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VI Faculty of Engineering
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Master of Science in Architectural Engineering

Master Thesis

Identi^{ty}-fication *and* ***Re-Integration*** *of* ***Social Spaces*** *around Meskel Square Area:*

Sustainable Solution for a Low cost housing and Design of Open Spaces
Addis Ababa, Ethiopia

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Last but not the least, we feel glad to say thanks to our family who gave us encouragement and support all along.

Thank You to All!!

Abstract

Reintegrating the Low income groups as a vital part of the city urban redevelopment process has been the aim focus of this thesis project. The fact that they are not considered well in the redevelopment of the city, made us wonder what we could do as students with backgrounds of architecture and engineering. Our main aim is opposing relocation. Even though the project aimed in these groups of people we broadened the extent of the project by considering other inadequate urban elements.

We thought Addis Ababa needed exemplary design solutions since there is lack of appropriate green and open spaces or their link with other elements of the city. Public art or attractions of any kind is also scarce. To integrate these two aspects we found an area which is the most important open space in the city – Meskel Square. Meskel Square is not only an important node of the city but it also holds slum housing at the back of it. The Local Development Plan (LDP) aims to relocate the inhabitants of the slums and proposed a cultural centre in the area. For us it was an opportunity to integrate the above mentioned two aspects as a whole with the cultural centre.

In this paper, the urban design focused on reintegrating urban elements; the open spaces and green networks. This is achieved by creating attraction points to the inhabitants of the city within. In addition we considered to re-link the transportation system along Meskel Square. The architecture, technological and structure focused on providing solutions based on the actual needs of the inhabitants and as well considering sustainable and appropriate technology for the building and the environment to attain architecture of its context. The aim of the project has been attained by the process of participatory design.

The chapters proceeding, tries to identify, analyze and give solutions to the above mentioned topics in brief beginning form informing and identifying the context. The analysis and the design procedures and the outcomes are illustrated clearly guided with figures. Moreover, references and bibliographies are listed to verify our data.

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1. Introduction

For our thesis we chose to develope an open urban design competition (at national level) for the center of the Ethiopian capital, Addis Ababa. The competition was launched by Beautification, Park and Cemetery Development and Administration Agency in September, 2010. The site , Meskel Square, is located at the heart of Addis Ababa, Ethiopia. It got its name from the annually celebrated spiritual holiday for the finding of the true cross ("Meskel"). The site is characterized by a center for busyness, transport, culture and politics. The aim of the competition was to upgrade the square (to give a new look) and to make it a place that will be more valuable and functional to non-vehicle users and a place all sorts of recreational and sport activities take place.

For our thesis we further develop the competition to integrate the surrounding area which include exhibition center, slum residential area, surrounding major streets and other incorporated functions which are planned to be transformed to cultural center by LDP (Local Development Plan). We start our approach from a wider angle ,which is from urban scale, to the detailed works of designing a low cost sustainable residential buildings. We went through different design processes by starting from urban design and continuing with the architectural design for the residential building. We have also tried to integrate technological and structural solutions for the sustainability of the buildings. We used the LDP for Addis Ababa and a research based book called "cities of change: Addis Ababa" as a reference throughout the design process.

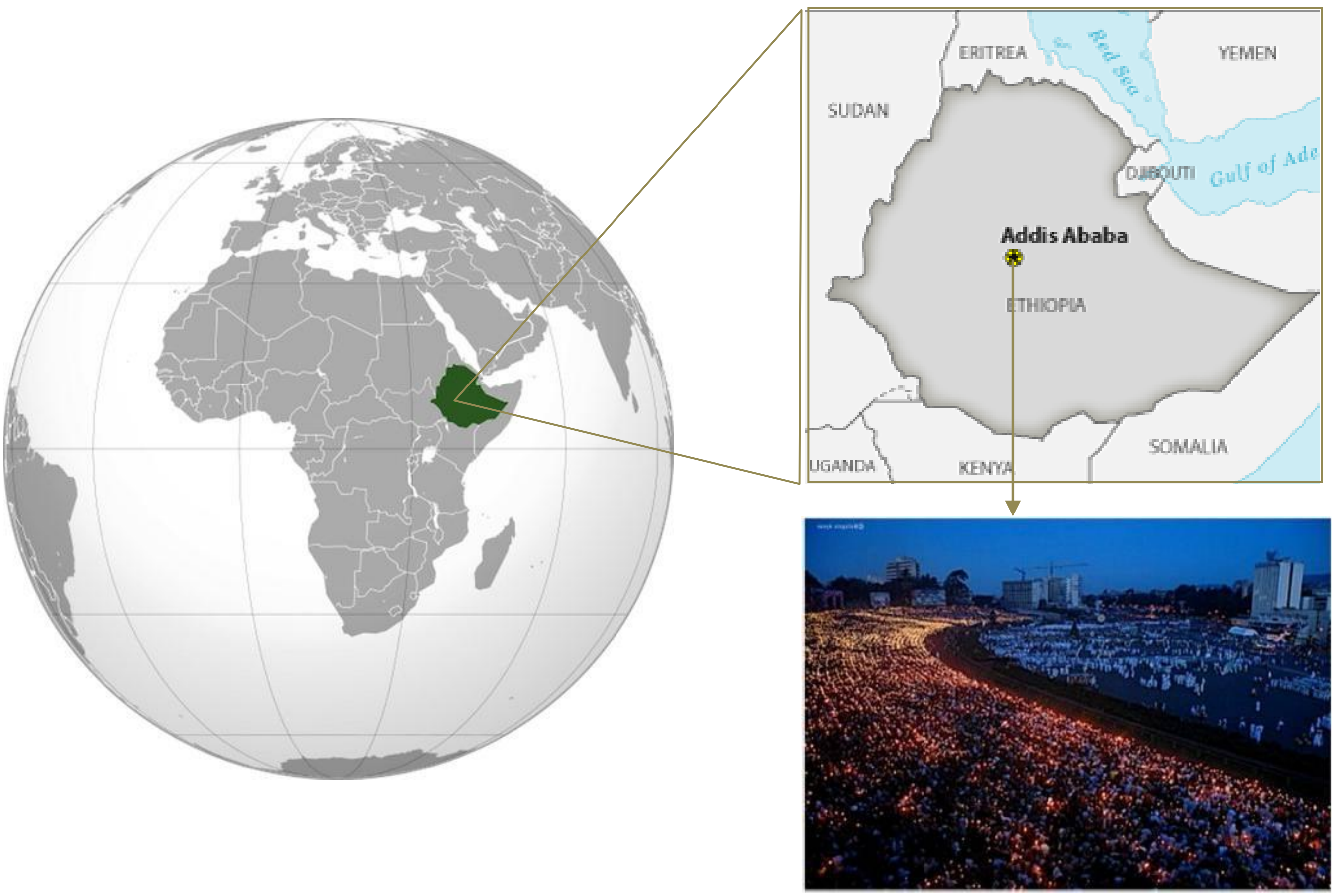

Fig. 1.1 Location of the site

I.I. Urban scale

For the Urban Design we focused on the surroundings of the square to the south side with functions of various types which include the existing exhibition, existing private bar, Slum residential houses, public school, private school and a national museum. The total area of the site is 22.5 hectares. To start our project from the urban scale we have gone through a lot of documents to have the knowledge of the existing situation. As introduced above, our reference was the LDP and this development plan suggests all this area to be dedicated for cultural center apart from the private school. Since the main goal of the design is to provide a space for the urban poor, where they used to live, without relocating them to other places we chose to keep the existing slum residential space and upgrade it to a better living quarter with appropriate material technologies and sustainable solutions. Since these people based their living on small scale businesses on a daily basis near to their living quarters and due to their low economical situation, we thought it will be a difficult task for them to go to some other locations and make adaptations. Apart from that we tried to refer to the development plans laid out by the local government. According to LDP the National museum which is located behind the square will be upgraded and the existing exhibition center will be demolished and replaced by new high rise building in a site near the old one, which will leave us with plenty of space for our open space design.

The design will include

- Upgrading the living condition by designing residential buildings for low income people,
- Commercial buildings with the addition of open linear local street market,
- Park area which consists a library and open air exhibitions inside,
- Recreation facilities which include cafeterias and restaurants,
- Provide space for a public school.

All the functions mentioned above, except public school and residential area, will serve as a cultural center. The local open street market will serve the low income residents as a source of income and the commercial buildings will serve the people attracted by the exhibition center.
Another focus area in the urban design includes the green network. This is because the green network is not well connected around our site and also throughout the city, while the parks are not well maintained and there is a huge shortage of green area. The aim of the project is to suggest how the green elements could be connected and also to provide a park to overcome the shortage in our site.
Another solution we tried to give in this project is streetscape. Due to the lack of maintenance and proper design of the streets, problems arose for both pedestrians and vehicles. In this project we will suggest suitable typologies of streetscape.

I.2. Architectural approach

In the architectural design process we mainly focused on designing a public housing for the low income group who are living in the slum residential area. Currently the policy makers believe in removing such elements from the centers and put them somewhere else along the peripheries of the city, but we believe that this slum residents and the urban fabrics created by their settlements should get recognition and be given the chance to transform and make them integral parts of the city's fabric. By doing this we will be ensuring the sustainability of the society . The design process is built upon concepts based on

- Simplicity
- Identity
- Social sustainability
- Interaction

At the end of this project, architecturally, we would like to accomplish the following goals.

- Affordable low income housing solutions through vertical densification,
- Upgrading the living standard of the neighborhood and also the city,
- Increasing cultural activities and social interaction,
- Provide apartments of different family sizes.
- To have sustainable living quarters by the use of local materials and easy construction systems.

Our purpose is to build a social housing which accommodates the daily needs of the society. This housing will be a sample or prototype in our site and if it gets acceptance by the society it will be adopted in different part of the city.

Generally we would like to make our project interactive and based on Participatory system, in which the society is part of the whole process right from the design up until the construction of the residential units.

2. Knowledge

2.1. History and context

Ethiopia, officially known as the Federal Democratic Republic of Ethiopia, is a country located in the horn of Africa. It has a population of around 81,220,000 inhabitants and is the second most populous country in Sub Saharan Africa. It occupies 1.13 million square kilometers of area and has a history of around 3000 years. Ethiopia is one of the ancient Sub-Saharan countries.

Table 1: Country Data[10]

Full name	**Federal Democratic Republic of Ethiopia**	
Capital	Addis Ababa	
Regions (plus 2 chartered cities)	Afar, Amhara, Benishangul Gumuz, Gambela, Harari, Oromia, Somali, SNNPR[11], Tigray, Addis Ababa, Dire Dawa	
Extension	1.13 million sq km	
Major languages	Amharic, Oromo, Tigrinya, Somali	
Major religion	Christianity, Islam	
Monetary unit	1 Birr = 100 cents	
Life expectancy	46 (men), 49 (women)	
HDI (2005)	0.406 (position 169 of 177 countries with data)	
Main exports	Coffee, hides, oilseeds, beeswax, sugarcane	
	1991	**2005**
Population (millions)	53	71
GDP per Capita (US$)	108	141
Inflation (% charge in consumer)	36	12
External debt (% of GDP)	97	16 (2006)
Poverty incidence (%)	46 (1996)	39 (2006)
Gross Primary school enrolment rate (%)	30	79
Under-five child mortality (per 1,000)	204 (1990)	123
Access to clean water (% of population)	19 (1990)	36 (2004)
Road network (km)	23,442 (2005)	37,018

Fig. 2.1 Location and Country Data for Ethiopia

Ethiopia is one of the oldest sites of human existence known to scientists.[1] It may be the region from which *Homo sapiens* first set out for the Middle East and points beyond.[2] Ethiopia was a monarchy for most of its history until the last dynasty of Haile Selassie ended in 1974, and the Ethiopian dynasty traces its roots to the 2nd century BC. Alongside Rome, Persia, China and India, the Kingdom of Aksum was one of the great world powers of the 3rd century and the first major empire in the world to officially adopt Christianity as a state religion in the 4th century. During the Scramble for Africa, Ethiopia was the only African country beside Liberia that retained its sovereignty as a recognized independent country, and was one of only four African members of the League of Nations. When other African nations received their independence following World War II, many of them adopted the colors of Ethiopia's flag, and Addis Ababa became the location of several global organizations focused on Africa. Ethiopia is one of the founding members of the Non-Aligned Movement, G-77and the Organization of African Unity.

The ancient Ge'ez script is widely used in Ethiopia. The Ethiopian calendar is seven to eight years behind the Gregorian calendar. The country is a multilingual and multiethnic society of around 80 groups.

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1 Michael Hopkin (16 February 2005). "Ethiopia is top choice for cradle of Homo sapiens".

2 "Humans Moved From Africa Across Globe, DNA Study Says". Bloomberg.com. 2008-02-21. Retrieved 2009-03-16.

2.2. Addis ababa

Addis Ababa is the capital city of Ethiopia and it is also known as "the political capital of Africa". Minilik II, who was emperor of Ethiopia between 1889 and 1913, founded Addis Ababa as the capital city in 1889. Addis Ababa means "new flower" according to the native language Amharic. This name was given to it when it was first founded by Empress Taitu, wife of Minilik II. It was founded on the hill of Entoto which is located north of Addis Ababa and this area is mainly covered with forestation. The city at that time had three main parts in which it developed around; political, religious and market centers.

- The first one is Entoto area , which was the first settlement on the hills by the royal families, was the political center,
- Secondly we find the saint George church, located at the center of Addis Ababa, which was the religious center, and
- Finally there was the Arada area which was the market place and it was the commercial center.


Fig. 2.2


Fig. 2.3


Fig. 2.4

In 1895/96 there was an attempt by Italy to invade Ethiopia whose troops were defeated, even though they retained the control over Eritrea. In 1930 Haile Selassie (known as well as the king of the Rastafarians) became Emperor of Ethiopia until the invasion of Mussolini's Italian troops (1936-41).

In the first part of the 20th century Ethiopia forged strong links with Britain, whose troops helped evict the Italians in and put Emperor Haile Selassie back on his throne. During this 5 year occupation by Italians Addis Ababa undergone major transformations in terms of urban structure. Until now some part of the city especially ones located around the commercial center such as Piazza, Casa Incis and Casa Popolare are influenced by the Italian architectural styles.

Addis Ababa is the center for political, economical and cultural activities. Also geographically it is located at the center of Ethiopia. The strong International airport serves Africa as a main connection with Europe and the rest of the world. The rail line also serves the capital to connect

Fig. 2.2 The old and the first settlement

Fig. 2.3 The old Arada Market

Fig. 2.4 Saint George church and celebration of Meskel

2.3. Geography

Addis Ababa situated at the center of Ethiopia. It is located latitude 9°1’48”N and longitude and longitude 38°44’24”E. It lies at an altitude of 2300 meters (7546 feet) and is a grassland biome. The city lies at the foot of Mount Entoto.

Fig. 2.5

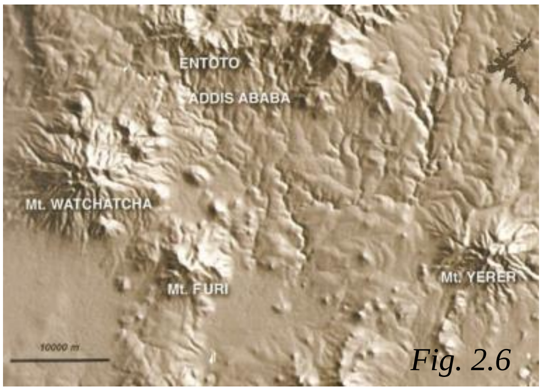


Fig. 2.6

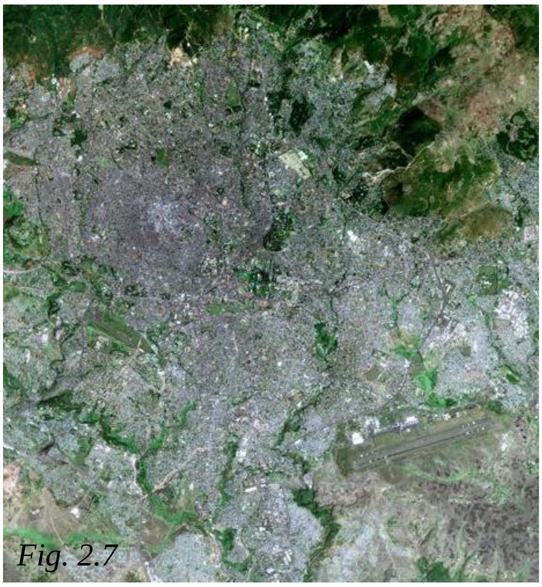


Fig. 2.7

Due to the high altitude Addis Ababa is not lucky to have any water bodies with in the cities except small rivers flow within it. Its total size is estimated to be around 520 km^2.

The lowest point is around Bole International airport at 2,326 metres (7,631 ft) above sea level in the southern periphery, the city rises to over 3,000 metres (9,800 ft) in the Entoto Mountains to the north.

The city is carved inwards from the surrounding four mountains, i.e. Entoto Mountain, Mount Watchatcha, Mount Furi and Mount Yerer , and this gives the city its visual attractiveness.

The natural landscape of Addis is pleasing since it is sheltered by the mountains with a flat terrain in the middle and the presence of a natural spring of hot water called "Filwuha", which was used for medical treatments and up until now for bathing.

The city is composed at one hand with hilly places and on the other places which are completely flat.

Fig. 2.5 Map showing the location of Addis Ababa

Fig. 2.6 Addis Ababa and its surrounding mountains

Fig. 2.7 Satellite image of Addis Ababa

2.4. Climate

Addis Ababa has a Subtropical highland climate. The city has a complex mix of highland climate zones, with temperature differences of up to 10°C, depending on elevation and prevailing wind patterns. The high elevation moderates temperatures year-round, and the city's position near the equator means that temperatures are very constant from month to month.

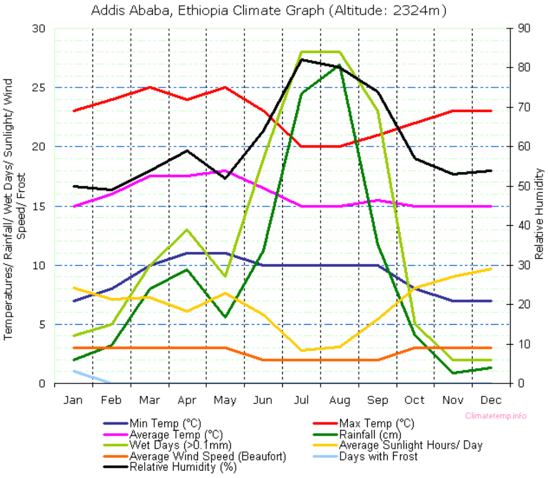


Fig. 2.8 Climate Data of Addis Ababa

	J	F	M	A	M	J	J	A	S	O	N	D
Max Daytime Temperature (°C)	23	24	25	25	25	23	20	20	21	22	22	22
Min Night-time Temperature (°C)	7	8	10	11	10	10	11	11	10	8	6	6
Hours of Sunshine (Daily)	9	9	9	8	7	7	6	6	7	8	9	10
Hours of Daylight (Daily)	12	12	12	12	13	13	13	12	12	12	12	12
Heat and Humidity Discomfort												
Days with some Rainfall												
Monthly Rainfall (mm)												
UV Index (Maximum)	11	11	11	11	11	11	11	11	11	11	11	11
	J	F	M	A	M	J	J	A	S	O	N	D

Fig. 2.9 Climate Data of Addis Ababa

Max Daytime Temperature (°C)	22	22°C (72°F) in November
Min Night-time Temperature (°C)	6	6°C (43°F) in November
Hours of Sunshine (Daily)	9	9 Hours per day in November
Hours of Daylight (Daily)	12	12 Hours per day in November
Heat and Humidity Discomfort		None in November
Days with some Rainfall		5 Days in November
Monthly Rainfall (mm)		9 mm (0.4 inches) in November
UV Index (Maximum)	11	11+ (Extreme) in November

Fig. 2.10 Climate Data for November

Max Daytime Temperature (°C)	20	20°C (68°F) in August
Min Night-time Temperature (°C)	11	11°C (52°F) in August
Hours of Sunshine (Daily)	6	6 Hours per day in August
Hours of Daylight (Daily)	12	12 Hours per day in August
Heat and Humidity Discomfort		None in August
Days with some Rainfall		14 Days in August
Monthly Rainfall (mm)		267 mm (10.5 inches) in August
UV Index (Maximum)	11	11+ (Extreme) in August

Fig. 2.11 Climate Data for August

- The average temperature in Addis Ababa, Ethiopia is 15.9 °C (61 °F).
- The range of average monthly temperatures is 3 °C.
- The warmest average maximum (high) temperature is 25 °C (77 °F) in March, May.
- The coolest average min/ low temperature is 7 °C (45 °F) in January, November & December.
- Addis Ababa receives on average 1089 mm (42.9 in) of precipitation annually or 91 mm (3.6 in) each month.
- On balance there are 148 days annually on which greater than 0.1 mm (0.004 in) of precipitation (rain, sleet, snow or hail) occurs or 12 days on an average month.
- The month with the driest weather is November when on balance 9 mm (0.4 in) of rain, sleet, hail or snow falls across 2 days.
- The month with the wettest weather is August when on balance 269 mm (10.6 in) of rain, sleet, hail falls across 28 days.
- Mean relative humidity for an average year is recorded as 60.7% and on a monthly basis it ranges from 49% in February to 82% in July.
- There is an average range of hours of sunshine in Addis Ababa of between 2.8 hours per day in July and 9.7 hours per day in December.
- On balance there are 2439 sunshine hours annually and approximately 6.7 sunlight hours for each day.
- On balance there are 1 days annually registering frost in Addis Ababa and in January there are on average 1 day with frost.

