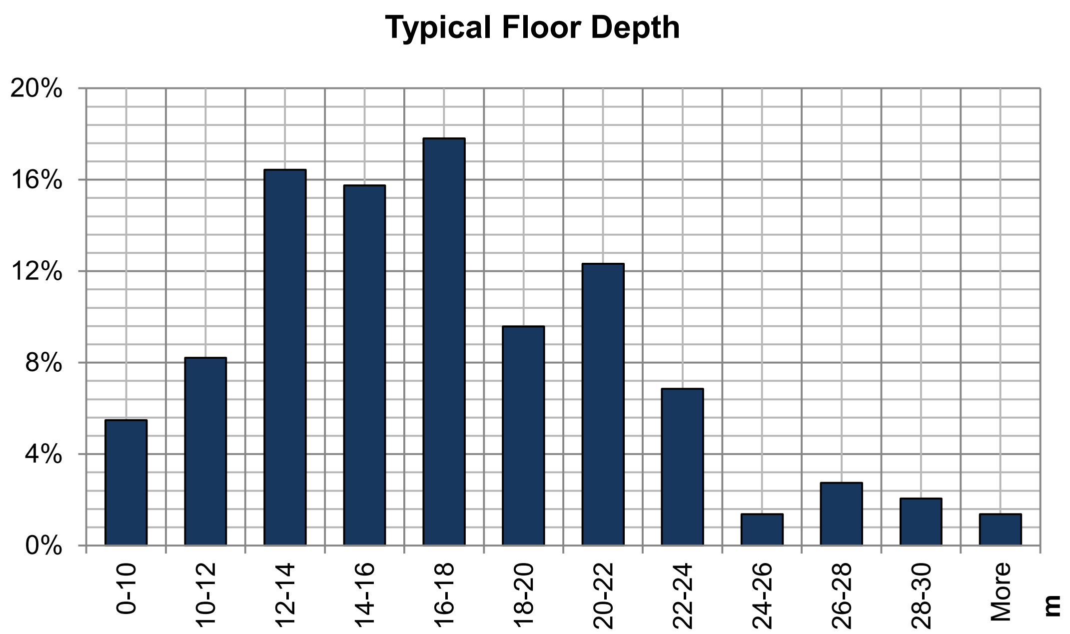


Figure 5-7: Floor depth results

The most frequent depth was found to be in the range from 16 meters to 18 meters and this width was used in about 18% pf the surveyed samples.

5.3.3.3. Typical Floor Height

Analysis of floor height showed that the most common used height was in the range between 3.4 meters to 3.6 meters. In general the heights were limited from 3.2 meters to 4.2 meters. The complete results were illustrated in figure (5-8) below.

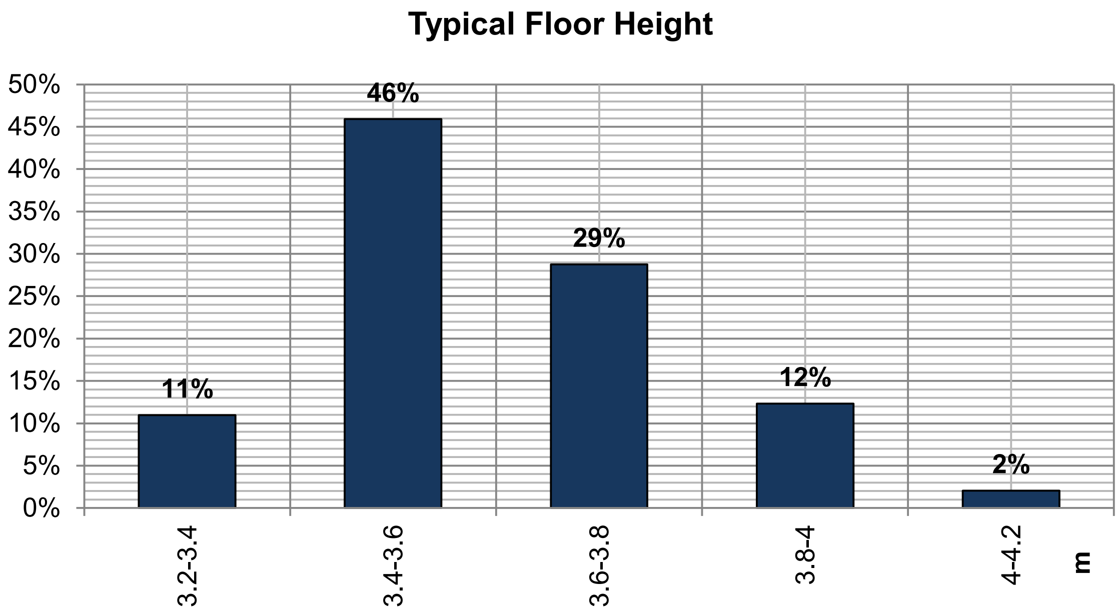


Figure 5-8: Floor height results

5.3.4. Construction Materials

This part of the research was divided to four parts. The first part was used to illustrate the results of the structures materials. Then followed by the second part which was dedicated to illustrate the results of the solid walls of the office buildings and the results of the transparent parts materials were illustrated in the third part. Finally the results of the doors and windows materials were discussed in the final part

5.3.4.1. Structure

Analysis results of the main structure's building materials showed that the structure of the office buildings was always made of reinforced concrete in 100% of the cases. Figure (5-9) below shows the results.

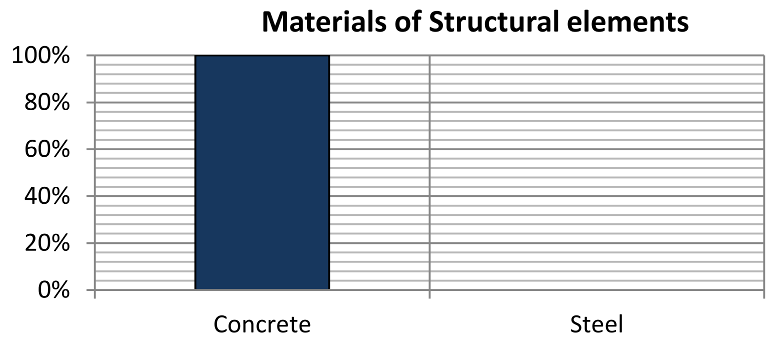


Figure 5-9: Structural elements construction materials results

5.3.4.2. Solid Parts

The walls of the building were classified to a solid parts and transparent part, the solid parts are the walls, and the transparent parts are either the windows or the curtain walls. The first survey was made to identify which is the most frequently used system, and then the materials of each one were surveyed.