2.5. Socio-Economic Aspects

2.5.1. Population

The 2007 Population and Housing Census results show that the population of Ethiopia grew at an average annual rate of 2.6 percent.

Population in Ethiopia[97]	
Year	**Million**
1971	31.7
1980	37.9
1990	51.5
2000	65.5
2004	72.7
2008	80.7
2012	84.3

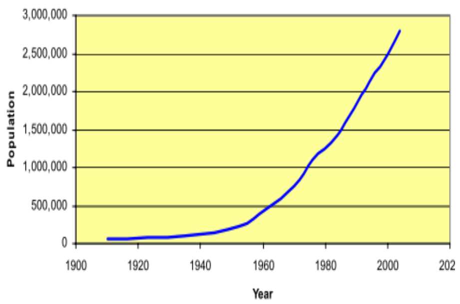


Fig. 2.12 Annual population of Addis Ababa UN habitat 2007

Year	Population	Average Annual Growth Rate (Percent)
1910	65,000	
1935	100,000	1.72
1952	317,925	6.80
1961	443,728	3.70
1970	750,530	5.84
1976	1,099,851	6.37
1984	1,423,111	3.22
1994	2,112,737	3.95
2000	2,495,000	2.77
2004	2.805,000	2.93

Fig. 2.13 Annual average population growth of Addis Ababa

Hosting 30 percent of the urban population of Ethiopia, Addis Ababa, the capital of Ethiopia and the diplomatic centre of Africa, is one of the fastest growing cities on the continent. Its population has nearly doubled every decade. In 1984 the population was 1, 412, 575, in 1994 it was 2,112,737, and it is currently thought to be 4 million. UN-HABITAT estimates that this number will continue to rise, reaching 12 million in 2024.

Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), Addis Ababa has a total population of 2,739,551, of whom 1,305,387 are men and 1,434,164 women; all of the population are urban inhabitants.

For the capital city 662,728 households were counted living in 628,984 housing units, which results in an average of 4.1 persons to a household. Although all Ethiopian ethnic groups are represented in Addis Ababa due to its position as capital of the country and located at the center of the country, the largest groups include

- Amhara (47.04%) ,
- Oromo (19.51%),
- Gurage(16.34%),
- Tigray (6.18%).

The religion with the most believers in Addis Ababa is Ethiopian Orthodox with 74.7% of the population, while 16.2% are Muslim, 7.77% Protestant, and 0.48% Catholic.

According to the 2007 national census, 98.64% of the housing units of Addis Ababa had access to safe drinking water, while 14.9% had flush toilets, 70.7% pit toilets (both ventilated and unventilated), and 14.3% had no toilet facilities. Adult literacy for men is 93.6% and for women 79.95%, the highest in the nation for both sexes.

2.5.2. Settlement

The settlement begun at the end of 19th century after Emperor Minilik settles in Addis Ababa at the hills of Entoto. The earliest settlements developed haphazardly around the king's palace and the camps ('sefers') of his generals and other dignitaries. It appears that just like the king, the generals preferred to live surrounded by the ranks and files of their subordinates. At the same time, and at least originally, substantial vacant spaces would separate the abodes of these dignitaries from those of their subordinates.

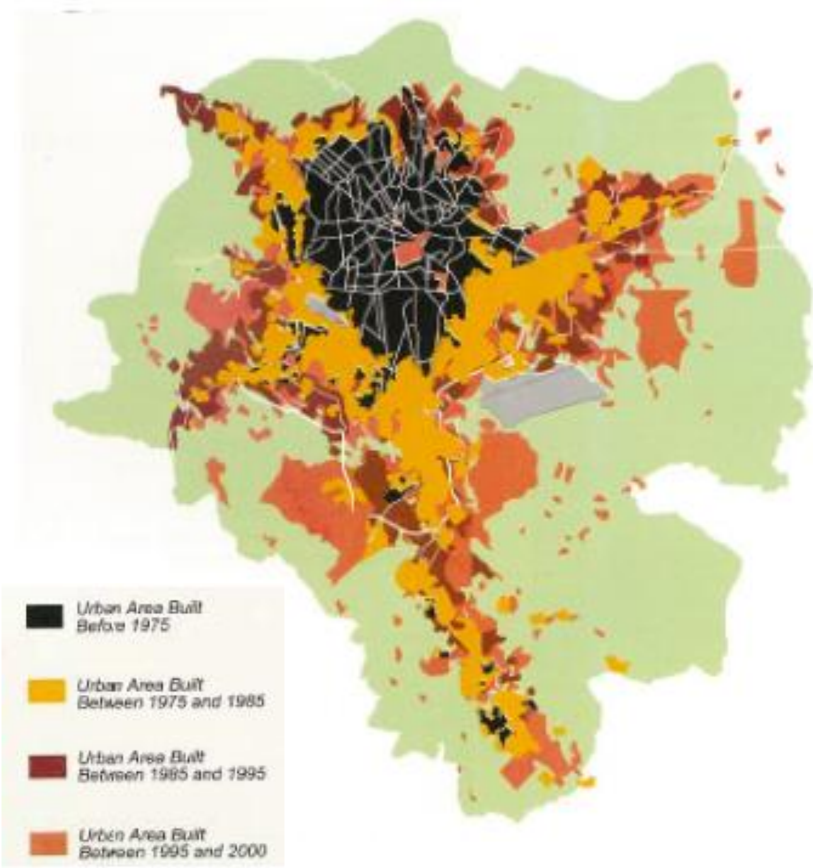
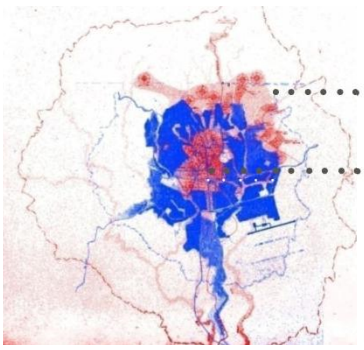
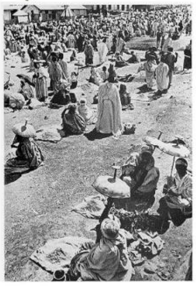


Fig. 2.14 Addis Ababa growth trends between 1975 to 2000

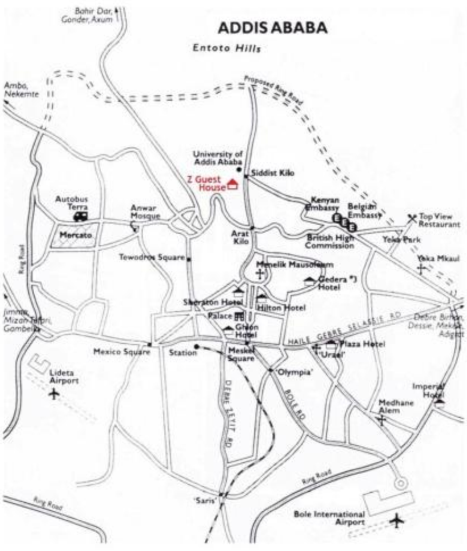
So first palace was situated at mount Entoto since it was a strategic point to watch for anyone coming or leaving the settlement. Thus, the landscape played a big role in the founding of Addis Ababa. The cities which were used as seats for previous governments had three main institutions. These were the Palace, the Market and the Church. They acted as three cores in a city. The same trend continued in Addis Ababa as well. The city grew around the Palace, the St. George Church and Arada which was the market. These were the political, religious and commercial cores of the city respectively. And this was the beginning for the development of Addis Ababa.



The first settlement around the palace at Entoto hill



The old mareket serve as a commercial center

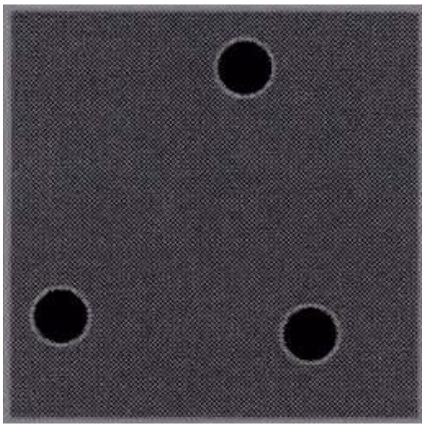


Further development to the center

Fig. 2.15 Development process of Addis Ababa

The settlement pattern of Addis Ababa reflected the social pattern of the feudal society of Ethiopia. The regional rulers *(ras)* would reside in the midst of their people have their settlements *(sifers)* and armies around the imperial palace *(ghebbi).* The sefers were scattered over a wide , rugged territory. As the permanence of this settlement was uncertain for the first decades , infrastructures were not developed and connections between the camps were not more than footpaths.

a/



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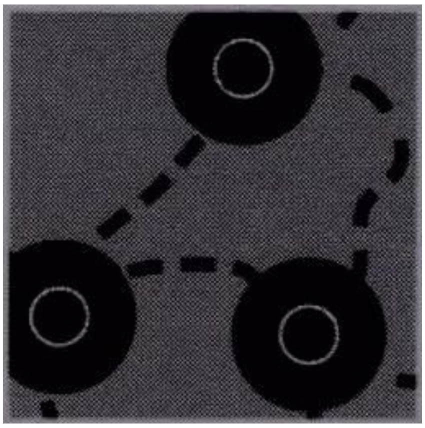

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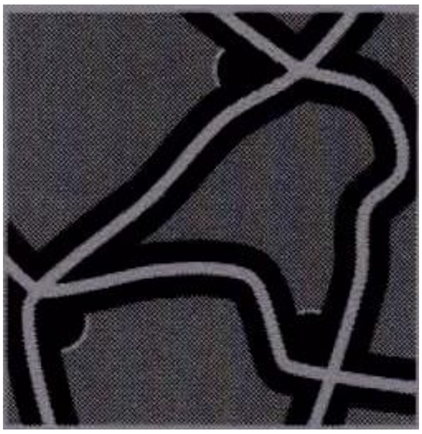


In contrast to a consciously planned city Addis was literally a city without streets. Only with the final decision to halt the movement of the imperial court were connecting bridges and streets laid-out in an organic manner along the undulating terrain. With further growth of the city, the dots of the first camps were connected and a network of streets formed.

Here, new and modern urban facilities, like shops, hotels, cinemas, administration, workshops, and the like emerged. In between these linear connections with modern features - *street-liners* - some large areas with mainly traditional building structures developed - *in-fills.* This pattern of settlement remains characteristic for the urban tissue of Addis Ababa, a city of currently 5 million inhabitants, until today.

The Addis Ababa Structure Plan of 2002 and the related set of building laws have enhanced the characteristics of this urban tissue. A wide woven grid with a mesh of approximately 1 x1 km is laid over the existing and expanding city areas. Buildings along these new, big roads need to conform to a minimum height of G+5.

As a result a new generation of *street-liners* with modern functions, like shopping centers, entertainment complexes, hotel chains, offices and apartment blocks are developed in linear strips . As Addis Ababa resisted the Western notion of centrality the indigenous structure of the urban tissue of Addis Ababa has basically remained the same.

Fig. 2.16 development patterns of Addis Ababa

a/ First Dots

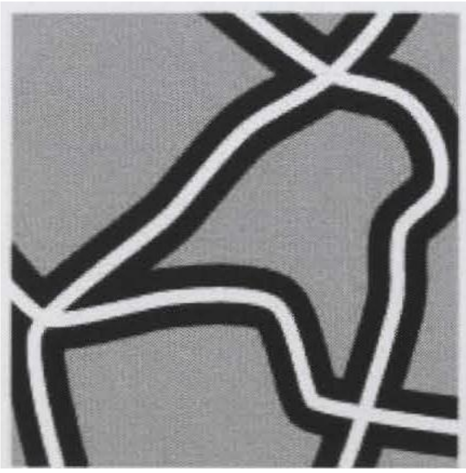
b/ Resulting developments

c/ Urban Tissue

Elements

Looking at the street-liners it can be observed that the linear space along the big streets in Addis Ababa has a purely functional purpose as opposed to the Western notion of public space in which streets have particular qualities to invite people to enjoy leisure time outdoors. An example from Addis Ababa: instead of one central market, many small and specialized building material suppliers are located along one street. The open space is used for display and workshops. Other more general users, like, for example taxis, beggars, and similar others are found, too. All other functions, for example leisure are indoors. In this city structure there are no public squares where the street space is widened so that important public events can take place.

a/



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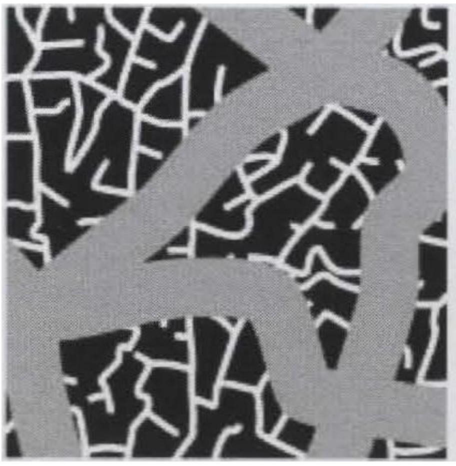


Fig. 2.17 Urban Tissue of Addis Ababa

a/ Street Liners

b/ In-fills

Looking at the in-fills, one finds the opposite: Streets are extensions of private space. Here, "housing is a verb". The most common typology is a low-rise detached house within a compound, which makes the neighbors invisible.

The houses of the rich and the poor are found in close proximity - ambassadors can live next to their guards and maids. A high degree of *mixity* can be achieved, which results in a positive social responsibility and security.

Despite the positive appraisal of the urban tissue of Addis Ababa, it should not be romanticized. Not more than an average of space per capita results in extreme overcrowding, access to drinking water is limited, the average life expectancy for city residents is 47 years.

The average income per household, often up to 10 persons, is about 30 USD a month. More than two-thirds of which has to be invested for food - therefore housing, transport, medical treatment, and education can hardly be afforded.

Qualities - MIXITY

Despite the precarious living conditions of its inhabitants the urban tissue of Addis seems to have obvious advantages.

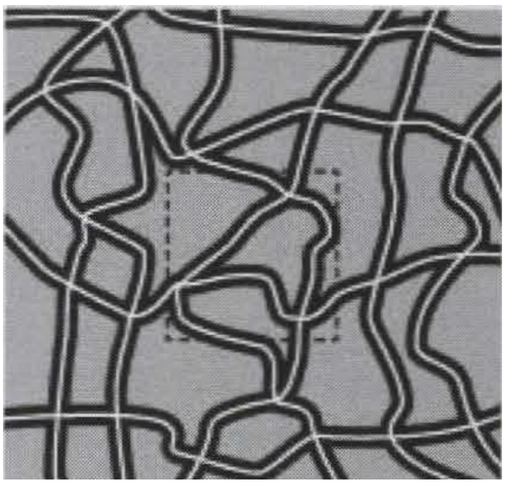
Mixity of Commercial and Residential Areas: The close proximity of *street-liners* and *in-fills* makes workplaces easily accessible by foot from residences. As the *street-liners* offer jobs for various income groups, they can also be accommodated next to each other in the in-fills, thus creating low-level job opportunities in middle or high-income households. Traffic is reduced and transport costs are saved, thus making more money available for food, housing, education and health care. This means that the city model has a direct influence on the affluence of its inhabitants.

Mixity of High- and Low-Income Groups: Instead of pushing the people living in these precarious situations

through slum-clearances from the city centre to the periphery, the urban tissue of Addis Ababa shows the advantages of mixing different income groups. Security does not only mean the absence of crime, but also the security afforded by the social net of a community, as, for example made possible by the micro-finance loan systems are established by these mixed groups.

a/

b/



Mixity of Building Typologies: Two different building typologies co-exist: mid- to high-rise structures along the *street-liners* and low-rise fabrics in the *in-fills.* Both are arranged such that homogenous spaces appear. On the one hand there is a space created by the mid- to high-rise structures aligned along the streets. On the other hand there are the typologically heterogeneous, bur equally low-rise in-fills for different income groups.

Mixity of Financing; All three mixities mentioned above - the functional, social and built mixity bring different financial capacities together. This creates opportunities for cross financing between high- and low- income residents and large and small businesses. For example, the gains from selling plots along the streets can be used for upgrading of the *in-fills.* Infrastructure built for high-income houses (sewerage, water, electricity, telephone) can be shared (or tapped) by low-income neighbors.

Fig. 2.18 Urban growth of Addis Ababa

a/ *mixity*

b/ urban growth

Mixity of Spaces: Due to the undulating topography of Addis Ababa the *in-fills* can only be seen from certain elevated viewpoints while moving through the highly enclosed streetscapes of the *street-liners,* strong identities are created through iconic buildings. Looking behind this curtain of modernity, one can experience totally different spatial identities in the *in-fills.* Streets are narrow, often dead-ends, and appear unordered at first sight. Their true identity is revealed only when stepping through a gate and entering a private secluded compound in which private outdoor spaces used for keeping animals, growing vegetables and thus saving or creating income are encountered.
To sum up, we can argue that the elements and qualities of the indigenous urban tissue of Addis Ababa seem to be a successful city model, advantageous for rich and poor inhabitants alike.

Potentials

Urban growth usually appears in two different ways: vertically or horizontally, either by replacing existing low-rise typologies by high-rises and thus increasing the density of an existing territory, or by increasing the
area of the territory by pushing the city limits further away from the centre. Both are expensive and cannot be considered appropriate for the African context with its rapid urbanization in poverty. The urban tissue described with respect to the case of Addis Ababa seems to indicate a solution. African metropolis should neither be centric or polycentric, but rather non-centric. Functions usually concentrated in a centre can be distributed along the linear developments of th e network of big streets. When th e city grows, the street network is extended, too. The in-fill s can then be areas where the poor can be accommodated, too . This results in a city model that can be expanded endlessly without changing its characteristics. Discussions are needed to find out if there are any limiting factors. It should further be researched which tool s would be necessary to steer the rapid growth of African cities along the lines of the city model described above.

Tools

The urban tissue under discussion here requires, first of all, a definition of a street network. Streets need to be adjusted to topography, which makes infrastructure investments more effective. The width of the organic mesh defines the relation of *street-liners* and *in-fills.* A width of 1*1 kilometer is found to be successful in Addis Ababa. Through planning the streets in this way, a spatial frame is defined. Expanding the street space at certain places creates variety and options for multifunctional use. The *in-fills* can be programmed in different ways. Yet, 'ghettoization' of the rich or poor should be avoided. Special attention needs to put on keeping certain in-fills for the low- or no-income groups. As informal settlements are apt to appear in any case, the question is rather how to integrate them into formal planning of extension areas.

To conclude, the present rapid urbanization in poverty in Africa requires an appropriate, indigenous city model. The case of Addis Ababa, the only large African city based on an indigenous pattern of settlement characterized by street-liners and in-fills demonstrates advantages, e.g. mixity of commercial and residential areas, mixity of high and low-income groups, mixity of building typologies, and mixity of financing. These patterns and qualities together form a city model that can overcome the centric city models introduced by colonialism and modernism and thereby establish a non-hierarchical, non segregated, non-functionalist city that can grow endlessly without changing its appropriateness in catering to the majority of its inhabitants - *the urban poor*.[3]

2.5.3. Housing

This original settlement pattern around the palace, church and market, supported by the prevailing social, cultural and economic conditions, eventually led to the gradual filling up of those vacant spaces and the emergence of a residential structure where the wealthy lived side by side with the deprived. The mixed residential structure that began in those days was not altered by the changes that took place in its economic base as the country opened up to Western civilization in the early 20th century and subsequently during the

Short-lived Italian occupation during this time, the Italian introduces modern buildings and new looks for buildings. Over the last three decades, a few, predominantly high-income, residential areas have emerged, especially in the south east and south west part of the city. A new upper middle class residential area also seems to be in the making in the eastern peripheries of the city. All over the city, the poor, the middle-income earners and the rich live side by side in apparent harmony.