For the first part, the results showed that in the solid parts of the office buildings mainly four building materials were used, brick, cement and sand hollow blocks and cladding (either aluminum or precast concrete). And the walls were made of bricks in about 40% of the cases. As shown in the figure (5-10) below.

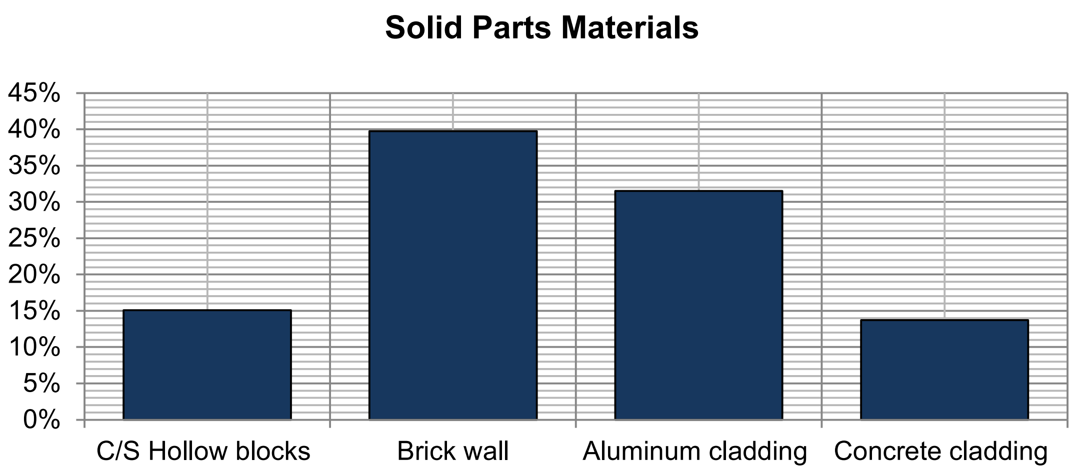


Figure 5-10: Solid parts construction materials results

It is noted that the materials used for construction were limited and the variety was very limited in the construction materials.

5.3.4.3. Transparent Parts

For the transparent parts, the analysis of the transparent parts of the buildings showed that these parts were aluminum and double-glazed panels curtain walls in 65% compared to 35% when these transparent parts were windows in the walls. The complete results illustrated in figure (5-11) below.

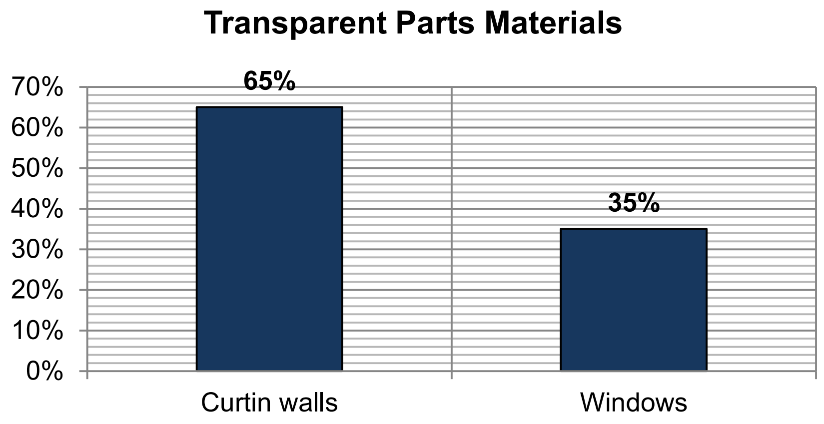


Figure 5-11: Transparent parts construction materials results

5.3.4.4. Doors and windows

The doors and windows questionnaire explained in the table (5-1) below shows that the outer doors of these samples were all made of aluminum and the double-glazed panels and protected by an external metal bars. The interior doors in 56% of the cases were made of aluminum frame and the panels were plywood and glass.

Table 5-1: Doors and windows material results

	Doors		Windows
	Exterior	Interior	
Materials	Aluminum/ Double glazing Doors with Steel protection bars	Aluminum doors/ plywood and glass panel	Aluminum/ Double glazing windows
Percentage	100%	56%	100%

The windows in all samples were aluminum double glazed windows. The complete results were illustrated in the previously mentioned table (5-1).

5.3.5. Results Summary

After identifying all the most common features in the office buildings, these characteristics were used to create the standard model of office buildings in Khartoum. And the final design was presented with the aid of the ArchiCAD program. The most common features of the office buildings in Khartoum were illustrated on the following figures (5-12), (5-13), and (5-14) which showed the plan, section and perspective of the final model respectively.