Major Events affect housing in Addis Ababa

- 1907 proclamation government interest in influencing the spatial organization of urban whereby private ownership of urban land became legal in Addis Ababa.
- In 1936 Italian occupation; production of new dwellings temporarily stopped shortly upon arriving in the city, issued proclamations that forbade "the repair of existing buildings or the erection of new constructions...until further notice". Because of these developments, Addis Ababa faced what seemed to be its first major housing shortage. The proclamation came at time when the city was riding high on the successful introduction of eucalyptus, an exotic tree that outsmarted native trees with its fast growth and abundant yield of timber. However they developed the first meaningful – if colonial – master plan for the city the population of the city doubled during the five years of Italian occupation.
- No stringent planned public guidance or control over housing development in Addis Ababa during the first 10 to 15 years after liberation as a result; most of the housing was built without any permits. In early 1970s, only about a quarter of the housing units produced in Addis Ababa had municipal permits.

[3] *The indigenous Urban Tissue of Addis Ababa: A city Model For the future; by Prof Dr. Joerg Baumeister and Prof Nikolaus Knebel*

- Until the 1974 Revolution, Addis Ababa's population was growing so fast that shelter requirements were met largely through the building of unauthorized and substandard dwellings.
- After 1974 revolution 500 residential building permits every year but records suggest the city built housing at a rate sometimes exceeded 4000unit per annum.
- Nationalization of urban land and housing and the proclamation No.47, 1975 did to the urban housing sector in the capital was none other than the disruption of a formerly vibrant housing market, which caused a sudden, acute housing shortage.

Due to rapid growth of the city and the population by 1994, the housing shortage in Addis Ababa was worse than it had been 10 years earlier.

History of informal housing in Addis Ababa

Population growth and migration towards Addis Ababa, the economic center of Ethiopia, is mainly linked to the country's political conditions over the last 130 years. Before 1974, the morphology of the city was a multi-centered one, based on historical and social bonds. Housing permits and building codes were mostly based on the needs and abilities of its residents. however, a significant shift in the development of the city occurred as early as 1907, when a proclamation was introduced that allowed private ownership of land in Addis Ababa, thus establishing the legal framework for private investment in the housing sector. unfortunately, most of the housing stock built at the turn of the century was destroyed as a result of the scorched earth policy immediately preceding the Italian occupation of 1936-1941.

The Italian occupation accelerated the urban economy of Addis Ababa. Trade, commerce, industry and wage labor (largely due to the huge construction projects of the Italians) replaced the mostly agriculture based income of the inhabitants. Seeking economic gains, increasing numbers of rural people arrived in the capital during this period, pushing the housing shortage to an extreme - the population doubled in the five years of Italian occupation. Subsequently, the government subdivided existing lots and buildings in response to the high demand. The structures erected were poorly built and lacked proper foundations, rain protection, or even hygienic features such as kitchens or toilets; the existing infrastructure of the city collapsed under these conditions. In the late 1960s, almost 70 percent of Addis Ababa's housing stock was built in a similar way - erected without any permits or proper land ownership - leading to an 'informal' urbanism. By the beginning of the 1970s, 95 percent of the land in Ethiopia was owned by only 5 percent of the population, which led to an uprising of the people against the government.

Following the 1974 revolution, and with the 1975 proclamation to nationalize all extra homes and urban land, the government became the sole provider and owner of housing, which they in turn, rented to the public. During this period, the government - controlled organizations, such as the Urban Dweller's Associations (*Kebele, Kefitegna, etc*) and the Agency for the Administration of Rental Houses (AARH), were established to promote, supply and maintain the city's housing Portfolio. The government introduced the Housing Construction Corporation to encourage new construction and distribute the necessary materials. The public sector provided low-income housing but could not satisfy the immense need generated by the growing population, primarily due to financial constraints and problems that arose out of public ownership. Between 1974 and 1991, private investment in the housing sector became insignificant; in combination with the limited resources provided by officials, this led to an acute housing shortage that further promoted the informal sector.

Since the 1991 transition of power, significant changes to the housing sector have been introduced. The government's goal was to develop a more market-oriented housing policy and to liberalize the housing markets by introducing a lease-based system. Credit facilities were established for potential homeowners, but mortgage rates were high and the housing stock was in short supply. the changes to the system did not affect the conditions of the poor. Today, almost 80 percent of the inhabitants of Addis Ababa still live in slum-like, informal conditions. Housing plays an important role for economic development and could lead to social imbalance if not treated adequately. [4]

Currently in Addis Ababa housings could be categorized as standard / sub standard, real estate/public housing, state owned/ private owned. Within the city of Addis Ababa one can find dwellings of various standards and these housings could be categorized as standard housings and sub standard housings based on their quality of construction and provision of proper living spaces. These dwellings are found throughout the city and are owned and constructed by residents long ago in times when there were no concrete rules for housing in the city.

Real estate housings are being constructed around the periphery of the city with the ownership of private developers by renting land from government through the lease -based system. Public housing programs have been launched in 2005 by government and they have been constructed within city center and around the periphery, to provide proper living quarters for those residents who were living in the sub-standard housing units, by demolishing the existing slum like housing patterns.

The current informal houses are those who have their land without the permit or knowledge of municipality. Those housings are located in the periphery of the city. These housings are not poverty driven like other developing countries; mainly middle-class households have illegally occupied the peripheral areas of western Addis Ababa. The lot sizes they find are often larger than those currently provided by municipal authorities for members of housing cooperatives. They acquire them mainly through purchase, either from farm households fleeing the encroachment of the built-up area of the city, or from land speculators. The building materials used in squatter units, known as "*chereka bet*" are similar to those used in the formal sector. Squatter settlements in Addis Ababa have rather poor access to basic urban services, including access roads and utilities, due to a combination of their peripheral location and recent establishment.

Slum vs. Non-Slum

Slums could be formal or informal housings which are constructed without basic facilities or utilities. Slums are easy to construct at a very low cost. There are two types of slum ;the major ones are those owned by "*Kebele*" (small state administration) and secondly we have sub-standard informal

[4] *The Making of the informal sector in Addis Ababa, by Dirk Hebel; Cities of Change: Addis Ababa, page 119*

settlements without the knowledge of state to meet the rapid growth of housing need and this contribute for the expansion of slum houses in the city.

How did slum settlements develop in Addis Ababa?

After the "*Derg*" military regime succeeding Haile Selassie nationalized all land and rental houses shortly after taking power in 1974. Rental houses were given to the Kebele (or dweller association) for administration, but having cut rent by as much as 70 percent, and passing all revenue to the central government, there was not much left for maintenance and construction. As a result, half of the Kebele houses, accounting for 40 percent of the total housing stock, need replacement. The most severe blow came with the ban on (*private sector*) the production of affordable rental accommodation that was included in the proclamation.

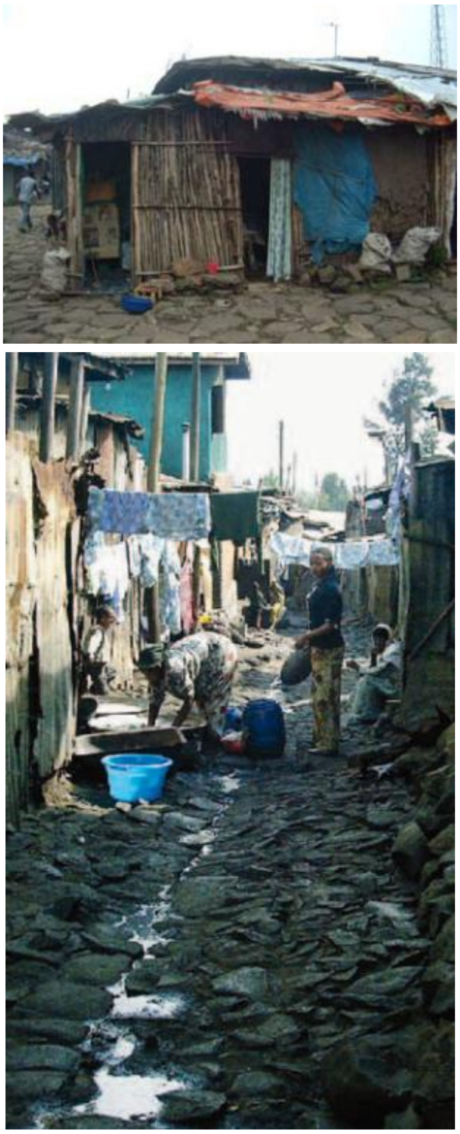


Fig. 2.19 Situation of slums in Addis

The public sector was neither willing nor capable of producing affordable rental accommodation. The Kebeles in charge of the bulk of the nationalized dwelling units lost interest in collecting rents, partly due to their inability to use the proceeds. In addition to this, with the rents once and for all fixed at very low levels, the Kebeles found it next to impossible to keep the properties in a proper state.

As a result, old slums only got worse. Public and private sector rental units account for 40.4 and 16.4 percent of the total housing stock respectively. Worsening housing conditions have combined with the emergence of squatter areas to cause a rapid increase in the proportion of the population of Addis Ababa that lives in such settlements.

The condition of the slum

- *26 % of the houses have no toilet facility (not counting the informal houses)*
- *33 % of households share toilet with more than six families*
- *29 % have no separate room for cooking only 38 % have private kitchen.*
- *34 % of the residents depend on water from frequently interrupted public taps.*

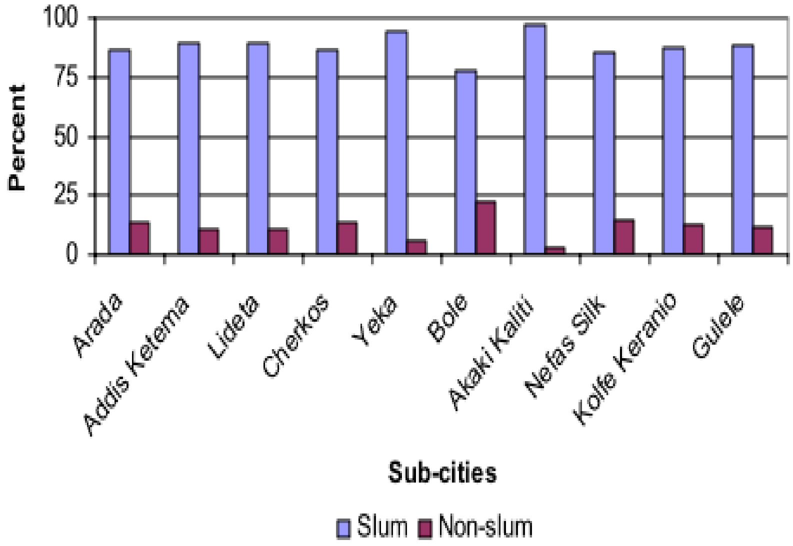


Fig. 2.20 Proportion of slum and non-slum houses in Addis Ababa[5]

- *75 % of housing units walls are made of mud and wood known as "chika" houses. With poor building standards and lack of proper foundations, most "chika" unit age quite rapidly.*
- *53 % have no ceiling.*
- *97 percent are single-story and 60 percent are attached row houses.*
- *Roofs are almost invariably made of corrugated iron sheets that make a vast and unpleasant rusty blanket in the central and older parts of the city.*

Public housing in Addis Ababa

Over 80% percent of the population of Addis Ababa currently lives in substandard, informal housing while attempting to accommodate the drastic increase in population. The Ethiopian government and developers are implementing new types of social housing called The Grand Housing Project, in order to improve the standard of living to that of modernized city. The government currently plans to build approximately 40,000 new homes each year following a western model of '*affordable*', condominium type residences. The goal is to replace the existing, informal housing with this type of social housing, which is an objective requiring extensive land clearance and temporary mass relocation. One of the main problems arising from this process is that majority of the people living in the poor quality housing cannot afford the requested down payments for new homes, let alone the monthly mortgage cost and high bills. On average most have to pay ten times more what they currently pay each month. The main reason that the residents *cannot afford these new accommodation* is because those affected would then *no longer have access to the same amount of land* they previously had had for producing and selling products, which in most cases their primary income. Another problem of relocation is the residences cannot afford the transport to come to the city center or to places of their job, which for many of them is around their old residence. Regardless of the feasibility there are problems in the allocation and implementation of the work. Problems encountering in the Construction, other than the low quality and wasteful construction, are the drastic deforestation of Eucalyptus tree for scaffolding and formwork, for the sixty-six thousand units completed to date when taking an average of approximately thirty-three units per building, 1.6million Eucalyptus trees needs to be cut down.
The main target users of the grand housing program are low income groups, who are further classified upper-low, middle-low and low-low income and some groups summed up under 'no income' group.

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[5] *Cities and citizens series, Urban inequities report, Addis Ababa UN HABITAT*

Typology of the housing

All the grand housing projects are 5 storey or G+4 buildings with simple floor plan and more regular shape.

The materials are

- Slab and column are made of concrete
- Walls with HCB
- Roof wit corrugated sheet
- And masonry stone used under ground floor slab.

The floor composition is more compact in order to use the floor area effectively; they develop four type of apartment's, which are studio (bachelor), single, double and three bedroom apartment. All of them have dining and living, kitchen and toilet. On the ground floor, depending on the location of the buildings, the design incorporates spaces for commercial purpose (shops, restaurants…).

2.6. Economy

Ethiopia was the fastest-growing non-oil-dependent African economy in the years 2007 and 2008. In spite of fast growth in recent years, GDP per capita is one of the lowest in the world, and the economy faces a number of serious structural problems.

Ethiopia produces more coffee than any other country in Africa. Ethiopia is also the 10th largest producer of livestock in the world. Other main export commodities are "chat", gold, leather products, and oilseeds. Recent development of the floriculture sector means Ethiopia is poised to become one of the top flower and plant exporters in the world.

Fig. 2.21 Economic Situation of Ethiopia Compared with the surrounding countries

Sectors	Workers
Trade and commerce	119,197
Manufacturing and industry	113,977
Home maker of deferent variety	80,291
Civil administration	71,186
Transport and communication	50,538
Education, health and social service	42,514
Hotel and catering service	32,685
Agriculture	16,602

Table 2.1 Sectors and employee in Addis Ababa [6]

[6] *Overseas Security Advisory Council - Ethiopia 2007*

Addis Ababa as a capital city it is the main center for business. Almost all the trade and commerce are in Addis Ababa it is characterized by typical of a consumer city, i.e., one where taxes, tributes and tithes were the principal source of income. Addis Ababa today has a diversified economy, being the main centre of public administration, commerce, manufacturing, finance, real estate and insurance.

Unemployment

Unemployment is one of the challenges in Addis Ababa. Large working groups still in seeking of a job, young graduates suffer from luck of professional jobs. Paralleling the drop in unemployment in Addis Ababa has been recent steady growth in the economy.

Those lucky enough to have "official" jobs acknowledged by the government (A large part of the 30% of unemployed residents are involved in "unofficial" street vending occupations), work in a classic capital city economy.

Economic growth

The national economy has grown 6-8 % in the last four years primarily as a result of managerial reforms and the elimination of price controls. Addis Ababa is now one of the fastest growing cities in the world. The economic boom has come inflation, which needs to be managed consistently with growth objectives.

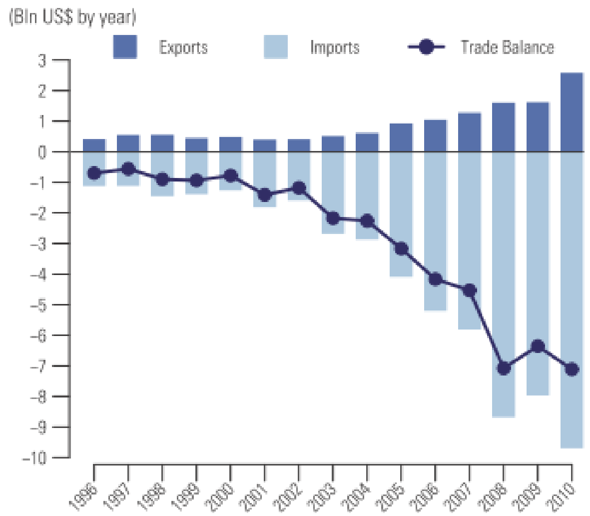
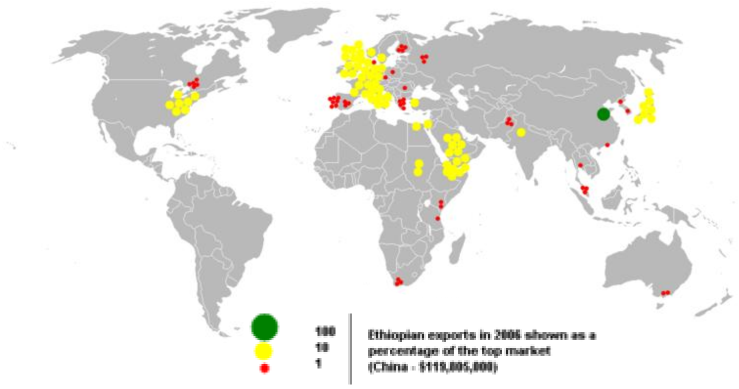


Fig. 2.22 Import, export and trade balance



The official inflation rate reached 12.3% in 2006, up from 8.6% in 2005, resulting from a strong upward pressure in food (14%), and non-food prices (7.2%), partly caused by the significant realignment of domestic oil prices in May 2006 to international levels and in consecutive years the inflation rate has been increasing specially after the Ethiopian millennium in 2008 now the inflation reaches 38.1%.

Exports grew at a 21 percent rate in 2006, but imports increased 22 percent from a larger base, leading to a widening of the balance of payments deficit and a reduction in foreign reserves.

Fig. 2.23 Ethiopian exports in 2006 shown as percentage of the top market(China- $ 119,805,000) [7]

[7] *Referred from http://en.wikipedia.org/wiki/Economy_of_Ethiopia*

Fig. 2.24 Over view of some portion of Mercato

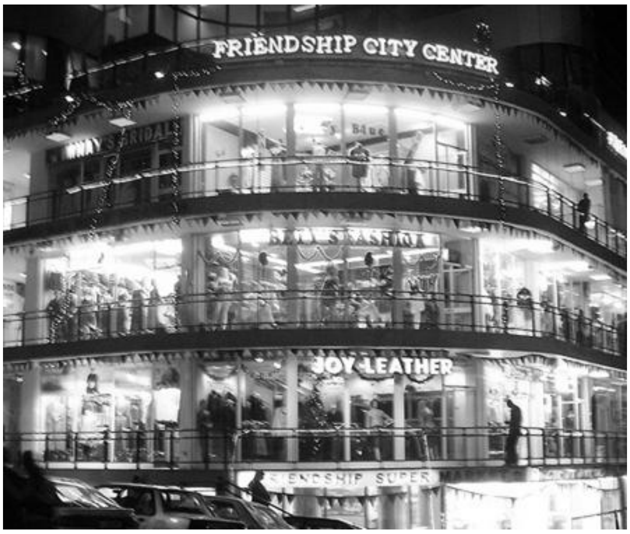


Fig. 2.25 The famous luxuries business street 'Bole road'

Fig. 2.26 Dembel city center: the first mall in Addis

Addis Mercato (Amharic for "New Market", popularly just ***Mercato***, from the Italian for "market") is the name for the large open-air marketplace in the Addis Ketema district of Ababa, Ethiopia, and for the neighborhood in which it is located.

Mercato is the largest open air market in Africa, covering several square miles and employing an estimated 13,000 people in 7,100 business entities. The primary merchandise passing through the Mercato is locally-grown agricultural products — most notably *coffee*.

The Addis Mercato was instituted by segregationist policies of the Italian occupational government. They restricted the historic *St. George (Arada) Mercato* to Europeans, causing the mostly Arab tradesmen to relocate a half mile to the west.

Over time, local shopkeepers displaced the Arab merchants and, since the 1960s, the Addis Mercato has had a mostly local flavor. The Addis Mercato has over 120 stores and one massive shopping center with 75 stores. Notable landmarks near the Mercato include the Al-Anwar Mosque and the Cathedral of the Holy Family.

Apart from Mercato there are several street lining market activities along the main roads of the city, most notably along the '*Bole*' road, '*Megenagna'* area and '*mexico*' square. The activities in this places are different from Mercato since they are incorporated with mixed use buildings and the main functions on this streets are shops, supermarkets, cafeteria ,restaurants and so on.

2.7. Culture

Ethiopia has a diverse mix of ethnic and linguistic backgrounds. It is a country with more than 80 different ethnic groups each with its own language, culture, custom and tradition. One of the most significant areas of Ethiopian culture is its literature, which is represented predominantly by translations from ancient Greek and Hebrew religious texts into the ancient language Ge'ez, modern Amharic and Tigrigna languages.

Religion

A large number of religions are traditionally practiced in Ethiopia, the most numerous today being Orthodox Christianity, followed by Islam. Traditional beliefs, usually categorized as Animism, attract a decreasing number of followers.

According to the national census conducted in 2007, over 32 million people or 43.5% were reported to be Ethiopian Orthodox Christians, over 25 million or 33.9% were reported to be Muslim, just under 14 million, or 18.6%, were Protestant, and just under two million or 2.6% adhered to traditional beliefs.[1] Neither in the 2007 census, nor in the 1994 census, were responses reported in further detail: for example, those who identified themselves as Hindus, Jewish, Baha'i, agnostics or atheists were counted as "Other".

The Kingdom of Aksum in present-day Ethiopia and Eritrea was one of the first Christian countries in the world, having officially adopted Christianity as the state religion in the 4th century.

Fig. 2.27 Celebration of Meskel Festival at Meskel Square

In addition to Christmas and Ester there are annually celebrated religious events in Ethiopia such as Meskel and Epiphany. Meskel Festival is based on commemorating the discovery of the True Cross and this celebration take place on Meskel square which is part of our site.

Costume

Women's traditional clothes in Ethiopia are made from cloth called *shemma* and used to make *habesha qemis*: it is basically cotton cloth, about 90 cm wide, woven in long strips which are then sewn together. Sometimes shiny threads are woven into the fabric for an elegant effect. It takes about two to three weeks to make enough cloth for one dress. The bottom of the garment or shirt may be ornamented with patterns.

Fig. 2.28 Different kinds of traditional clothing in Ethiopia

Men wear pants and a knee-length shirt with a white collar, and perhaps a sweater. Men often wear knee-high socks, while women might not wear socks at all. Men as well as women wear shawls, the *netela*. The shawls are worn in a different style for different occasions. When going to church, women cover their hair with them and pull the upper ends of the shawl about their shoulders reproducing a cross (*meskel*), with the shiny threads appearing at the edge. During funerals, the shawl is worn so the shiny threads appear at the bottom (*madegdeg*).

Women's dresses are called *habesha qemis*. The dresses are usually white with some color above the lower hem. Bracelets and necklaces of silver or gold are worn on arms and feet to complete the look. A variety of designer dinner dresses combining traditional fabric with modern style are now worn by some ladies in the cities.

These traditional clothes are still worn on a day-to-day-basis in the countryside. In cities and towns, western clothes are popular, though on special occasions, such as New-year (*Enkutatash*), Christmas (*Genna*) or weddings, some wear traditional clothes.

Often, a woman will cover her head with a *shash*, a cloth that is tied at the neck. *shemma* and *kuta* (*gabbi*), gauze-like white fabrics, are often used. This is common among both Muslim and Christian women. Elderly women will wear a sash on a day-to-day basis, while other women only wear a sash also called a *netela* while attending church.

Cuisine

The Ethiopian cuisine consists of various vegetable or meat side dishes and entrees, often prepared as a *wat* or thick stew. One or more servings of *wat* are placed upon a piece of *injera*, a large sourdough flatbread, which is 50 cm (20 inches) in diameter and made out of fermented *teff* flour, i.e. indigenous to the country and is grown on the Ethiopian highlands.

a/

b/

c/

One does not eat with utensils, but instead uses injera (always with the right hand) to scoop up the entrees and side dishes. Traditional Ethiopian food does not use any pork or seafood (aside from fish), as most Ethiopians have historically adhered to the Ethiopian Orthodox Church, Islam, , or Judaism, all of which prohibit eating pork.

Additionally, throughout a given year, Orthodox Christians observe numerous fasts (such as Lent), during which food is prepared without any meat or dairy products. Another food eaten in Ethiopia is Doro wat, which is chicken stew with hard boiled eggs. There are many varieties of "*wat*", e.g. chicken, beef, lamb, vegetables, lentils, and ground split peas stewed with hot spice called "*berbere*".

As shown the picture the social value of gathering around the traditional food is very high. The favourite drink of many Ethiopians is "*bunna*" *(coffee)*. "Bunna" is drunk in Ethiopia in a unique and traditional way known as a "*coffee ceremony*". This is one of the most important social gathering which could take place inside the house or outside space. The society chat, share information and celebrate events while drinking coffee.

Fig. 2.29 Traditional ways of dinning in Ethiopia

a/ People eating wat with injera

b/ Coffee Ceremony

c/ An Ethiopian woman preparing Ethiopian coffee at a traditional ceremony. She roasts, crushes and brews the coffee on the spot

Cultural Institutes

Addis Ababa is a center for culture since it is composed of many nations and nationalities of Ethiopia. Many cultural institutes both international and national are located in Addis Ababa, such as the Italian cultural institute, Goethe cultural institute (German), and Pushkin education and cultural Institute.

The fossilized skeleton and a plaster replica of the early hominid Lucy (known in Ethiopia as *Dinkinesh*) is preserved at the Ethiopian National Museum. Addis Ababa museum also another historical museum which is located within our site.

2.8. Land Use

Mixed Social and land use patterns, which indicate co-habitation of an area by different income group and the mixture of different compatible functions in a clustered neighborhood, can be cited as the unique character of Addis Ababa. Addis Ababa has become a uniquely decentralized city marked by a socially and programmatically mixed urban fabric. Moreover, it manifests a remarkable self-organized informal urbanism. Most of the land used areas are composed of mixed use.

No.	Major Landuse	Symbol	Functions	Non - permitted Development
1	Mixed use area 1.1 Existing mixed Use Area	BA	Mixed development	Industries, manfactures and storag that require more than 500m2 areas Military establishments and prison waste treatment plants and landfill sites
	1.2 Proposed mixed use area	EA	Mixed development	All Services listed on number 4 Mining and quarry
2	Center	MC	Main Center	Industries, manufacturies and storages which requeries more than 500m2 areas. Military establishments and prison waste treatment plant and landfill sitas Mining and quarry
		SC	Sub - Center	
3	Green Area	F	Forest	All except those presented as part and parcel of a Green development project
		GR	Green Along Rivers	
		P	Park	
		MA	Agriculture	
4	Main Social and municipal Services 4.1 Existing Social and Municipality Service	HE	Higher Education	All except those presented as part and parcel of a social serves project
		H	Hospital	
		S	Stadium	
		FS	Festival site	
		MC	Cemetry	
	4.2 Proposed Social and Municipality Service	HE	Higher Education	
		H	Hospital	
		S	Stadium	
		FS	Festival site	
		MC	Cemetry	
		SH	Slaughter - house	
5	Manufacturing and Storage 5.1 Existing Manufacturing and Storage	IS	Industry and Storage	
		TP	Treatment plant	
	5.2 Proposed Manufacturing and Storage	IS	Industry and Storage	All except those presented as part and parcel of manufacturing and storage projects
		LS	Landfill Site	
		RD	Rail Depot	
		FT	Freight Terminal	
		TP	Treatment Plant	
6	Terminals	PT	Terminal	All except those presented as part and parcel of a terminal project
		AP	Airport	

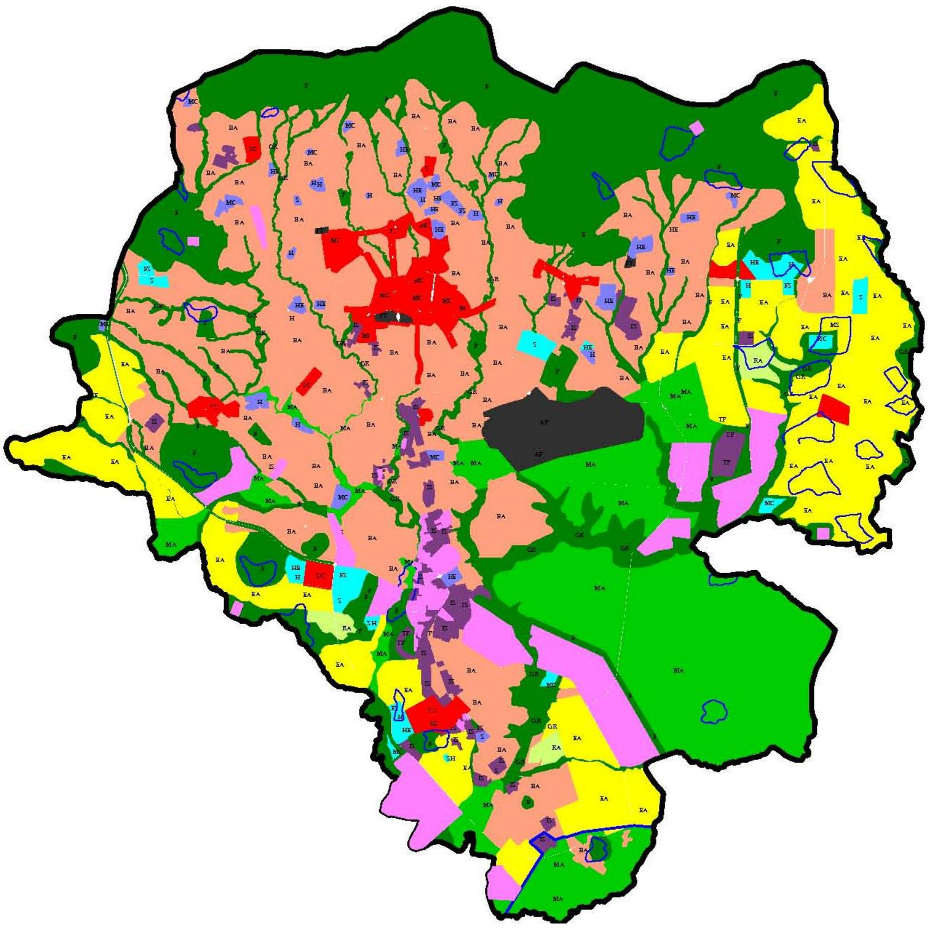
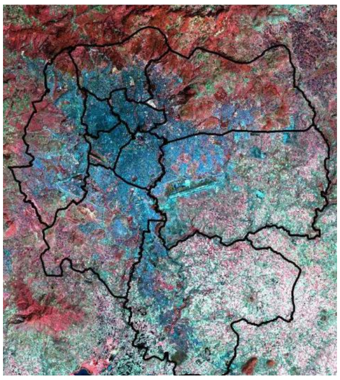


Fig. 2.30 Map: showing the land use of Addis Ababa and the red part indicates the main center of the city.

a/


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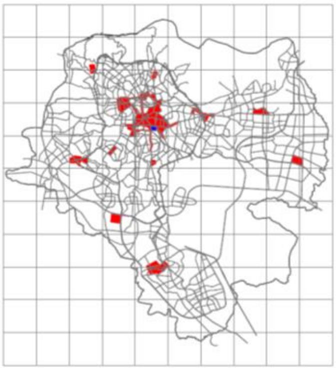

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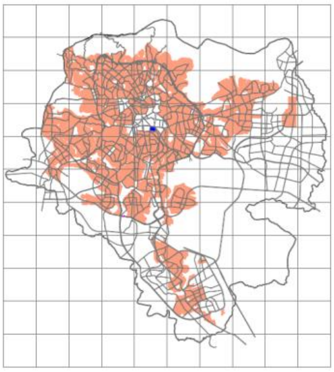

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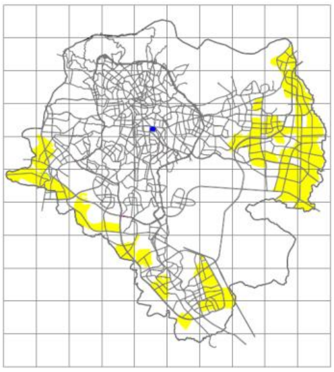
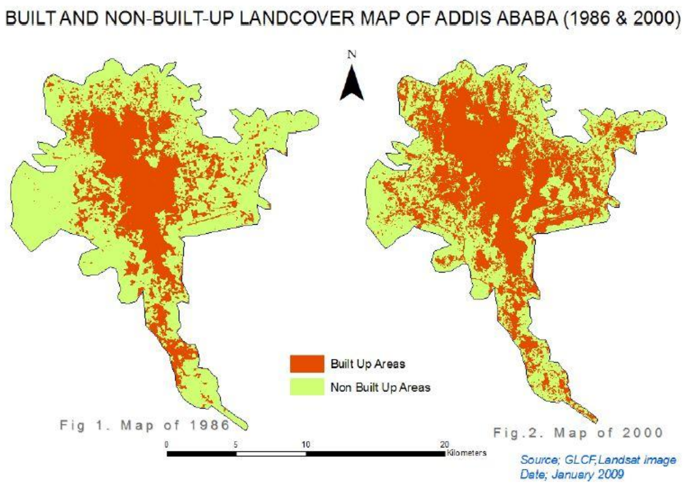


e/


Addis Ababa is now divided in to 10 sub-cities namely Arada, Lafto, Bole, cherkose, Addis ketema, Ledeta, Yeka, Akaki kality, Nefas Selk, Kolfe Keranio, Gulele. North part of the city is characterized by mainly by Educational institutes and governmental offices but going further residential areas also located. At the geological center of the city most of the land is occupied by old building and it has a unique look of Italian city due to their occupation in 1936, this is the so called the old city of Addis Ababa. Now it becomes mainly a commercial center due to the direct connection with the main business center which is Mercato. All periphery of the city is becoming a residential zone at an alarming rate due to high demand of housing by middle and high income people. One of the challenges of Addis Ababa is the slum areas which occupy most of the central part of the city, 80 % of the people live in substandard houses, this houses are located few steps away from main roads or major business areas. Now due to the construction boom in Addis Ababa the government is taking measure to completely remove and replace with standard houses.



This figure shows how the city is growing fast by compromising the green and open spaces through the last two decades.

Fig. 2. 31 Maps: Functional distributions in Addis Ababa

a/ Landsat image of Addis Ababa[8] and the boundaries of the 10 sub-cities (blue colour indicates built up areas, red is vegetation).

b/ Main and sub-centers of the city

c/ Mixed use distribution

d/ Proposed mixed use around the peripheries

e/ Green and open areas

[8] *Cities and citizens series, Urban inequities report, Addis Ababa UN HABITAT*

Meskel square and African Avenue

Meskel square and Africa Avenue are the most central part of the city in terms of function. The existing land use type around the square is predominantly cultural. The exhibition center serves as a trade fair center and also incorporates incompatible land uses such as Juventus community club, schools and residences. The spaces which exist at the back of the commercial line of Africa Avenue are composed of one- story residential buildings which are made of traditional construction materials.

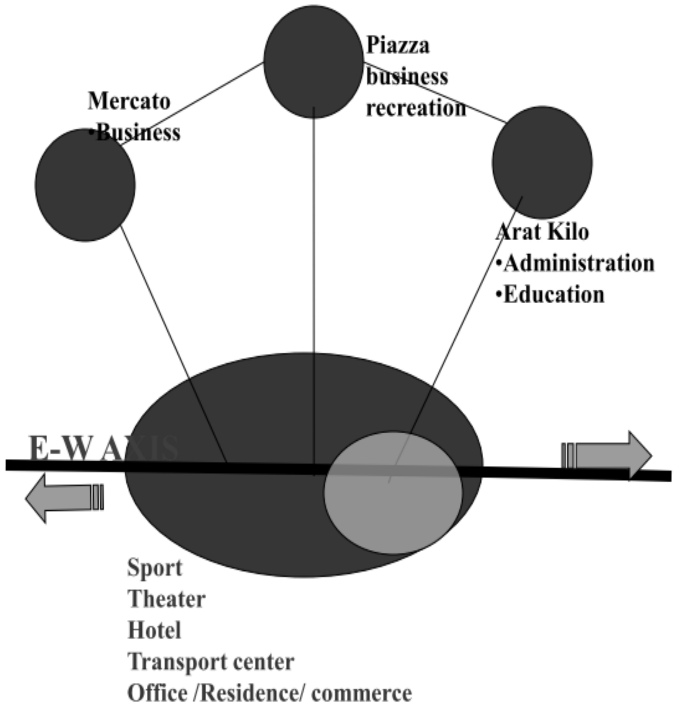


Fig. 2.32 Connection diagram of meskel square with the main functions around the city as per LDP.

Land use along Africa Avenue is of a mixed type. Residential buildings are rapidly transforming into commercial or hybrid buildings. Medium - high rise building development is also emerging with commercial activities on the ground floor and residence mixed with business on upper floors, making the street very active.

On the other hand, high rise buildings are clustered along Africa Avenue. The buildings with sufficient set back from the street predominantly render the street with a unique character of its own. The unique character of the buildings is due to the uniformity in design (harmony), construction, material and the singularity of the developer.

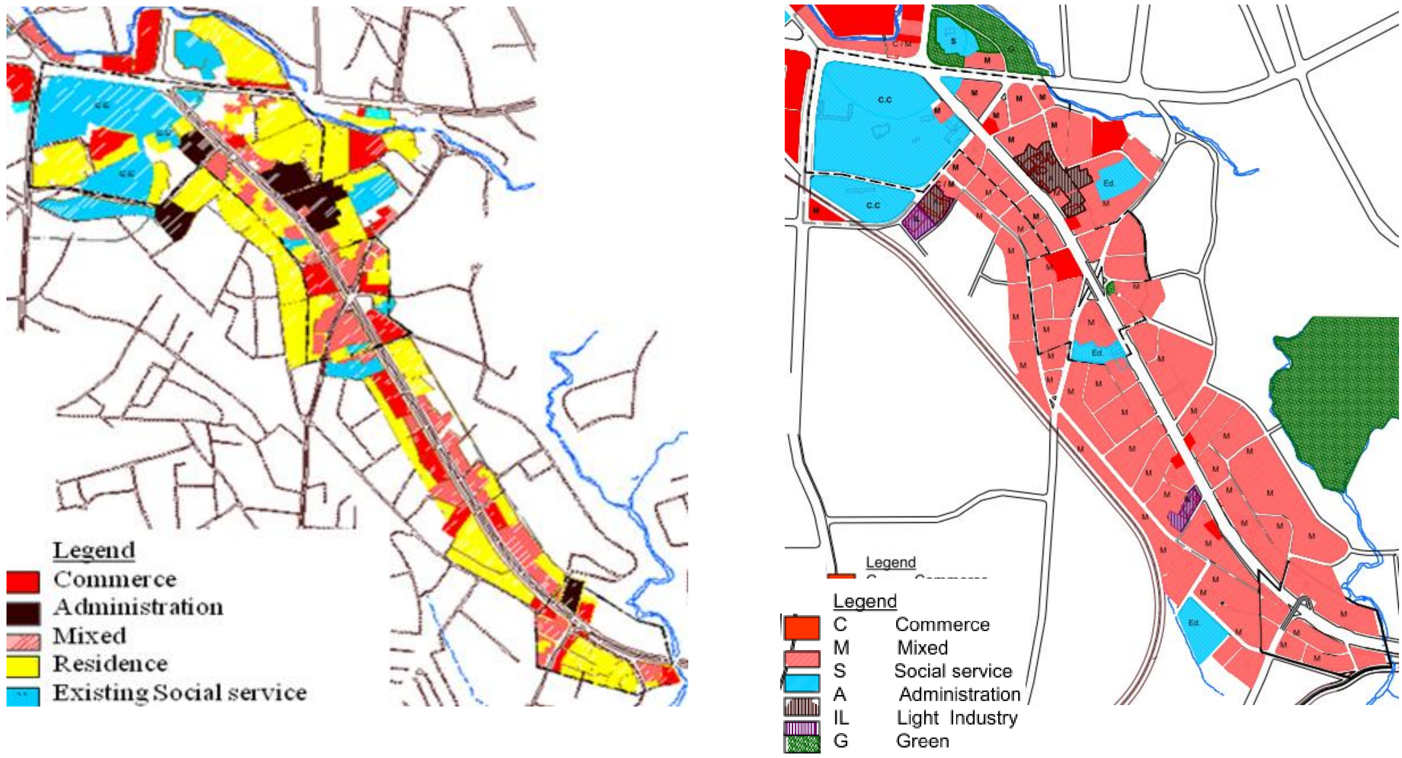


Fig. 2.33 Land use around Meskel square from the LDP: Existing and proposed

Meskel square LDP

Proposal

1. Preserve Meskel square & its adjacent compound area for cultural park & trade fair center which serves not only Addis Ababa & the regions but also East African countries. Thus to fulfill the large area demand as well as the compatibility of functions, it is proposed to relocate the incompatible functions & reserve the whole blocks including Labor union office bldg. as part of the exhibition center.
2. Commercial land use on the western& eastern /opposite / side of the civic center
3. To activate Meskel square 365 days a year by bringing a variety of functions in to the area and increase accessibility to the exhibition center.

Remark

Proposed Social service land use behind Meskel square consists

- Museum & its expansion
- Proposed Information center and city library (design completed)
- Cultural & Exhibition center & its future expansion and parking

Land use	*Area in hectares*	
	Existing	*Proposal*
Mixed(commercial, residential office, administration)	*28.3*	*28*
Service cultural center	*8.5*	*17.2*
Education	*3*	*3*
Circulation and open space	*27.9*	*19.7*

Table 2.2 Land use around Meskel square from the LDP : Existing and proposed

2.9. Transport

Addis Ababa city transportation is served by limited modes of transportation. Taxi and buses are the major mood of transportation next to walking. Currently there is no mode of rail transportation or water transportation.