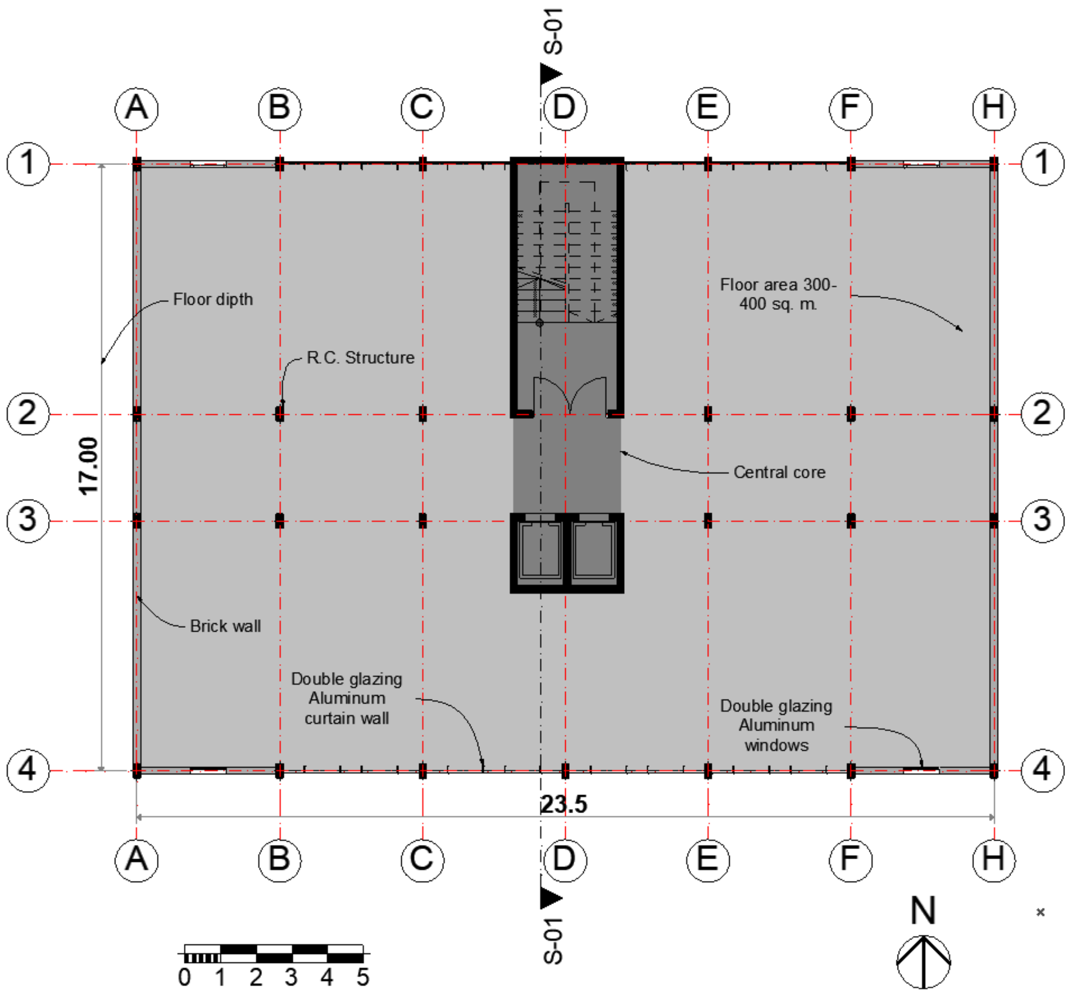


Figure 5-12: Plan of the office building testing model and the most common features are highlighted

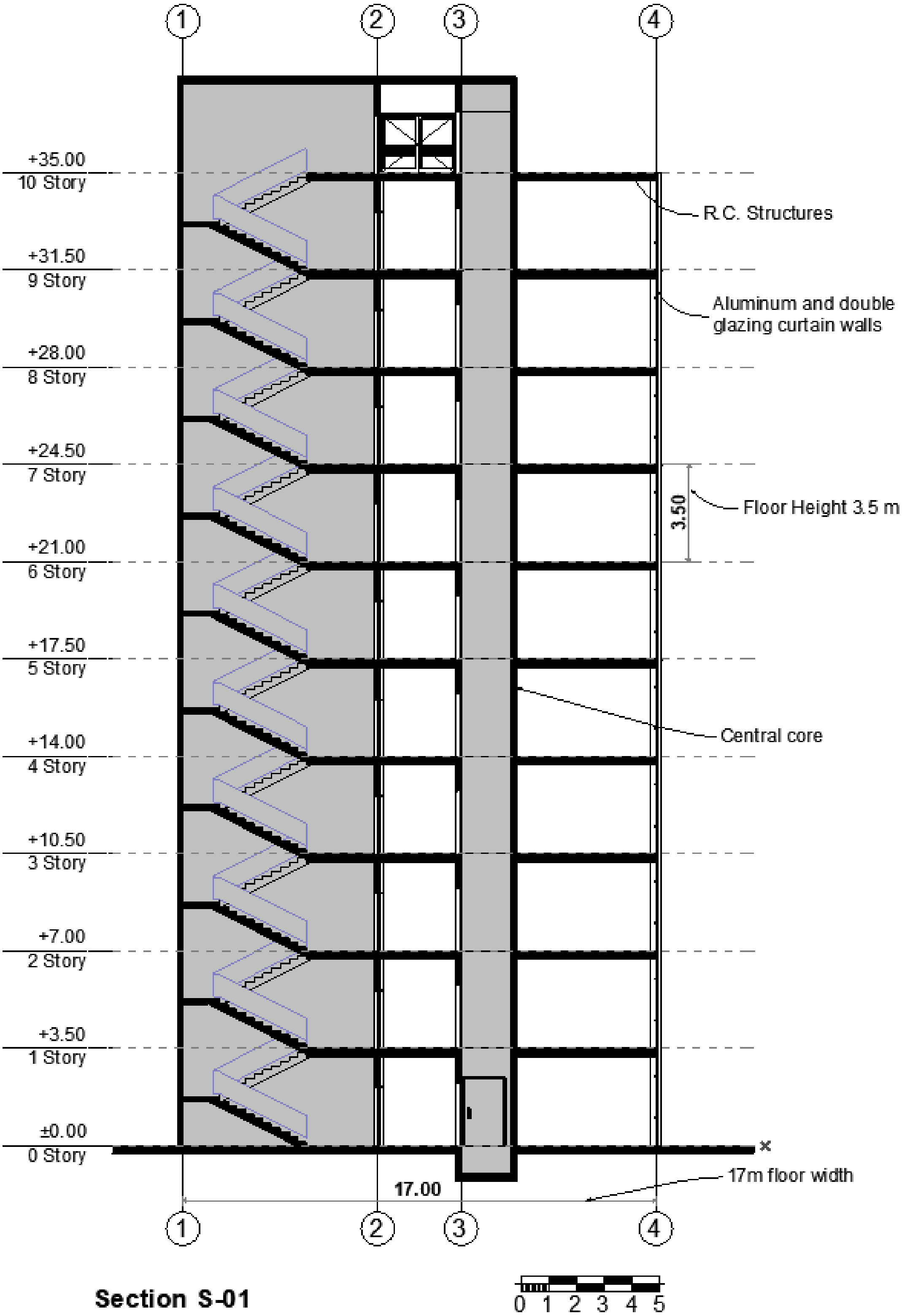


Figure 5-13: Section of the office building testing model and the most common features are highlighted