Walking and cycling

In other part of the country urban areas bicycle is one mode of transportation. But in Addis Ababa the role of bicycle is insignificant (World Bank African Region Scoping Study 2002) due to the topography of the city. Flat terrain is rear instead it is full of hills and downs in addition to that people doesn't have the culture to ride a bicycle.

Fig. 2.34 African Avenue night view

Fig. 2.35 Majority of the society using walking as way of travelling

Walking is the main means of transportation for a number of residents. Walking is the dominant mode if all short trips are considered (60.5%). There is large volume of pedestrians. Inhabitants have the culture to walk during free time and after work especially on wide and commercial streets like African Avenue one of the busiest street and preferable street for walk.

But there are no walkways over a large length (63%) of the roadway network. This is a major concern because it contributes to the increased pedestrian involvement in traffic accidents (10,189 accidents occurred in 2004.). Unlike other cities in the country,[9] bicycle use is insignificant because of topographic inconveniences.

Public transport

The main Public transportation in Addis Ababa is buses and taxis. Public transport in the city consists of conventional bus services provided by the publicly owned "*Anbessa*" City Bus Enterprise, taxis operated by the private sector, and buses used exclusively for the employees of large government and private companies. The city bus enterprise have 524 buses[10] , but now 500 buses are being added these Buses have 30 seats each; they have a carrying capacity of 100 people in a crowded situation. Currently more new buses which have a more carrying capacity are being assembled in Addis. Taxis have a carrying capacity from four (small taxis) to 11 persons (large taxis) or minibuses.

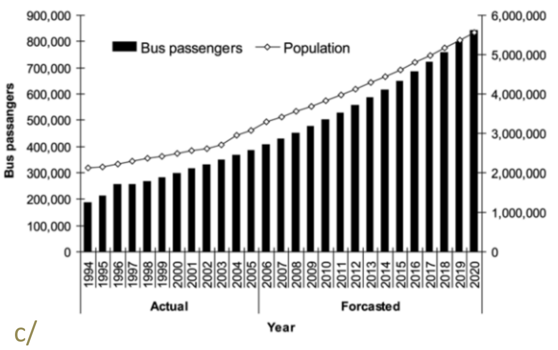
Buses

The absence of an up-to-date structure in the bus company, shortage of finance, and reduction of the subsidy from the government are the biggest challenges for the service. The lack of well-defined performance parameters to evaluate the operational efficiency of the bus company is also a constraint for development. The other challenge is the constant growing demand of user which is directly related to the rapid growth of the population.

[9] *Ethiopian Road Authority, 2005*
[10] *Journal of Public Transportation, Vol. 10, No. 4, 2007*

a/

b/



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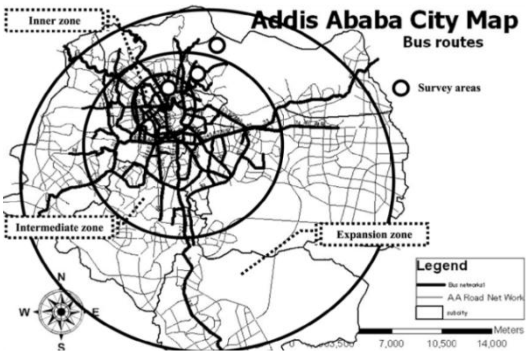


Year	Registered Taxis	Growth Rate (%)
1999–2000	8266	-
2000–2001	8847	7.0
2001–2002	9910	12.0
2002–2003	9930	0.2
2003–2004	9262	-6.7
2004–2005	11806	27.5
Average	8.0	

Registered and Inspected Taxis for 1999–2005

Table 2.3 Growth rate of taxi [12]

Fig . 2.37

One of the discouraging things to use buses in Addis is the long waiting and longer duration of trip. This occurs due to one management problem no superior supervisor for drivers, the other is the high user and high traffic problem. The average passenger waiting time is *30-45 minutes*; the average travel time is 45-60 minutes and average for bus to passengers is 1:1000 but this figure may decrease due to the introduction of the new buses. Due to this reason people are discouraged to use bus those who can afford to use a taxi always prefer to use taxi or anther alternate mood of transportation. Public transportation is an important element in day-to-day activities in Addis Ababa because, it is a relatively affordable means of transportation, infrastructure is not sufficient to promote private vehicle ownership, and it promotes reduction of environmental pollution and traffic accident.

Fig . 2.36 Figures showing the trend of bus usage

a/ *People waiting in queue for a bus*

b/ *Population and Bus Passenger Growth* [11]

c/ *Addis Ababa city road and bus network*

Taxis

Public transport service is highly dependent on taxis as a mode despite high fares (taxis are an expensive means of transportation when compared to buses), which are not affordable, particularly for the low-income group (i.e., the urban poor) mostly used by middle income or high income groups. Of the 14,083 taxis operating in Addis Ababa in 2005, 12,283 had 12 seats and 1,800 were small taxis with 4 seats. The 12 seat taxis are the most used or popular means of transportation they are called "blood vessel of the city". Taxi is the speeds are affected by frequent stopping for loading and unloading. Inadequate vehicles, loading extra passengers, and bad behavior of taxi drivers and their assistants are some of the disadvantage of using taxis.

Fig . 2.37 Taxis in queue waiting for users

[11] *The Bus Company and Central Statistics Authority*
[12] *Addis Ababa Transport Authority, 2005.*

Rail transport

As future development plan, Ethiopia will be connected by rail transport throughout the country and with other neighboring countries. In the new development, it is planned to construct a rail way more than 5000km[13].

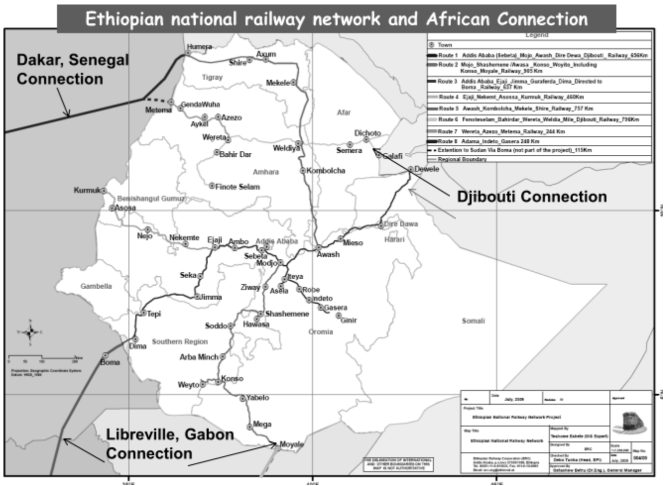


Fig. 2.38 Proposed National rail way network of Ethiopia

Light rail (Tram)

Due to the high demand of the public transport providing additional means of transportation is obligatory. The Ethiopian railways corporation (ERC) launched a project called Addis Ababa light rail transit in September 2010. It covers a total length of 34.25 km from this North-South line covers 16.9 km and East-West line 17.35 km and these two lines (i.e. North-South and East-West lines) use common track of about 2.7km.

The project could be delayed because part of it was originally planned to pass through Meskel Square, instead a new design is expected to be done, which takes the route behind the Addis Ababa Exhibition Centre. The reason for this is said that Meskel square will have its own project of 4.3Km *Meskel Square-Bole Bridge project.* Therefore the site will be served by the new means of transportation. As shown on figure *a/* by lightly shaded lines, the future expansion will extend to the boundary of the city. The construction is already begun in 2011.

a/

b/

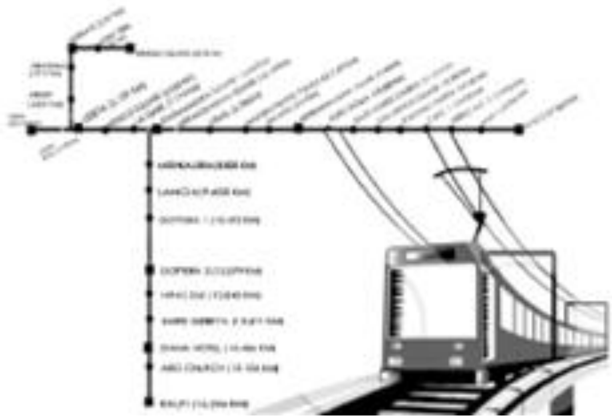


Fig. 2.39 Proposed Light rail networks in Addis Ababa

a/ Different Phases of the Light rail transport construction

b/ North- South and East- West light rail line which will be constructed in the first phase

[13] *July 2012 Ethiopian Railways Corporation (ERC), Yehualaeshet Jemere (MSc. CEng) Chief Officer, Construction and Project Execution Department*

Parking

According to studies, sufficient parking facilities are one of the major focuses to develop Addis Ababa's transportation structure. According to the city administration plan, the road from Meskel Square to Megenagna and from Meskel Square to Bole International Airport (Africa Avenue) are priority areas that need immediate parking lots as there is a large concentration of vehicles in these areas that lack sufficient parking facilities compared with the traffic flow. The existing parking service is inadequate and suffers from structural problems, mainly street parking. Street parking also affect the public transport especially when taxis (minibus) try to load or unload customers they will be forced to stop in the middle of the road because of occupation of sideways by parked cars. Consequently it has contributed to inefficient utilization of the road network, safety and congestion problems. Thus parking remains one of the critical issues that need to be addressed through the transport planning of the city. One of the proposals of the revised master plan of the city is the provision of adequate parking spaces by developing proper off-street parking facilities to reduce bottlenecks and congestion at critical road intersections and locations.

2.10. Green Cover and Open spaces

The northern hills of Addis Ababa, which were the first settlements, were once covered with mixed indigenous forests consisting of various tree species. However, already at the end of 19th century, the natural vegetation was reduced significantly due to population growth and expansion of the city. Since 1895 Eucalyptus species have been introduced for satisfying the growing demand of wood for fuel, construction material and to reduce the Pressure on the remaining natural vegetation and this rapid growth is still a challenge for green areas. Still now "Mount Entoto" is the biggest green cover in the city. According to the master plan, it is planned to integrate green areas into city level, district and local open spaces.

Fig. 2.40

Fig. 2.41

Forestry

At the wide city level, there are forest areas which are usually on mountains and are being preserved and forestation activities are being taken seriously. These areas are well managed in the sense of preservation of trees and forestation. But, people do not use these areas since they are not easily accessible and do not have the necessary facilities to be used as recreational areas.

Fig. 2.40 Forest cover at Yeka mountain

Fig. 2.41 Forest cover at Mount Entoto

Parks

The district level green areas include street sides, parks, plazas and most of the open spaces found in the center of the city. The district level open spaces are officially designated as plazas, squares, streets and parks. Currently, there are seventeen parks in the city which have their own reserved space and are considered as main places for recreation.

a/


b/


c/


d/


The city parks are mainly used for weddings, graduation and other community activities. On other days, they are used by the local people for the purpose of relaxing areas, reading areas and meeting places. The management of these places looks relatively good. They are not properly managed when it comes to the use of the spaces. Services given by the parks are cafeteria and restaurant services. These are popular places of recreation in the city.

Local open spaces

At the local or small neighborhood level, there are many open and green areas which are used for festivals, children playgrounds and other social activities. These places are not yet designed or planned. Some of them are left out spaces between residential houses and the ones which are distinguished as urban open spaces are not managed well. Most of these places are being either sold for private investors or used as housing plots for real estates and condominiums. But for the low income people this open space is a place for many activities and social gathering places. Nowadays, the vegetation coverage of Addis Ababa including individual trees in private yards is estimated at 7,900 ha by the Urban Agricultural Office (UAO), covering 14.6% of the total area. About 98% are plantation forests mainly consisting of Eucalyptus trees.

Fig. 2.42 Parks and Local Open Spaces

a/ Reading and resting in parks

b/ Small scale zoo in parks

c/ & d/ Local Open spaces which are used as playgrounds

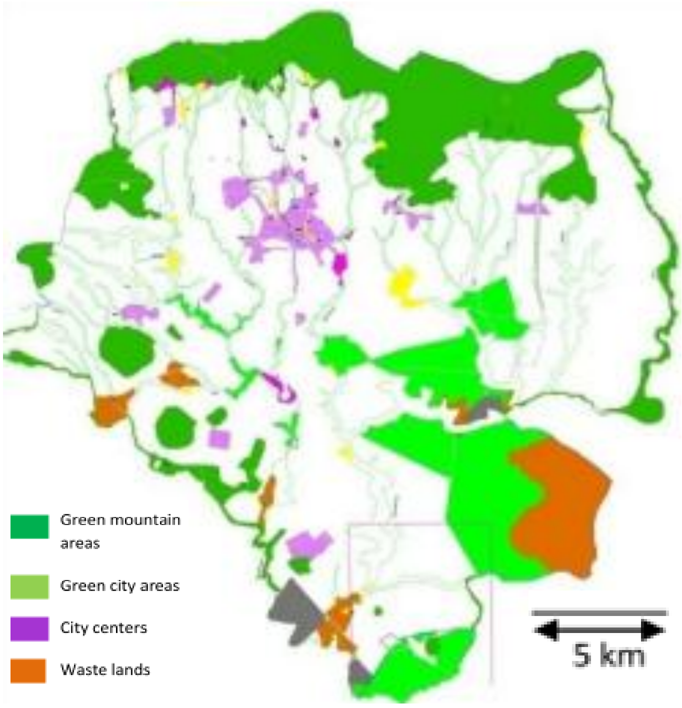
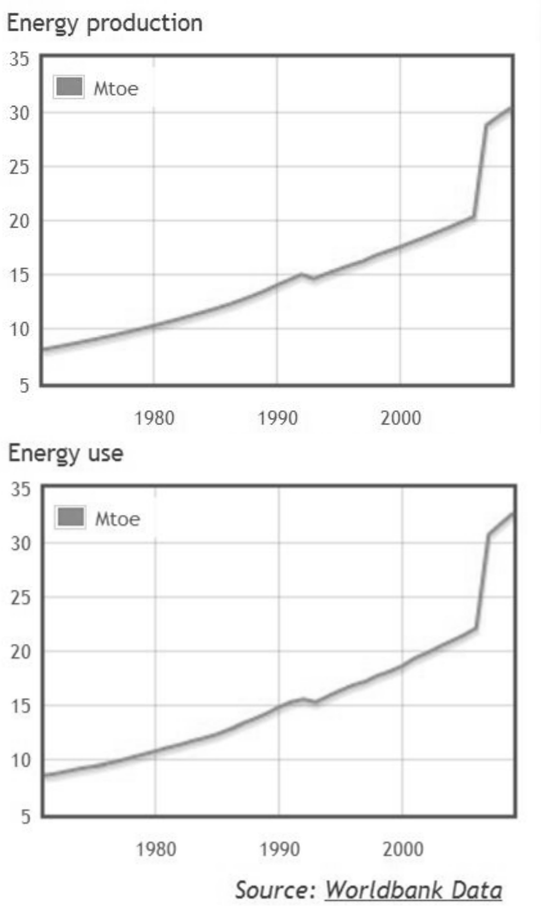


Fig. 2.43 Current open and green space in the city

The revised Addis Ababa Master Plan (Addis Ababa City Government 2002) sets ambitious policy goals for the green sector in general, and the forest sector in particular. About 22,000 ha or 41% of the total area of Addis Ababa is reserved for the green frame of which more than half (about 12,500 ha)[14] is foreseen for forestry. In other words, the present forest area needs to be increased by 58% while the existing forests have to be brought under sustainable forest management regimes. Now green area per person is 0.7m^2 while in Paris it is 12m^2 per person.

2.11. Energy sources



Total installed electricity capacity (2008): 929

- Hydro-electric: 84.36%
- Conventional thermal: 14.85%
- Geothermal: 0.79%

Total primary energy supply (2009): 32,678 ktoe

- Bio-fuels and Waste: 92.0%
- Petroleum Products: 7.1%
- Hydro-electric: 0.9%

Ethiopia relies heavily on a limited set of renewable energy resources to meet its requirements: principally biomass for thermal energy in the residential and commercial sector and large hydropower for electricity. It has yet to develop its other renewable and non-renewable resources in significant scale.

[14] JOURNAL OF THE DRYLANDS 1(2): 108-117, 2006
[15] Renewable Energy and Energy Efficiency Partnership, http://www.reegle.info/countries/ethiopia-energy-profile

One of the defining characteristics of the energy sector in Ethiopia is its overwhelming dependence on biomass energy. Biomass energy, consisting of wood, charcoal and agricultural residues, provides 92% of the total final energy consumed. The main uses for biomass energy are for residential and commercial cooking. Biomass residues are also used in the sugar and tea industries. More recently, liquid bio-energy in the form of ethanol has started to be used as a gasoline (E10) in Addis Ababa. Per capita consumption of bio-energy in Ethiopia is about 1 ton; annual consumption of biomass energy exceeds 80 million tons.

Reliance

Ethiopia does not produce fossil fuels and imports all its requirements. The annual import of fossil fuels now stands at 2 million tons. There has been some exploration for oil, but no commercial deposits have yet been found.

Extend network

Demand for energy is growing rapidly in Ethiopia. Electricity consumption on the national grid has grown at more than 12% annually, petroleum consumption at 11% and biomass at 6%. Access to sustainable and improved energy services are, however, still very low with only 41% of the population having access to grid electricity. Per capita electricity consumption is only *35kWh* and per-capita consumption of petroleum fuels is 23kg. These figures compare unfavorably even to Sub-Saharan Africa levels.

The national power utility maintains two different power supply systems: the inter-connected system (ICS) and the self-contained system (SCS). The ICS is the national grid, and uses power sourced from hydroelectric, geothermal and diesel plants. The SCS consists of mini-hydropower plants and isolated diesel generators spread across the country.

Capacity concerns

Ethiopia relies principally on biomass for thermal energy in the residential and commercial sector meaning about 200,000 ha of forest cover is lost annually because of the population's need for firewood. With it, about two billion square meters of soil is lost annually due to erosion. Farm yield potential is therefore reduced by 2% every year.

If Ethiopia carries out its current energy development plans, the country will soon be more than 95% dependent on hydropower. Extreme hydropower dependence leaves Ethiopia's power sector vulnerable to drought, an increasingly risky scenario due to climate change. Falling reservoir levels will affect Ethiopian electricity consumers and export revenues.

Renewable Energy

In Ethiopia still approximately 70-80% of the primary energy share is taken from biomass. But the biomass, basically wood which is processed to charcoal, is neither cultivated in a sustainable way nor is it used efficiently. About 80-90% of the electric power is generated from hydropower but still electricity is not distributed for more than 50% of Ethiopian people. Fossil fuels account only for 5% of the primary energy consume, they cost nearly 50% of the export earnings.

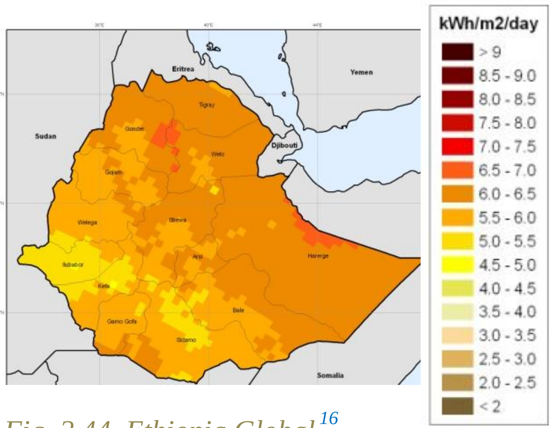
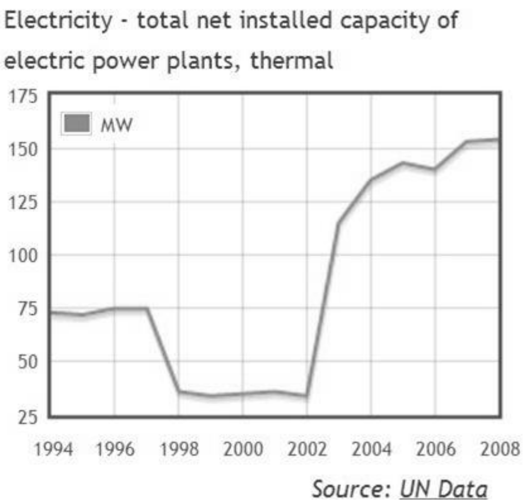
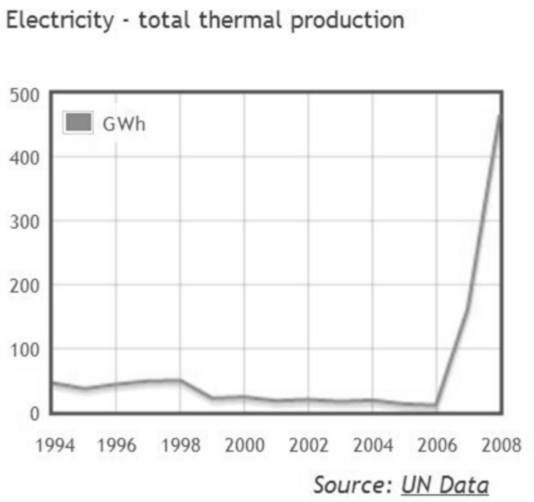


Fig. 2.44 Ethiopia Global[16] *Horizontal solar radiation*





Therefore it seems to be recommendable to extend a sustainable use of renewable energy sources. The potential of renewable energy is promising the sun is strong because we are close to equator and a lot of water runs down from the highlands and several hot springs can be found easily in the giant African Rift Valley which is not far from Addis Ababa.