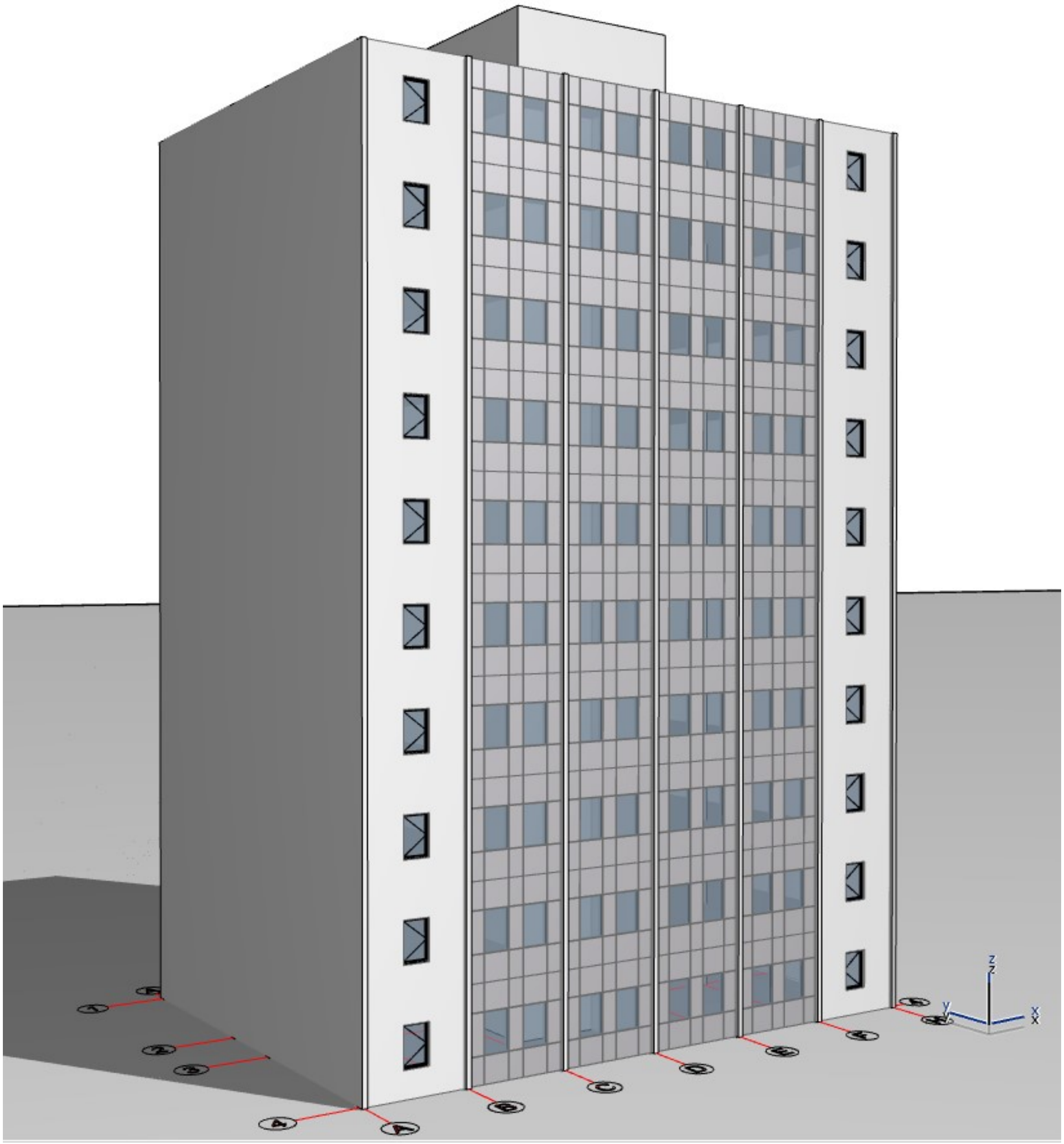


Figure 5-14: Perspective of the office building testing model

5.4. Conclusions

- The results of the office buildings showed that the general layout of the building was the one in which the core of the building (stairs, lifts, and services) was located in the center of the building in about 98% of the cases.

- The survey showed that the common floor area was between 300-400 m^2, the width of the floor was 17 m, and the floor height was 3.5 meters for about 25%, 18%, and 47% of tested samples, respectively.

- For building materials, reinforced concrete was used in 100% of the cases to create the structure of the building.

- The walls in about 40% of the cases were 25-cm-thick brick walls treated on both sides with cement and sand plaster and then coated with 3 layers of paint.

- The transparent walls are curtain walls made of aluminum and double glass in 65% of the cases. The windows were made of Aluminum and double glazing in 100% of the cases.

- For doors and windows, the external door, on one hand, was made of aluminum frame and double glazing panels protected by exterior steel bars in 100% 0f the tested samples, and on the other hand, the interior door was made of aluminum frame and the panels was made of plywood and glass in 56% of the cases.

Chapter-6

Summary, Recommendations and future studies

6.1. Summary

The aim of this research is to create standard testing models for buildings that consume most of the energy in Khartoum. Additionally, this research aims to throw light on the most common features of these building types and discuss them in depth. As the statistics showed that the residential buildings and the office buildings consume the vast majority of energy in Khartoum and they consume approximately 52% and 18% respectively of total energy consumed by all buildings in Khartoum as in 2016 estimations. Therefore, these building types are the main fuscous of this research.

The importance of this research is illustrated by the fact that it bridges the wide gap in the basic information about the buildings types in Khartoum. This basic information is fundamental and crucial for any proposals to improve the performance or to develop new technologies in these buildings types. Not only that, but also there are no studies at all about building types in Khartoum, which makes this research crucial and very importance for any future researches or future development for the building types in Khartoum.

In order to achieve this aim, it was necessary to study the buildings types in Khartoum and determine the general factors that affect them such as environmental factor, cultural factor, social factor, legal and technical factors (such as construction materials, adapted technologies, etc.). Moreover, it is also necessary to survey samples of each building types and analyze the results of these surveys. Then use the results of this analysis in order to identify the most common characteristics in each building type. Then use these common features in the light of the general factors that affect each building type to create the standard model of that building type.

Standard testing model for a building type is a model consists of the most common features for that building type. These standard testing models are used in the fields of environmental performance, sustainability research, energy consumption, indoor thermal comfort, building materials development, national building stock energy consumption prediction, building stocks strategic development plans, etc. There are many examples of the standard testing models all over world especially for residential buildings due to its regularity and the Japanese detached house standard testing model is one of them. Moreover, the European union devoted huge efforts to collect, analyze, and create standard testing models for residential buildings in about 21 European countries including UK. Since these models were created they have been used in many researches in different fields which illustrate the importance of the standard testing models for building types.

Since there are three building types studied in this research, three different research methodologies have been used and each one of them was designed carefully to suit the target building type. The detailed methodology of each building type was presented in the dedicated parts of each tested building type.

For the first type of the tested building type which was the single-floor house, Google high-resolution satellite images were used to study the general layout patterns of the single floor house spaces. Three partial neighborhood samples, one in each city of the three cities of greater Khartoum, were selected. Each sample contained about 350 houses. In addition to one complete neighborhood was selected from one of the oldest third class residential areas to test various house patterns. It contained about 15000 houses. Then form the complete neighborhood, 100 random house samples were selected to survey the dimensions of spaces, construction materials, and the doors and windows. This information was then used to create the standard model for this type of building.

The results of single floor house study showed that the uniform pattern is applied in about 40% of tested samples in the satellite images. In addition, after analyzing the results of the survey and inspection of the selected samples of the houses that were built according to the uniform pattern, the results showed that the most common dimensions (height, width and height) of the spaces are as follows: Room is (4.4m × 4.2m × 3.8m), Hall is (5.7m × 3m × 3.2m), Saloon is (7.4m × 3.2m × 3.8m), the kitchen is (4.4m × 4.2m × 3.8m), and finally the bathroom is (2.2 × 2.2m × 3.2m). The survey of building materials showed that the most commonly used material in the wall is 35 cm of brick (one and half brick wall), which is plastered on both sides with 3 cm of cement and sand plaster in 88% of the studied cases. The roof is made of I section steel beam that used to carry wooden beams, overlaying mats of the cane and was filled with 5-10 cm of soil, and the external surface was treated with layers of mud. This type of roof is used in 38% of the studied cases. As for the doors and windows, the doors are made of steel and are manufactured in local workshops in 76% of the tested samples. Windows are made of steel frame and glass panels with external steel protection bars in 82% of the cases.

For the second building type which was the residential apartments, the methodology of the research was based on the analysis of samples of apartment designs after they were collected from architects, companies and individuals to identify the most common features. Total number of 85 project which contained 163 different apartment designs were collected form 4 companies, 23 architects, and 24 owner. These samples were analyzed searching for the most common features. Then these features were used to create the standard testing model for this building type. This methodology was adopted due to the spreading of this building type all over the city and between other building types which made surveying them directly is difficult and costly.

The results of the survey analysis on apartment samples showed that the most common type of apartments is the Two-Bedroom Apartment type. The results of the space dimensions survey showed that, the most common dimensions of each space are as follows: Bedroom is (4.5m × 4.1 m), Master Bedroom is (6.2 m × 4.1 m), Hall is (6.2 m × 4.1 m), Kitchen is (4.5 m × 4.1 m) and finally the Bathroom is (2.1 m × 2.1

m). The floor height is 3 m in about 64% of the cases. The survey also showed that structural elements of the buildings (columns, beams, and slabs) are made of reinforced concrete in 100% of the cases. And the floor height is 3 meters in 64% of cases. Moreover, a 25-cm-thick brick wall treated with 3 cm of cement and sand plaster on both sides is used in about 56% of the cases. The doors are made of wood in 45% of cases and windows are made of wooden frame and double glazing in 68% of the cases.

As for the office buildings, office buildings that are more than 6 floors high were inspected and surveyed in the Central Business District (CBD) of Khartoum. The (CBD) of Khartoum was chosen as it combines all kinds of office buildings from all historical ears, form the very old buildings, to the building which were constructed in the last two years. Buildings that are more than 6 floors high were chosen because the number of floors is the main difference between commercial buildings and office buildings according to planning laws in Khartoum. The total number of the inspected and surveyed samples was 146 samples of office buildings. The inspection was carried out by testing the buildings dimensions, space layouts, building materials, and the doors and the windows and when it was not possible to identify the materials, the maintenance department in that building was requested to provide the researcher with the required information. After analyzing the results of this survey and selecting the most common features in office buildings, these features were used to create the standard model of office buildings.

The results of the office buildings showed that the general layout of the building is the one in which the core of the building (stairs, lifts, and services) was located in the center of the building in about 98% of the cases. The survey showed that the common floor area is between 300-400 m^2, the width of the floor is 17 m, and the floor height is 3.5 meters for about 25%, 18%, and 47% of tested samples, respectively. For building materials, reinforced concrete is used in 100% of the cases to create the structure of the building. The walls in 36% of the cases are 25-cm-thick brick walls treated on both sides with cement and sand plaster and then coated with 3 layers of paint. The transparent walls are curtain walls made of aluminum and double glass in 65% of the cases. For doors and windows, the external door, on one hand, is made of aluminum frame and double glazing panels protected by exterior steel bars in 100% of the tested samples, and on the other hand, the interior door is made of aluminum frame and the panels was made of plywood and glass in 56% of the cases. Finally the windows are double glazing aluminum windows in 100% of the surveyed samples.