Solar energy

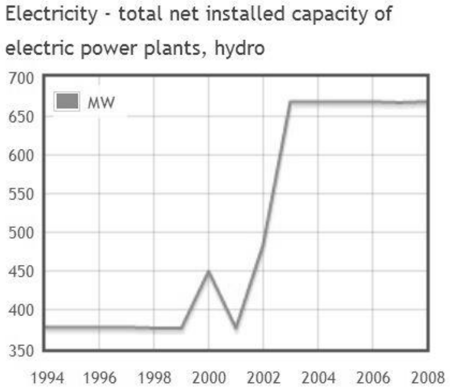
For Ethiopia as a whole, the yearly average daily radiation is 5.26 kWh/m^2. This varies significantly during the year, ranging from a minimum of 4.55 kWh/m^2 in July to a maximum of 5.55 kWh/m^2 in February and March. Addis Ababa gets solar radiation approximately 5.5-6KWh/m^2/day.

On a regional basis, the yearly average radiation ranges from values as low as 4.25 kWh/m^2 in the areas of *Itang* in the *Gambella* regional state (western Ethiopia), to as high as 6.25 kWh/m^2 around *Adigrat* in the Tigray regional state (northern Ethiopia). Current uses of solar energy are for off-grid rural applications in homes, rural telecoms and in the social sectors (water pumping, health services, schools). Solar energy is also becoming an important alternative to water heating in the major cities. The current total installed photovoltaic power in Ethiopia is about 3.5MW, three-quarters installed in telecom stations (mostly in mobile towers but also in other stations). Solar water-heating installations are in a thousand or so units in Addis Ababa and the major cities.

[16] *Renewable Energy and Energy Efficiency Partnership,* http://www.reegle.info/countries/ethiopia-energy-profile

Biomass

Bio-energy uses in Ethiopia are generally not sustainable: according to a recent study, in more than two-thirds of districts bio-energy uses surpass sustainable yields. Bio-energy contributes to greenhouse gas emissions, due to deforestation and non-renewable use of biomass, in addition to other local environmental problems it creates. There is significant potential to diversify bio-energy sources into liquid bio-fuels and energy recovery from urban domestic and industrial waste. The export of bio-fuel could be an important source of foreign currency for Ethiopia, where there is currently no significant fossil fuel production.



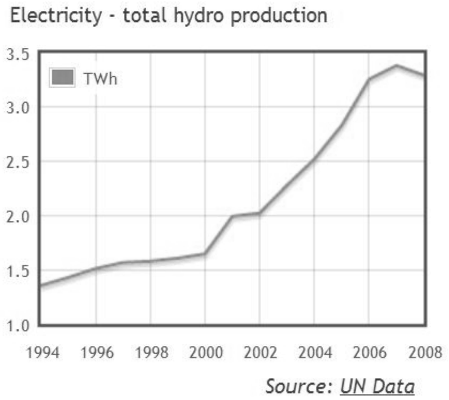


Fig. 2.45 Blue Nile River

Hydro-power

Up to 90% of the electrical energy produced in the country comes from hydropower plants. The reasons for this are found in the climatic and geographic conditions of the country: Ethiopia has a comparatively mild and rainy climate, and the presence of the Blue Nile is a major contributor to the country's water resource. With an estimated *159,300 GWh/year*[17] of unexploited potential, hydropower is the most economically viable energy resource for Ethiopia, but only 5% of the available potential is utilized.

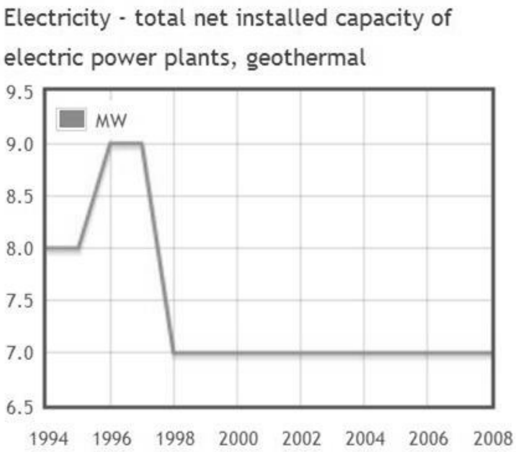
The government has now made considerable commitment to accelerate the development of hydropower resources with the view to increase output to 40GW (or about a quarter of the total potential available) by 2015 to 2020. Hydropower plants in Ethiopia are large and getting larger; projects now under construction include two hydropower plans with capacities of 1800MW and 5200MW. There are fewer than 50 micro hydropower plants in Ethiopia, with combined generating capacity below 10MW.

Wind

"When there is no hydro there is wind, when there is no wind there is hydro. A good match" This statement of a GTZ energy researcher about the climate conditions in Ethiopia suggests that wind energy can provide an important contribution to a sustainable energy supply. But until today wind power does not have a mentionable share in Ethiopia's energy mix.

[17] *Renewable Energy and Energy Efficiency Partnership, http://www.reegle.info/countries/ethiopia-energy-profile*

Ethiopia also has exploitable reserve of 10,000 MW[18] of wind energy, with an average speed of 3.5 – 5.5 m/s, 6 hours/day. Small towns, villages, farms and other scattered loads in remote areas provide ideal situations in which electricity generation from wind is convenient compared to conventional diesel generation or grid connection. The available information identifies two basic zones with homogeneous periodicity separated by the rift valley. In the first of these, covering most of the highland plateaus, there are two well-defined wind speed maximals occurring, respectively, between March and May and between September and November, according to location.



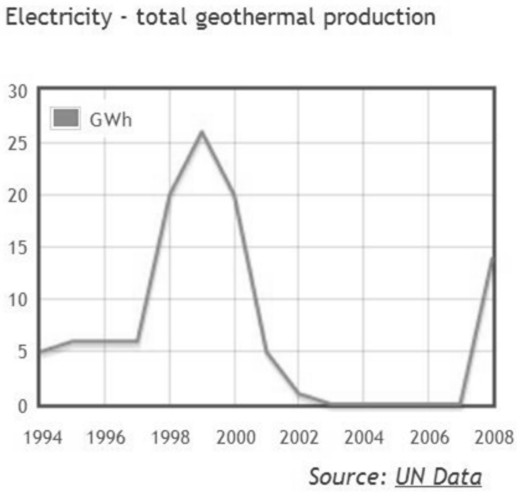


Fig. 2.46 The Great rift Valley

In the second zone, covering most of the *Ogaden* and the eastern lowlands, average wind velocity reaches maximum values between May and August. Wind-power generation is now considered a viable supplement to hydropower on the national grid and two wind farms are now under development in the north and central parts of Ethiopia, with combined capacity of about 170MW. There are plans to develop six more wind farms, with total capacity of 700MW.

Geothermal

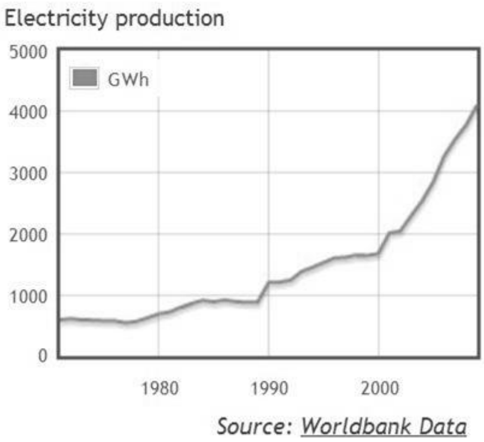
Geologically, Ethiopia has a great potential for the energetic use of heat from the underground. This is mainly due to the great African Rift Valley, which runs through the country. The Rift Valley is a huge rift and fault system that will divide east Africa from the African continental plate in the far future.

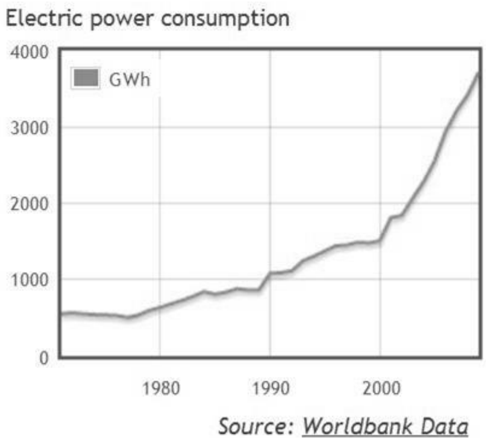
In the Rift Valley there are still active volcanoes and also several hot springs. Hot springs can be found everywhere in Ethiopia. They were even one reason for the foundation of the capital Addis Ababa.

Ethiopia has geothermal power potential estimated to range from 700 to 5000MW. One small geothermal plant (7MW) was developed in the mid-1990s but has ceased production after a few years. The current power system expansion plan indicates that a 70MW geothermal plant will come online by 2015.

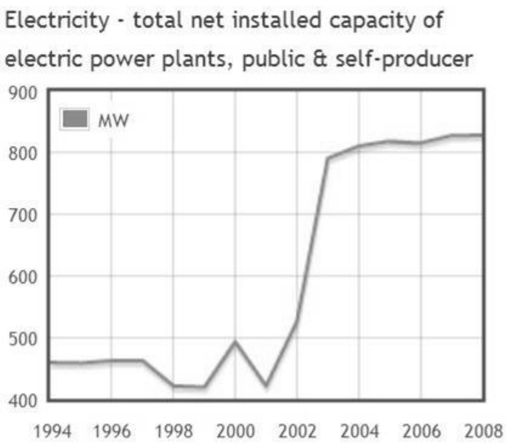
[18] *Renewable Energy and Energy Efficiency Partnership, http://www.reegle.info/countries/ethiopia-energy-profile*

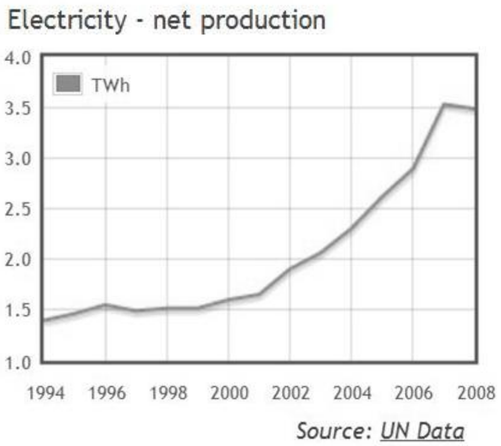
Electricity

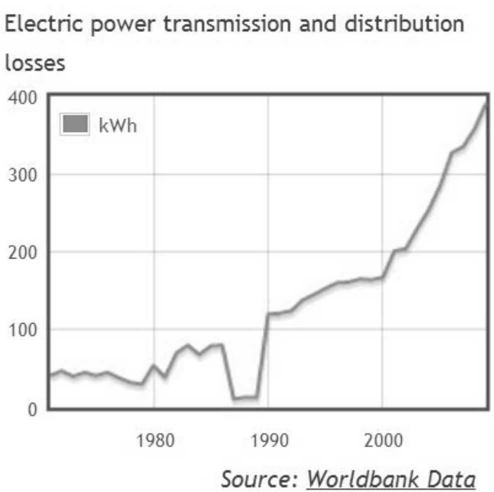




This Various graphs show that how the demand for electricity is growing in a much bigger dimension than the population growth. It is an indicator that we should be able to utilize our renewable energy sources to have a sustained environment for the future.







Though the geological energy potential is excellent, it is difficult to develop this energy source in Ethiopia. A major problem is that high-tech equipments necessary to exploit are very expensive for a developing country like Ethiopia.

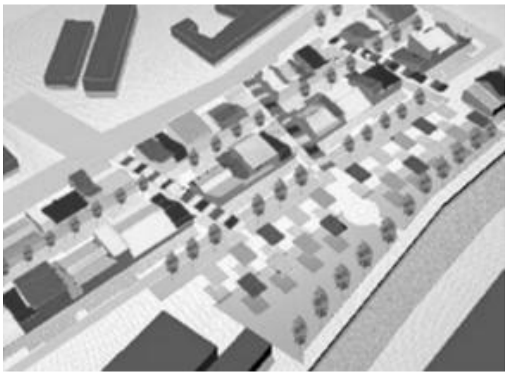
In comparison to most other countries in the world, Ethiopia has extremely low energy consumption per capita. And the country also has a large share of renewable energy sources in its energy mix: Apart from the transport sector, which is almost completely energized by fossil fuels.

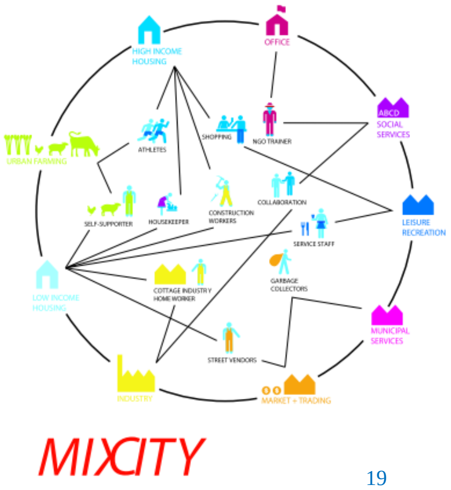
Energy efficiency

The electricity losses through transmission and distribution in Ethiopia are around 20%, which is much higher than the international average of 12-13%. Most of the loss happens during distribution from the national grid to end users. The World Bank is financing projects to promote efficiency and the automation of distribution. Low energy consumption and the use of renewable energy are important indicators for an environment-friendly and sustainable energy supply. A major problem is that biomass, which covers the majority of Ethiopia's primary energy demand, is used in a very inefficient way, leading to deforestation and further environmental problems like soil erosion. Hence, the lack of access to modern energy services leads to traditional biomass use, and biomass use in turn leads to unsustainable environmental harm.

2.12. Urban Context of the city

As mentioned in the previous topics such as settlements, the urban situation is mostly characterized by Mixity. Most of the areas are a mixture of different functions; especially along main roads commercial activities are common and when it comes to the internal spaces the majority of the functions are residential housings and small offices.





[19]

Fig. 2.47 Mixity in all aspect

Central part of the city which is Meskel square and the surrounding mainly characterized by cultural activities but also business and some governmental offices exist.

Along the African avenue which is south of Meskel square is the most vibrant part of the city many commercial activities, many people walking along this street most of the residences change to commercial centers. The geographic center of the city which is called Piazza and Mercato (the largest open market in Africa) are the business core of the country. The suburban area of the city is manly characterized by the grid patterns mainly occupied by the upper and middle income residential units. This residential area is modern relatively to the city and grid urban composition.

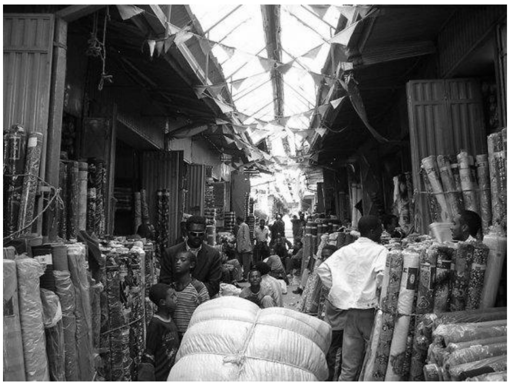


Fig. 2.48 Commercial activities in Mercato

Fig. 2.49 CMC residential area (One of the newly built urban settlements with regular Grid fabrics)

[19] June 8 2009,Cities of change Addis Ababa , transformation strategies for urban territories in the 21st century

2.13. Architectural features of the city

In Addis Ababa the majority of the areas are composed of slum residences. But since the construction sector is growing fast many of this slum areas are under transformation. Social housing, private housing, private and governmental offices and commercial building became the main architectural features of the city.

a/

b/

c/

d/

e/


In Addis Ababa there are about five types of housing typologies: Small houses/ sheds, Apartments, Condominiums, Row Houses and Villas. Unlike Europe, where typologies usually depend on the time and the architectural style of the period, Ethiopia's typologies seem to vary much more according to the income of the owner.

Social housing which was started in 2004 was somehow ruining the aesthetics of the city. One of the problems of this housing is the low standard construction and many faults. In addition to that the layout of these housing blocks doesn’t have a pattern or a fabric to follow.

Ethiopia currently lacks a coherent national housing strategy that could begin to avoid the bad images that have been instilled during the last few decades.

Private housing development started in 1997 by "Hayat" real estate in Addis Ababa, but now there are many real estate developers. Construction of almost all private houses are in the suburb area of the city; these areas are characterized by their modernity which is completely different from the city center.

Fig. 2.50 Various Housing Typologies in Addis Ababa

a/ Slum residences

b/ Condominium aerial View

c/ Condominium street View

d/ Suburb private housings in Addis Ababa

e/ Row Houses in Addis Ababa

In the last 5 years Private and Governmental offices are launching an architectural competition for a modern office building designs and modern buildings are being constructed under construction now.

a/

b/

c/

d/

The architectural feature of the commercial buildings in Addis Ababa became a significant image of the city. The main characteristic of these buildings are having a huge glass facades with curved or regular shape mostly from six to 10 story height. This characteristic now is believed to be "modern building" among many of the developers and owners but these is not Ethiopian architecture these is the influence of newly emerging modern cities like Dubai, on the research book it calls it "*Dubai fever*". For example, *Bole* road was planned as a residential street, but high rises sprung up between the homes, resulting in a new claims on the urban space. Areas devote to sidewalks have been converted to parking spaces used by the visitors and the inhabitants of the high-rises. Bole road has become a six-lane, heavily trafficked street, with little room for pedestrians to walk between the scattered, discontinuous high-rises that pepper the sides of the street. A rapidly growing economy, and therefore a rapidly growing building industry, has created a huge demand for building materials. Architects are also in high demand, with developers calling for rapid completion of the design and building process in order to receive immediate returns. Calls for instantaneous modernization have put the country in furor. Lately there have been more reasons to 'think local'. The current economic crisis has had a major effect on the ability of Ethiopia to import materials cheaply. shortages in foreign exchange have led to rationing and the scarcity of many construction materials, including cement. Ethiopia is finding itself at cross-roads, 'a critical zone'. It needs to shake up the affliction of 'Dubai fever' because if it continues to do that, it is not only altering its urban form, but also encouraging certain economic models to take hold ,which could create serious implications and ultimately lead to a division of the nation's capital.[20]

Fig. 2.51 Various Governmental and private high-rise buildings

a/ African Union Head Quarter

b/ Ethiopian Electric corporation new office

c/ Dembel City Center

d/ Getu Commercial Center

[20] *Cities of change Addis Ababa , transformation strategies for urban territories in the 21st century*

2.14. Technology and Research

The Building sector started to use prefabricated building components. This technology is believed to reduce the cost of buildings by 40 percent from the existing way of construction. Buildings, specially for commercial purpose, are using new façade technology which have its own advantage and disadvantage.

a/

b/

c/

Fig. 2.52 Different construction and material solutions

a/ New prefabricated frame structure system

b/ Exterior view of SUDU

c/ Interior View of SUDU

But the main challenge of the country is all this new technologies are imported from another country. Industries have little roll in the economy of Ethiopia. Many materials for construction are imported including cement, ceramic, finishing materials…etc.

But nowadays the leading higher education institute, i.e. Ethiopian Institute of Architecture, Building Construction and City Development (EiABC), is undertaking various types of researches to provide sustainable solutions for housing by experimenting on different locally available materials. The current research activities include:

SUDU-Sustainable Urban Dwelling Unit

The dwelling was designed based on the current urban conditions and need in Ethiopia. It is a showcase for integrative disciplinary thinking and an experimental laboratory for evidence to convince decision makers, economists, environmentalists, urban planners and architects to rethink traditional building methods and social space requirements, in order to find new ways to build a city. The SUDU project is a first step to re-search, re-apply and re-invent vernacular building techniques that fit the Ethiopian context. Designed for the urban setting, it is a cost-efficient housing proposal which is a ground plus one building having a foot print area of 55 square meters. It is built using rammed earth wall technique, Catalonian dram vault flooring with cut stone and compressed stabilized earth block wall and roofing.

a/

b/

c/

d/

Fig. 2.53 Different construction and material solutions

a/ & b/ different views of SECU Building

c/& d/ Internal and External Views of SRDU Building

SECU- Sustainable Emerging City Unit

The SECU building is a double-storey experimental prototype to present a provocative and innovative design for housing for emerging settlements, as well as inspiring the construction industry and the government and decision makers at large. The research discusses the potentials of innovative building materials for fast growing housing solutions in Ethiopia. The building was realized in 3 months with experts and students from EiABC together with the chair of building construction. The whole house was structurally built out of compressed straw board panels, which will soon be produced in Ethiopia in cooperation with a German company called STRAWTEC. The research is part of the capacity building initiative as well as the higher academic education reform collaborations between EiABC, the Bauhaus University Weimar and the ETH Zurich/Singapore.