6.2. Recommendations and future studies

This research has opened great horizons to develop general classification of all buildings in Khartoum, that classification and building typology will have the required precision in such standard models. And that will provide researchers and decision makers with greater knowledge about the building types in Khartoum.

The single-floor houses are one of the most important types of buildings in Khartoum due to their wide spread and they are inhabited by the vast majority of Khartoum residents. This research covered the most common pattern among them, so in the future the other patterns should be studied and modeled scientifically.

The final suggested model for the single-floor houses has been shown from the observations that it represents the nucleus of all large houses for extended families and that model is expanded by adding additional spaces to this nucleus such as rooms, halls, and bathroom. In the future, these spaces can be carefully studied to develop standard models for the development of this type of building.

In residential apartments, there is a new trend led by the large real estate companies to invest in this type of building. These new projects were constructed in large areas and using architectural designs that were different from the designs of the small residential plots. Therefore, in the future, these buildings should be studied comprehensively to create a standard model for them because the researches showed the growing market for these types of buildings.

The results of the office buildings in Khartoum showed that there was huge range in the floor areas and the floor depth (building size). Therefore, the office buildings should be divided according to its age to old buildings, medium-age buildings and new buildings and according to its size to small, medium and large buildings. This classification will create a matrix consists of nine boxes to cover all possibilities of the office buildings in Khartoum.

After the completion of these standard models, wide horizons will open for researchers to carry out research at the national level on Khartoum. As well as decision makers, these standard testing models will enable them to develop future policies that increase the efficiency of buildings in energy consumption and reduce the carbon dioxide production.

This optimistic plan to classify most of the important building types in Khartoum and make standard testing models for them will encourage all other cities in Sudan to create their own standard models that represent the building typology in each city.

References

References

Abdin, Y. E. (2013). *Sudan in Figures 2008 -2012 (Arabic)*. *Central Bureau of Statistics - Sudan* (Vol. 1). Khartoum/ Sudan. Retrieved from www.cbs.gov.sd%0A

Adekunle, T. O., & Nikolopoulou, M. (2016). Thermal comfort, summertime temperatures and overheating in prefabricated timber housing. *Building and Environment*, *103*, 21–35. http://doi.org/10.1016/j.buildenv.2016.04.001

Ahmad, A. M. (2000). Khartoum blues: the deplanning and decline of a capital city. *Habitat International*, *24*, 309–325.

Ahmed, a. M., & Kurosawa, K. (n.d.). Analytical Evaluation of Housing Patterns in Sudan- Case Study: Evaluation and Improvement of Plan Types of Detached House in Khartoum. *Journal of Environmental Engineering*, *598*, 11–19.

Ahmed, E. M. A., Osman, M. A., & Ali, M. E. M. (2016). Shoring for Deep Excavation in Urban Khartoum , Sudan. *International Journal of Emerging Technology and Advanced Engineering*, *6*(1), 87–93.

Ahmed, N., & Elhag, M. M. (2011). Major climate indicators of ongoing drought in Sudan. *Journal of Hydrology*, *409*(3–4), 612–625. http://doi.org/10.1016/j.jhydrol.2011.08.047

Bahreldin, I. Z. (2006). Preparing for urban future Riverside development, concepts and strategies; a Case study of Khartoum-Sudan. *Jeddah International Urban Forum-JIUFX*, 1–15.

Ballarini, I., Corgnati, S. P., & Corrado, V. (2014). Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project. *Energy Policy*, *68*, 273–284. http://doi.org/10.1016/j.enpol.2014.01.027

Ballarini, I., & Corrado, V. (2017). A new methodology for assessing the energy consumption of building stocks. *Energies*, *10*(8). http://doi.org/10.3390/en10081102

Berry, L. B. & L. O. C. F. R. D. (2015). *Sudan a country study*. (LaVerle Berry & Library Of Congress. Federal Research Division, Ed.) (5th ed.). Washington, DC: Federal Research Division, Library of Congress. Retrieved from https://www.loc.gov/item/2014043450/

Big Sand storm Khartoum. (2014). Retrieved July 25, 2017, from https://c1.staticflickr.com/1/229/481131304_f0a909c68a_z.jpg

BPIE. (2011). *Europe's Buildings Under the Microscope*. Buildings Performance Institute Europe (BPIE). Retrieved from http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf

Calm, J. M., Hanson, S. S., Marriott, C. E., Amrane, K., Higa, R. T., Hogan, J. F., … Woodford, M. W. (2007). ASHRAE STANDARD Energy Standard for Buildings Except Low-Rise Residential Buildings. *Society*, *8400*, 404–636. http://doi.org/http://dx.doi.org/10.1108/17506200710779521

Corrado, V., Ballarini, I., & Corgnati, S. P. (2012). *Typology Approach for Building Stock National scientific report on the TABULA activities in Italy*. Torino, Italy.

Electricity, R. of S.-M. of W. R. and. (2016). Sudan Potentials , Opportunities and challenges in Energy field. In *10th German-African Energy Forum* (p. 45). Hamburg.

Elhoweris, M. N. S. (2008). the Impact of Residential Lands Classification on City & Neighbourhood Design. In *Third Architects Scientific Conference in Sudan* (pp. 1–10).

Elkhalifa, A. A. (2011). *THE CONSTRUCTION AND BUILDING MATERIALS INDUSTRIES Appropriate and Innovative Local Building Materials and Technologies for Housing in the Sudan*. Universita Di Camerino.

ELSAYED, A. H. O. (2015). *THE APARTMENT-VILLA: A STUDY ON THE MECHANISM OF TRANSFORMATIONOF PRIVATE VILLAS IN KHARTOUM-SUDAN*. *University of Khartoum 2015*. University of Khartoum/Faculty of Architecture.

Fernando Murillo; and others. (2009). *Urban Sector Studies and Capacity Building for Khartoum State*. (E. M. For, Ed.) (First). United Nations Office at Nairobi: United Nations Human Settlements Programme (UN-HABITAT). Retrieved from www.unhabitat.org

Ghaffarian, S., & Ghaffarian, S. (2014). Automatic building detection based on Purposive FastICA (PFICA) algorithm using monocular high resolution Google Earth images. *ISPRS Journal of Photogrammetry and Remote Sensing*, *97*, 152–159. http://doi.org/10.1016/j.isprsjprs.2014.08.017

Haywood, I. (1985). City Profile; Khartoum. *Cities*, *2*(3), 186–197.

Huang, J., & Franconi, E. (1999). *Commercial heating and cooling loads component analysis* (Final repo). *Environmental Energy Technologies Division, Lawrence Berkeley National*

Laboratory, Berkeley, CA. Berkeley: Building Equipment Division of the U.S. Department of Energy.

Huge snad storm in Khartoum. (2011). Retrieved July 25, 2017, from http://ronnieborr.com/blog/wp-content/uploads/2010/06/Sand-and-dust-rain-down-on-us-as-we-make-our-way-home...1.jpg

Ioannou, A., & Itard, L. C. M. (2015). Energy performance and comfort in residential buildings: Sensitivity for building parameters and occupancy. *Energy and Buildings*, *92*, 216–233. http://doi.org/10.1016/j.enbuild.2015.01.055

Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., & Djurovic-Petrovic, M. (2010). A review of bottom-up building stock models for energy consumption in the residential sector. *Building and Environment*, *45*(7), 1683–1697. http://doi.org/10.1016/j.buildenv.2010.01.021

Khartoum Building Regulation Codes 2008. (2008). Khartoum/ Sudan: Khartoum: Ministry of Urban Planning and Public Utilities. Retrieved from http://gopp.gov.eg/wp-content/uploads/2009/10/اللائحة-التنفيذية-144-لسنة-2009.pdf

Kuklick, H. (2008). Salubrious Khartoum: Building a Colonial City, 1899-1912. *Histories of Anthropology*, *4*, 205–216. http://doi.org/10.1353/haa.0.0042

Loga, T., Stein, B., & Diefenbach, N. (2016). TABULA building typologies in 20 European countries—Making energy-related features of residential building stocks comparable. *Energy and Buildings*, *132*, 4–12. http://doi.org/10.1016/j.enbuild.2016.06.094

Malarvizhi, K., Kumar, S. V., & Porchelvan, P. (2016). Use of High Resolution Google Earth Satellite Imagery in Landuse Map Preparation for Urban Related Applications. *Procedia Technology*, *24*, 1835–1842. http://doi.org/10.1016/j.protcy.2016.05.231

Mata, É., Kalagasidis, A. S., & Johnsson, F. (2013). A modelling strategy for energy, carbon, and cost assessments of building stocks. *Energy and Buildings*, *56*, 100–108. http://doi.org/10.1016/j.enbuild.2012.09.037

Mata, É., Sasic Kalagasidis, A., & Johnsson, F. (2014). Building-stock aggregation through archetype buildings: France, Germany, Spain and the UK. *Building and Environment*, *81*, 270–282. http://doi.org/10.1016/j.buildenv.2014.06.013

Merghani, a. (2001). *Thermal comfort and spatial variability in courtyard houses in hot dry* *climates*. University of Cambridge.

Mohamed, E. T., & Abdalla, K. N. (2010). Effect of a radiant panel cooling system on indoor air quality of a conditioned space. *OIA*, (1), 2–7.

MOHAMMED, A. A. M. A., & Takaguchi, H. (2016). Environmental Improvement Proposal of Sudan Building Codes to Solve Horizontal Expansion and Low-Population Density Problems in Khartoum. In *13th International Conference of Asian Institute of Urban Environment* (Vol. 1, pp. 85–90). Changchun, China: Asia Institute of Urban Environment.

Morehart, C. T., & Millhauser, J. K. (2016). Monitoring cultural landscapes from space: Evaluating archaeological sites in the Basin of Mexico using very high resolution satellite imagery. *Journal of Archaeological Science: Reports*, *10*, 363–376. http://doi.org/10.1016/j.jasrep.2016.11.005

Mustafa, A. (1993). The Neighbourhoods of Khartoum, Reflections on their Functions, Forms and Future. *Habitat INTL.*, *16*(4), 27–45.

NA. (2017). Roofs - Nazareth Village. Retrieved October 22, 2017, from http://www.nazarethvillage.com/blog/2015/02/24/roofs/

Nemry, F., Uihlein, A., Colodel, C. M., Wetzel, C., Braune, A., Wittstock, B., … Frech, Y. (2010). Options to reduce the environmental impacts of residential buildings in the European Union-Potential and costs. *Energy and Buildings*, *42*(7), 976–984. http://doi.org/10.1016/j.enbuild.2010.01.009

Omer, A. M. (2002). Overview of renewable energy sources in the Republic of the Sudan. *Water Resources*, *27*, 523–547.

Omer S. Osman, , Amira O. S. Osman, and I. Z. B. (2011). Architecture in Sudan: The Post–Independence Era (1956–1970). Focus on the work of Abdel Moneim Mustafa docomomo. *International Committee for Documentation and Conservation of Buildings, Sites and Neighbourhoods of the Modern Movement (Docomomo)*, *1*(44).

Osman, R. A. (2015). Towards Sustainable Houses in Rural Areas in Sudan The case of Blue Nile state, 134–140.

Patela, N. N., Angiuli, E., Gamba, P., Gaughan, A., Lisini, G., Stevens, F. R., … Trianni, G. (2015). Multitemporal settlement and population mapping from landsatusing google earth engine. *International Journal of Applied Earth Observation and Geoinformation*, *35*(PB), 199–208. http://doi.org/10.1016/j.jag.2014.09.005

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, *40*(3), 394–398. http://doi.org/10.1016/j.enbuild.2007.03.007

Population, N., General, C., & Security, S. (2010). Sudan Millennium Development Goals Progress Report 2010. *Technology*.