SRDU- Sustainable Rural Dwelling Unit

Under the chair of housing, similar to the SUDU, it is situated in the township of Gubre, Guragye zone. It a ground plus mezzanine building which is under construction. we are using locally available straw and clay soil to produce adobe blocks with high concentration of straw to minimize cracking and reduce weight.

3. Urban Design

3.1. Project Area

Our Project area is located at the heart of the capital, Addis Ababa, and this site composes of different cultural, commercial and socio-economic activities. It is also one of the places in the city which has a high traffic density due to the six major roads surrounding it. The total are of the site to be designed is about 22,5 hectares.

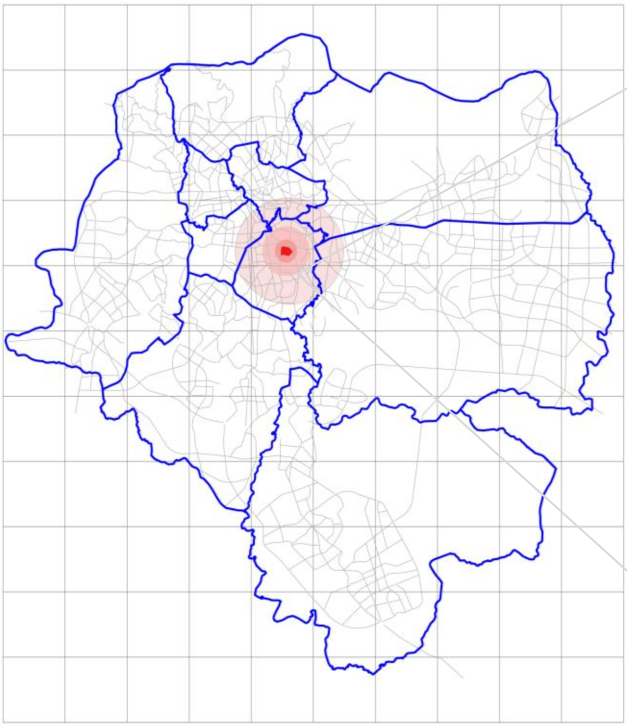


Fig. 3.1 Different sub-cities of Addis Ababa

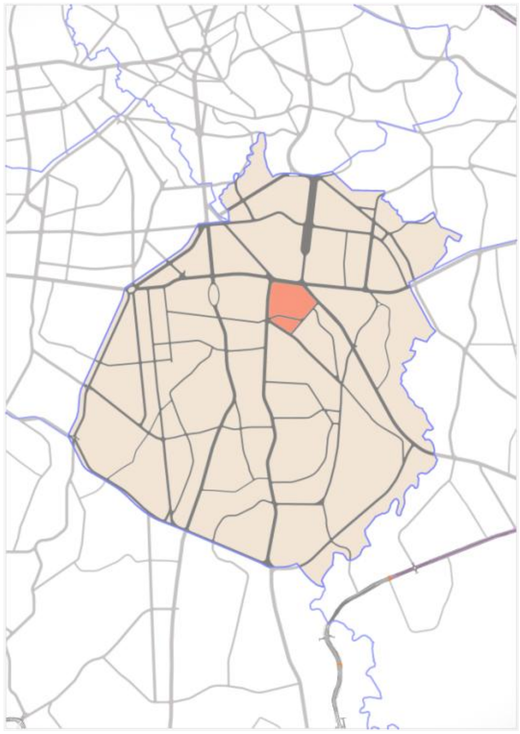


Fig. 3.2 Cherkos Sub-city

Fig. 3.3 The Project Area

3.2. Comparative Analysis

A comparative analysis has been conducted in order to be able to realize the scale of our project in comparison with some very well known places in different areas. The area is compared with two well known places which are familiar for many in which one of them is Parco Sempione in Milan, Italy and the other one is an area in Lecco, Italy which includes the Train station and the biggest commercial center in the city ,i.e. Centro Meridiana, which is designed by Renzo Piano.

Fig. 3.4 Comparison with Parco Sempione of Milano

Fig. 3.5 Comparison with an area in Lecco

3.3. Urban Fabric

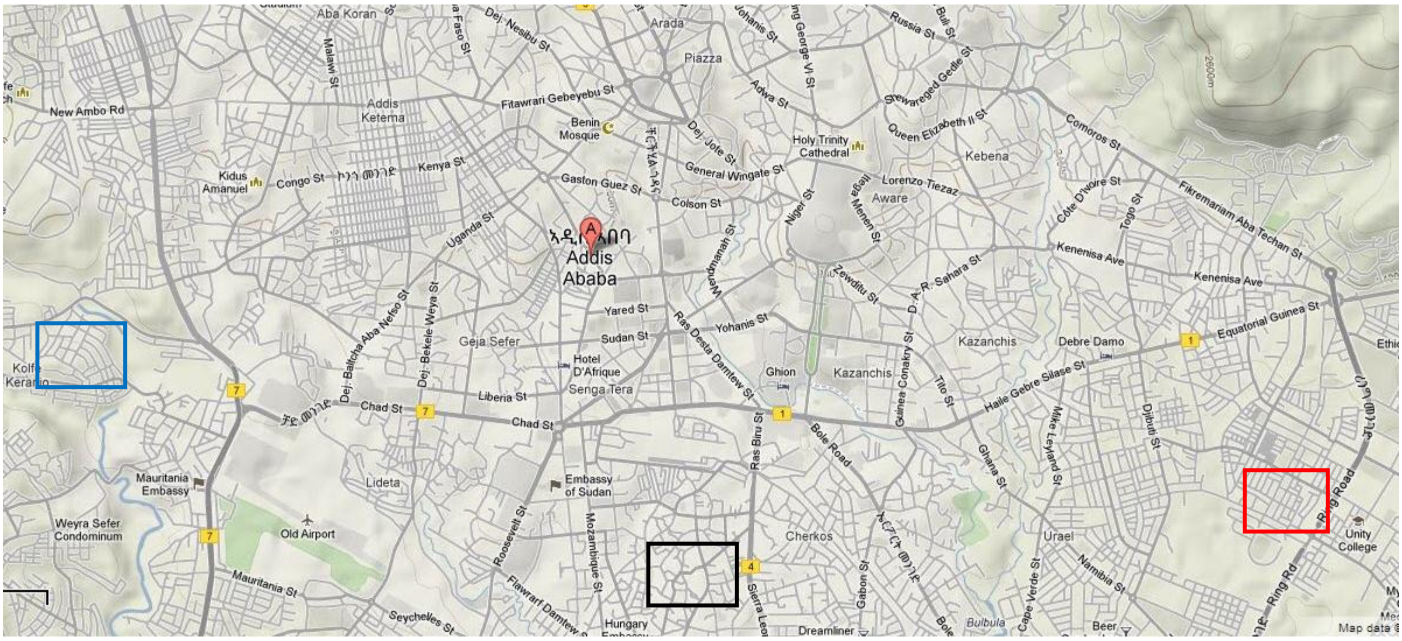


Fig. 3.6 Urban Fabric of Addis Ababa

Type 1- *This is the most common type of fabric in which we can find throughout the city. This type of fabric shows us the indigenous patterns of settlement and it also avoids the problems of segregation and centralization.*

Type 2- *This type of fabric is common along the peripheral lines of the city. It features a grid layout schemes mainly for modern looking recent expansions of residential blocks.*

Type 3- *Mixture of the above two types with a very natural transition from one to the other. This type of fabric along with the indigenous patterns of settlement demonstrate the "mixity" of the city i.e. mixity of commercial and residential areas, mixity of high and low-income groups, mixity of building typologies, and mixity of financing.*

3.4. Site Analysis

The Area around Meskel square is mainly composed of mixed use (commercial and housing) activities and functions which are more related with governmental and social activities.

From this picture one can understand that our site is located at the center of the organic fabrics created by the irregular nature of the roads.

Fig. 3.7 Mobility Networks around the site

The site in this case serves as a center since it is mainly enclosed by various types of governmental, commercial and social activities.

Fig. 3.8 Site as Main Center with various governmental and social activities

As we have seen in the urban fabric analysis, in the indigenous patterns of settlements, whenever we have the street-liners along the main roads it is clear that we will find the in-fills next to them. and this picture shows us the dense distribution of mixed use activities next to the main center.

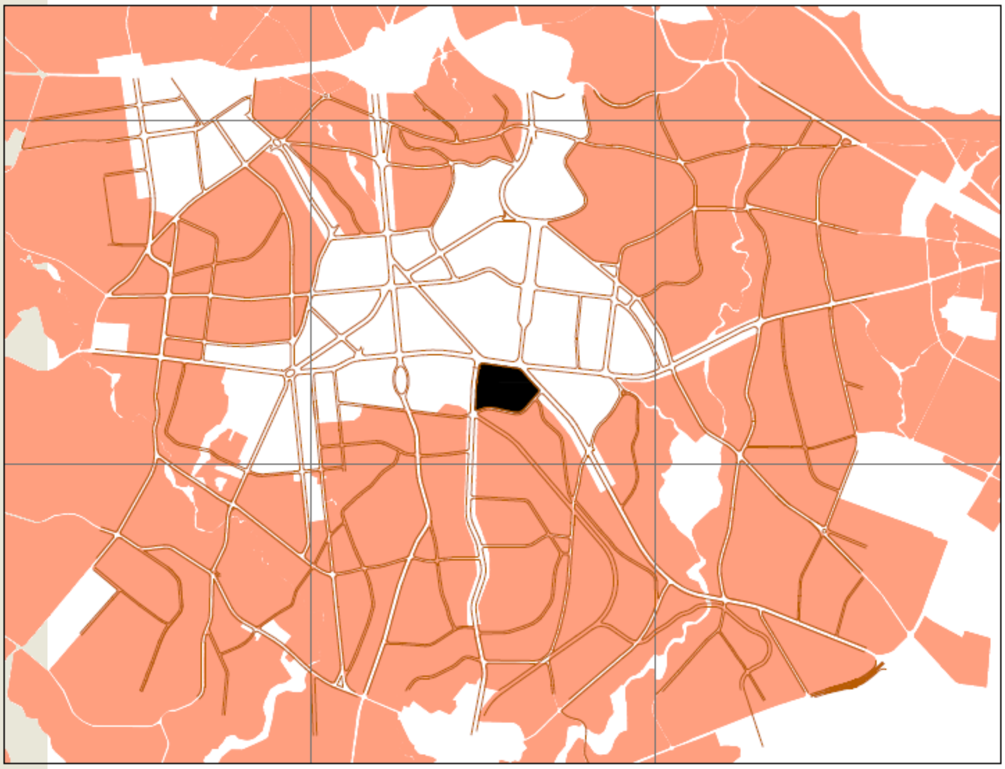


Fig. 3.9 Mixed use (commercial and housing) activities

We have segments of green fabrics along the nearby rivers. These elements don't have a proper connection. Due to the presence of highly dense housing and commercial activities the green elements are limited on the peripheries of the city.

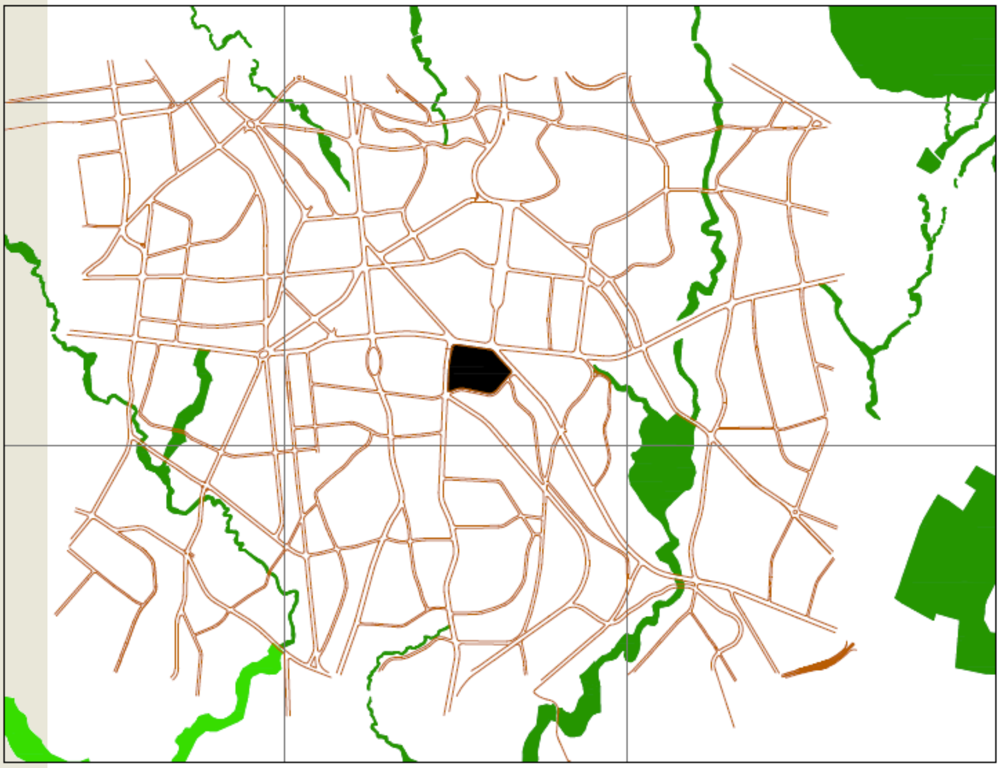


Fig. 3.10 Green Spaces in close proximity to our Site

Here this picture illustrates that the site is located somehow in a hilly area. There is about 10 meters difference between the highest and lowest points inside the site and due to this we can say that it is a good place to have a visual experience of the city.

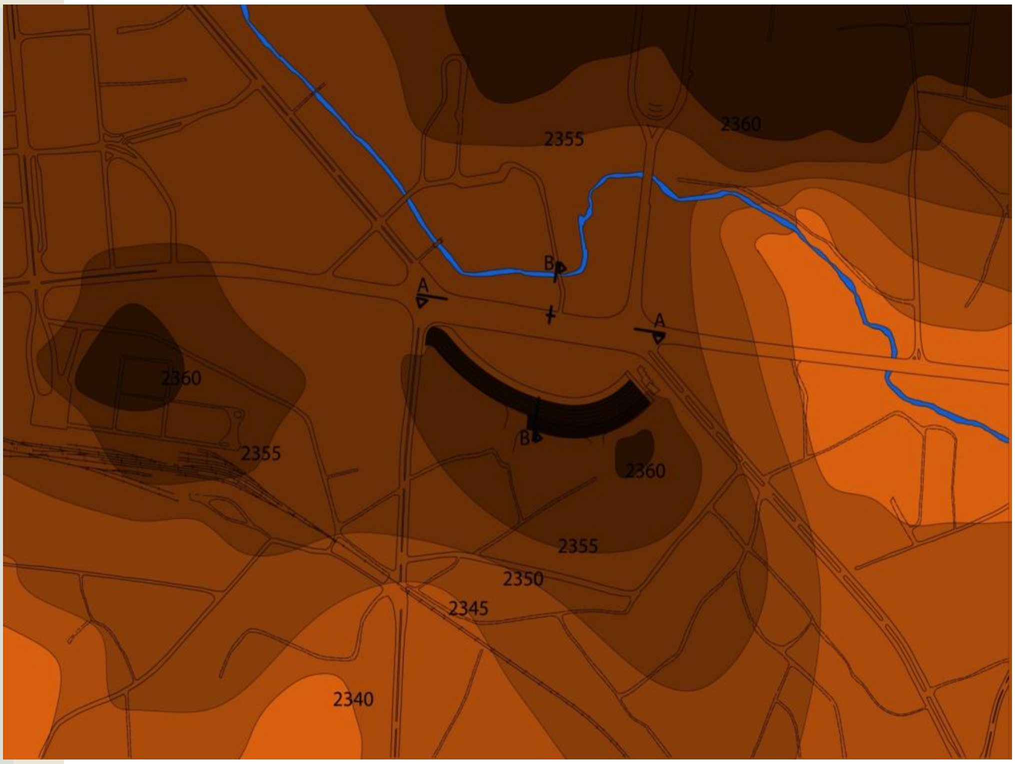


Fig. 3.11 Topographic Map of site surrounding

The Various activities in and around the site are not organized in a planned manner. The distribution of the spaces is random, i.e. there is no balance in the combination of solids and voids.

Fig. 3.12 Solid Vs Void

Commercial activities and main governmental offices are mostly lined along the streets, which makes them the street liners, and the slum housing elements are located behind the main activities, in which they are the in-fills .

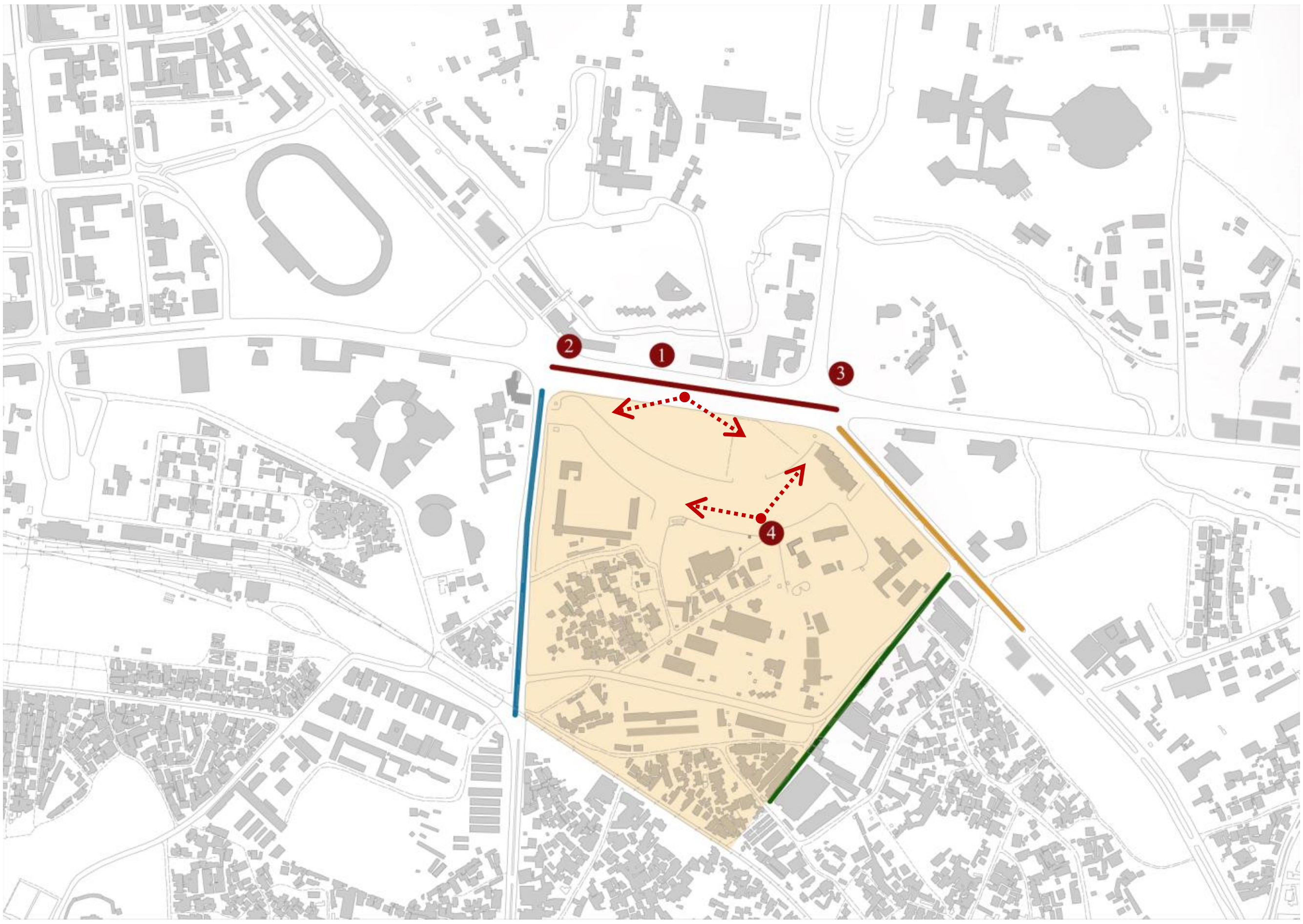
Fig. 3.13 Distribution of functions around our site