Pulighe, G., & Lupia, F. (2016). Mapping spatial patterns of urban agriculture in Rome (Italy) using Google Earth and web-mapping services. *Land Use Policy*, *59*, 49–58. http://doi.org/10.1016/j.landusepol.2016.08.001

Pushak, N., & Foster, V. (2011). *Sudan's Infrastructure: A Continental Perspective*. *Afirca Infrastructure Country Diangnostic AICD* (Vol. 5713). Washington, DC 20433.

Rabah, A. A., Nimer, H. B., Doud, K. R., & Ahmed, Q. A. (2016). Modelling of Sudan ' s Energy Supply , Transformation , and Demand. *Journal of Energy*, *2016*, 14. http://doi.org/http://dx.doi.org/10.1155/2016/5082678

Roy, U. K., & Roy, M. (2016). Space standardisation of low-income housing units in India. *International Journal of Housing Markets and Analysis*, *9*(1), 88–107. http://doi.org/10.1108/IJHMA-12-2014-0057

Ruellan, M., Park, H., & Bennacer, R. (2016). Residential building energy demand and thermal comfort: Thermal dynamics of electrical appliances and their impact. *Energy and Buildings*, *130*, 46–54. http://doi.org/10.1016/j.enbuild.2016.07.029

Sand storm in Khartom. (2015). Retrieved July 28, 2017, from http://cache.desktopnexus.com/thumbnails/690535-bigthumbnail.jpg

Sara Pantuliano; others. (2011). *City limits: urbanisation and vulnerability in Sudan- Khartoum case study*. London.

Sarzin, Z., & Mehta, B. (2011a). Sudan: Issues in Urban Development. *World Bank Report*, (63785), 9–70.

Sarzin, Z., & Mehta, B. (2011b). *Sudan: Issues in Urban Development; Phase 1 – Overview of the Urban Landscape*. *World Bank Report (Report No. 63785-SD)*.

Scary Sand storm Khartoum. (2016).

Standard, A. (2013). Cooling Loads Calculations. *Ashrae Standard*, 1–14.

State, K. (2013a). Sudan Central Bureau of Statistics. Retrieved August 12, 2017, from http://www.cbs.gov.sd/en/files.php?id=7#&panel1-4

State, K. (2013b). Sudan Central Bureau of Statistics. Retrieved August 16, 2017, from http://www.cbs.gov.sd/en/download.php?id=1&file=The Projected Population of States.doc&count=630

Sullivan, P. J., Nasrallah, N., & Buvsbm, N. (2010). *Improving Natural Resource Management in Sudan*. *Special Report 242*. Washington DC.

UDAGAWA, M. (1985). The suggestion of standard detached house model. *AIJ 15th Symposium*, pp23-33.

UNEP. (2017). *Atlas of Africa Energy Resources*. UNEP Africa Office: United Nations Environment Programme. Retrieved from http://hdl.handle.net/20.500.11822/20596

Zakaria, B. I. (2012). *Bridging The Gaps In Community Participation In The Sudanese Village Organization Process*. Waseda University.

Zhu, J., & Chen, B. (2015). Experimental study on thermal response of passive solar house with color changed. *Renewable Energy*, *73*, 55–61. http://doi.org/10.1016/j.renene.2014.05.062

Appendixes

1-Data Collection Form of Single-floor House

Sample No.	

Dimensions Inspection

	Length	Width	Height	Wall thickness
Room-1				
Room-2				
Hall-1				
Hall-2				
Kitchen				
Saloon				

Materials Inspection

	Door	Windows	
		Frame	Panel
Room-1			
Room-2			
Hall-1			
Hall-2			
Kitchen			
Saloon			

Construction Material Inspection or Questionnaire

	Wall	Roof
Room-1		
Room-2		
Hall-1		
Hall-2		
Kitchen		
Saloon		

2-Data Collection Form of Apartment Buildings

Project No.	

Apartment Type	1-BR	2-BR	3-BR	4-5 BR

Dimensions / **Balcony**

	Length	width	height	Balcony	
				Yes	No
Room-1					
Room-2					
Room-3					
Room-4					
Room-5					
Hall-1					
Hall-2					
Hall-3					
Kitchen					
Saloon					

Construction Materials

	Door	Windows	
		Frame	Panel
Room-1			
Room-2			
Room-3			
Room-4			
Room-5			
Hall-1			
Hall-2			
Hall-3			
Kitchen			
Saloon			

Construction Materials

Structure	
Walls	

3-Data Collection Form of Office Buildings

Building No.	

Dimensions

Floor Area	
Floor Depth	
Floor Height	
wall thickness	

Core Location

	1	
	2	
	3	

7		**4**
8		**5**
9		**6**

Construction Materials

	Materials
Structure	
Walls	
Solid Walls	
Ex. Doors	
In. Doors	
Windows	

Transparent Parts	Curtin Walls	Windows

List of Publications

Published Papers

[1] Mohammed, A. A. M. A., & Takaguchi, H. (2018). STUDY OF KHARTOUM SINGLE FLOOR HOUSE LAYOUTS USING GOOGLE SATELLITE HIGH RESOLUTION IMAGES. J. Environ. Eng., AIJ., Vol. 83(744), pp. 205–214.

Conference Proceedings

[1] MOHAMMED, A. A. M. A., & TAKAGUCHI, H. (2016). Testing Model for Office Building in Khartoum; Spatial Analysis Study. In 日本建築学会大会学術講演梗概集 (pp. 543-544). Hiroshima: AIJ.

[2] MOHAMMED, A. A. M. A., & Takaguchi, H. (2016). Environmental Improvement Proposal of Sudan Building Codes to Solve Horizontal Expansion and Low-Population Density Problems in Khartoum. In 13th International Conference of Asian Institute of Urban Environment (Vol. 1, pp. 85–90). Changchun, China: Asia Institute of Urban Environment.

[3] MOHAMMED, A. A. M. A., & TAKAGUCHI, H. (2016). Testing Model for Apartments in Sudan; Spatial Analysis Study for Apartments in Sudan. In 日本建築学会大会学術講演梗概集 (pp. 543-544). Fukuoka: AIJ.