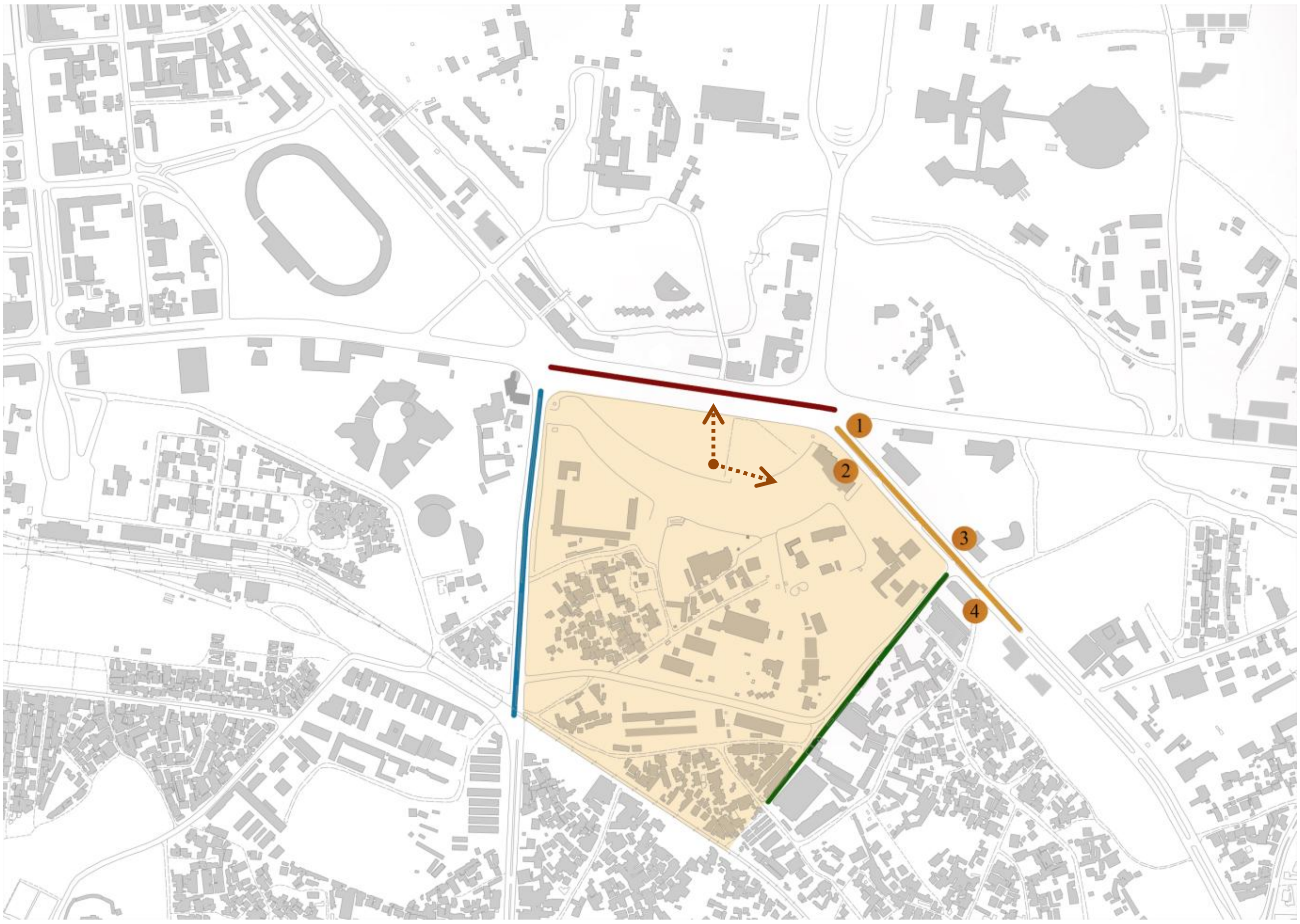
The site is located at the junction of the six main roads of the city. Due to this reason the road in front of the square is composed of 16 lanes and this makes it one with a high traffic density and this is difficult for pedestrians to cross it.

There is lack of connection between the green elements around the site. And bringing the green networks to the site will be one of the main issues of the project.

Fig. 3.14 Road and Green Network

3.5. Site Features



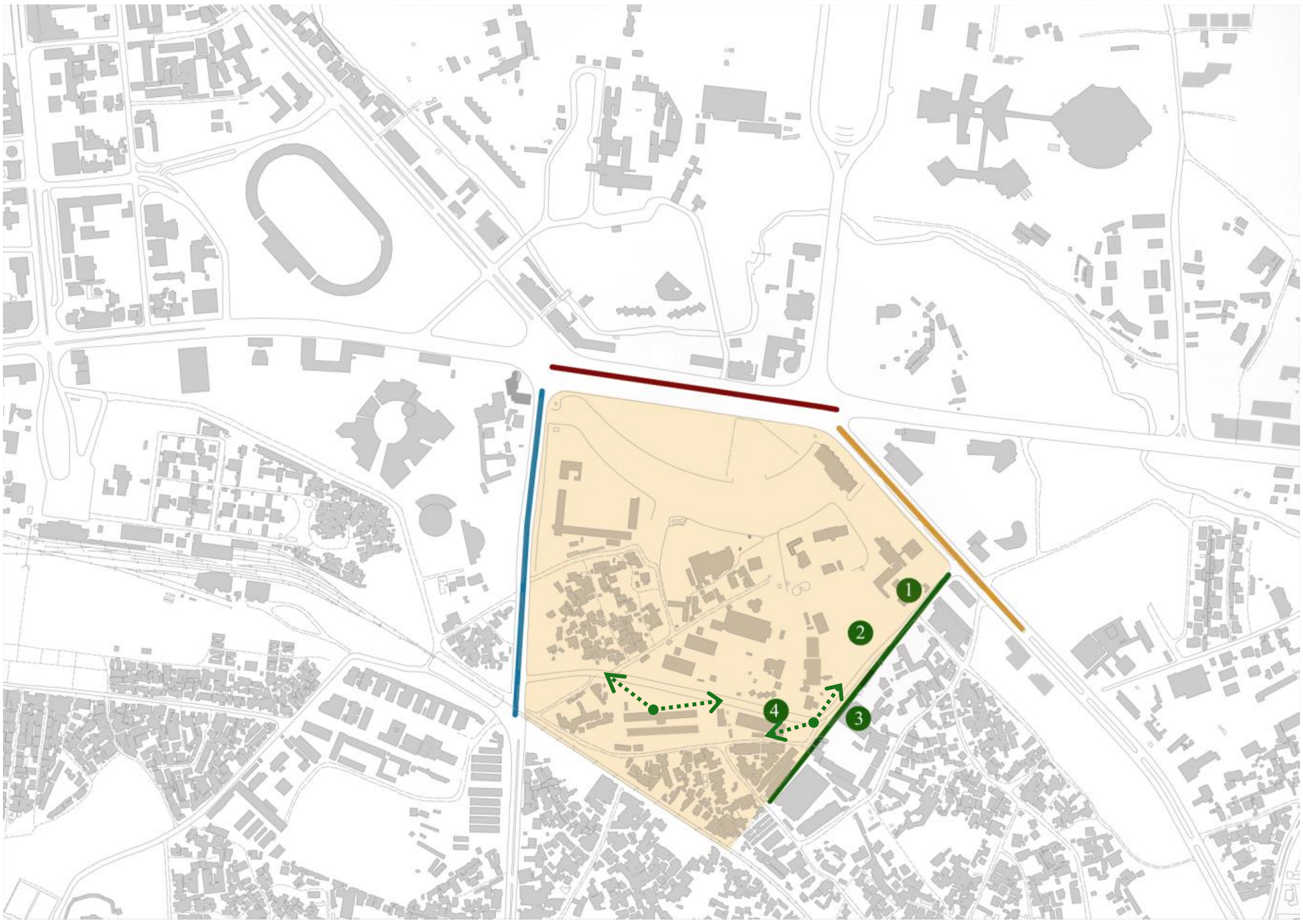

1
2
3
4


1


2


3


4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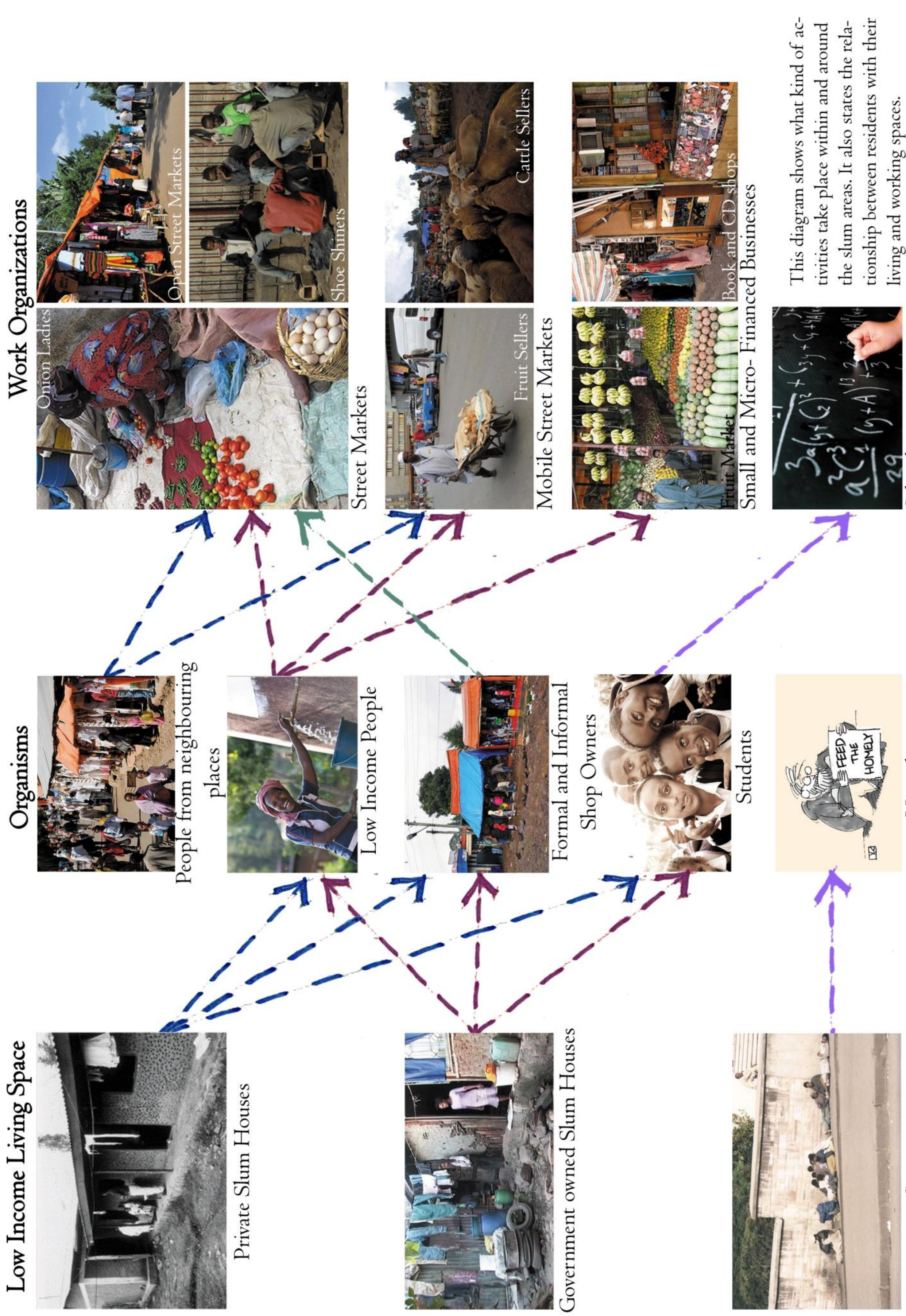


This diagram shows what kind of activities take place within and around the slum areas. It also states the relationship between residents with their living and working spaces.

3.6. SWOT Analysis

Based on all the information gathered about our project area (by meeting with people, researching from books and internet) we have tried to sort out the Strengths, Weaknesses, Opportunities and Threats (S.W.O.T) analysis of the area.

3.6.1. Strength

- Located at the heart of the city and served by major roads and important nodes.
- Surrounded by highly commercial and active public areas which are easily accessible from any direction .
- The Place has high Socio-economic value and center for religious ceremony (Meskel festival)
- Hosts big concerts and special events and also serves as political gathering place.
- Daily Sports activities and also stages The Great Ethiopian run and car races.
- Existing exhibition center which is already familiar to most of the society.
- Huge open area in a crowded city.


Meskel Festival

Great Ethiopian Run

3.6.2. Weakness

- Most of the infill's are dominated by slum housing and sub-standard buildings.
- Poor waste treatment and disposal mechanisms.
- The area lucks architectural identity and harmony, and the landscape is not very well treated.
- Lack of infrastructure and public utilities.
- High unemployment.
- Pedestrian walkways are not sufficient along the streets.
- The Main road along the square is too wide (16 lane) and it is difficult for pedestrians to cross it and there is also high traffic congestion.

Traffic Problems

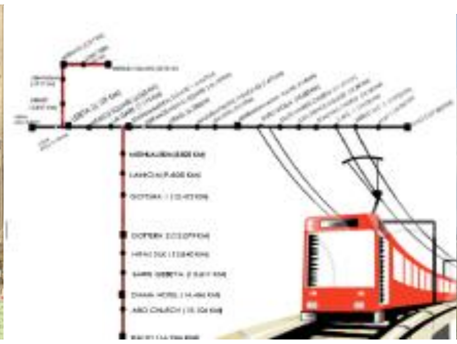
Open space without treatment

Slum Housing

3.6.3. Opportunities

- The site is in front of Addis Ababa national stadium and there are also some important buildings, such as the head quarter of African Economic commission and proposed multistory exhibition center, which are located in close proximity.
- Addis Ababa is capital for most of the activities such as business, politics, culture and so on.
- The Local development plan encourages the transformation of the area with a more social background.
- The site is located in the junction point of two newly proposed, currently under construction, light rail (tram lines) transportation systems .
- New construction is booming in the capital.

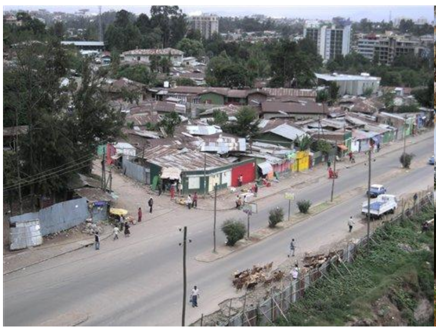

New Constructions


Proposed tram lines


Proposed Multistory Exhibition

3.6.4. Threats

- Bad image of the capital city.
- There is a growing difference between rich and poor.
- Growing modernization which is conflicting with cultural identity.
- Rise of construction prices due to crisis in the global economy.
- Limited local Engineering and construction capacity.
- Inhabitants resistance to behavioral change.
- Economical Problem.


Bad look


Modern with cultural look

No Cultural Recognition

3.7. Goals and Visions

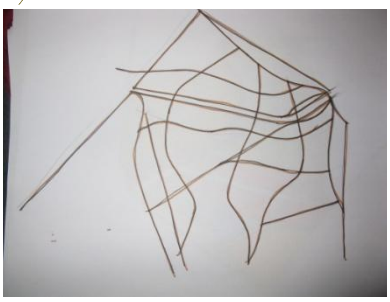
Based on the above existing situation analysis we have come up to understand what is needed to be done around the site so as to improve the living conditions of the society by building upon the positives and improving the negative outcomes of the analysis.
For a better and clear understanding we set out the following goals and visions and their subsequent strategies.

- Making sure the safety and sustainability of the site by effectively providing multiple pedestrian and bike paths along with green networks,
- Manage and define roads according to use and provide alternative means of transportation,
- Slum upgrading and urban renewal by designing a prototype low cost housing,
- Identify and connect Urban Open Spaces (green corridors),
- Balance the proportion between construction versus green/open area,
- Upgrading the quality of life while keeping Identity of the society,
- Encourage vertical densification,
- Proper design of negative spaces,
- Create Job Opportunities.

3.8. Concept Development

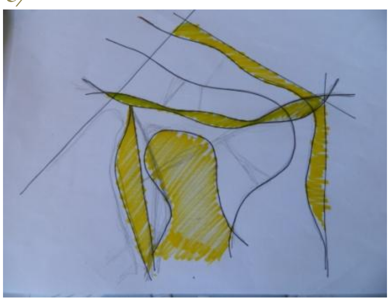
a/

b/



The idea for the concept development of the urban design based on the social integrity that exists between people. As has been discussed in knowledge part of this paper, mixity has been a real character that existed starting from the old days. The social mixity is the reason for the current living and planning styles that can be explored around the city. Most part of the city features an indigenous patterns of settlements and this settlements are organic in nature. Our design is aimed to facilitate and build upon those settlement patterns and provide an upgrading mechanism for the social life which currently exists in the slum areas. In the next few pages we have put in order various schematic illustrations to support our conceptual development and come up with a master plan that will suit the life styles of the society.

c/



d/

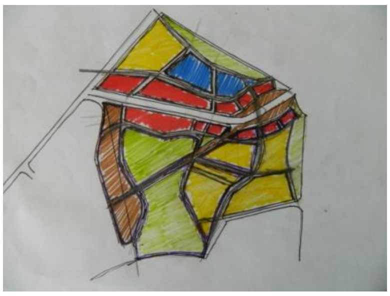


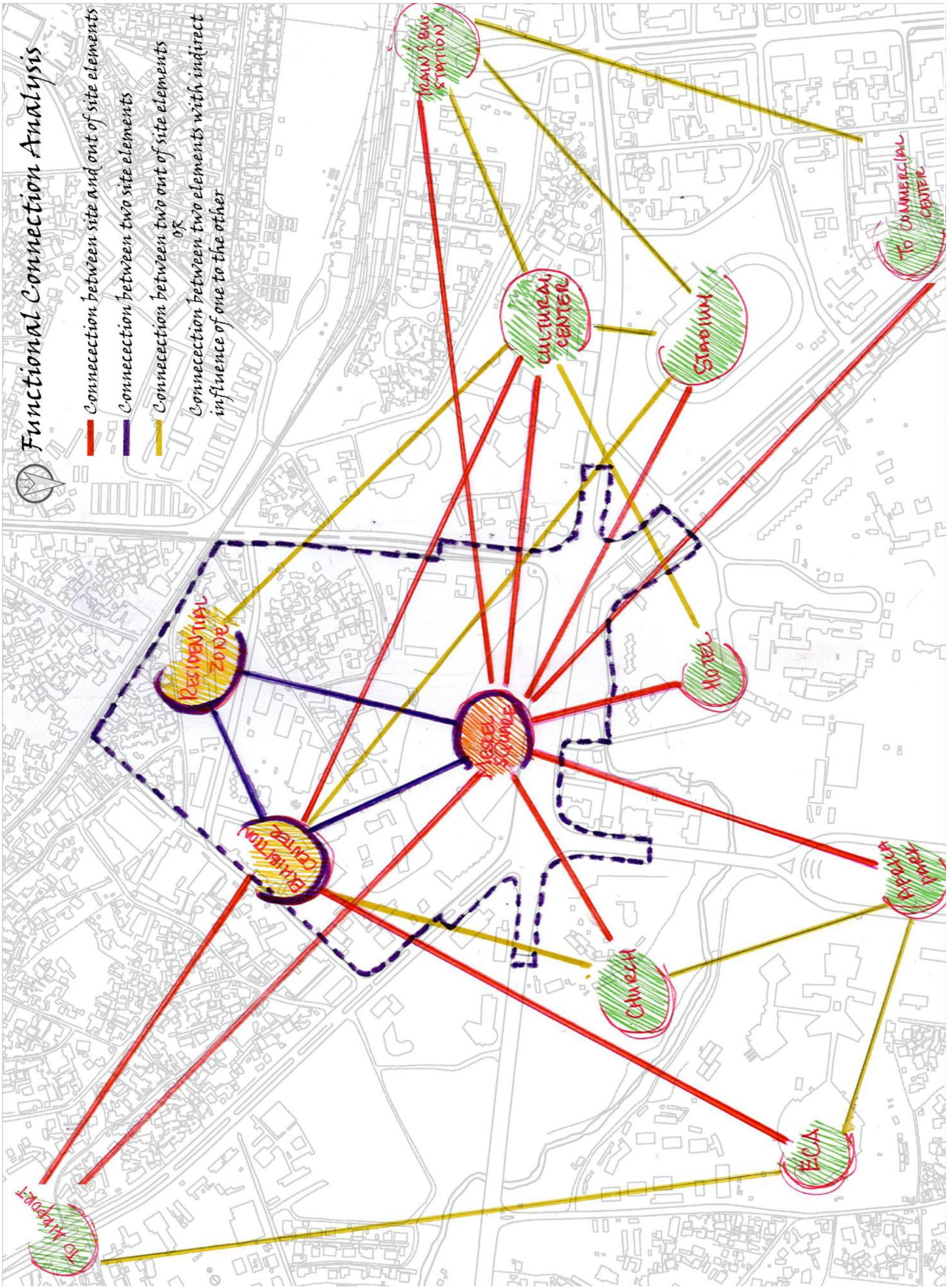
Fig. 3.15 Preliminary concept development

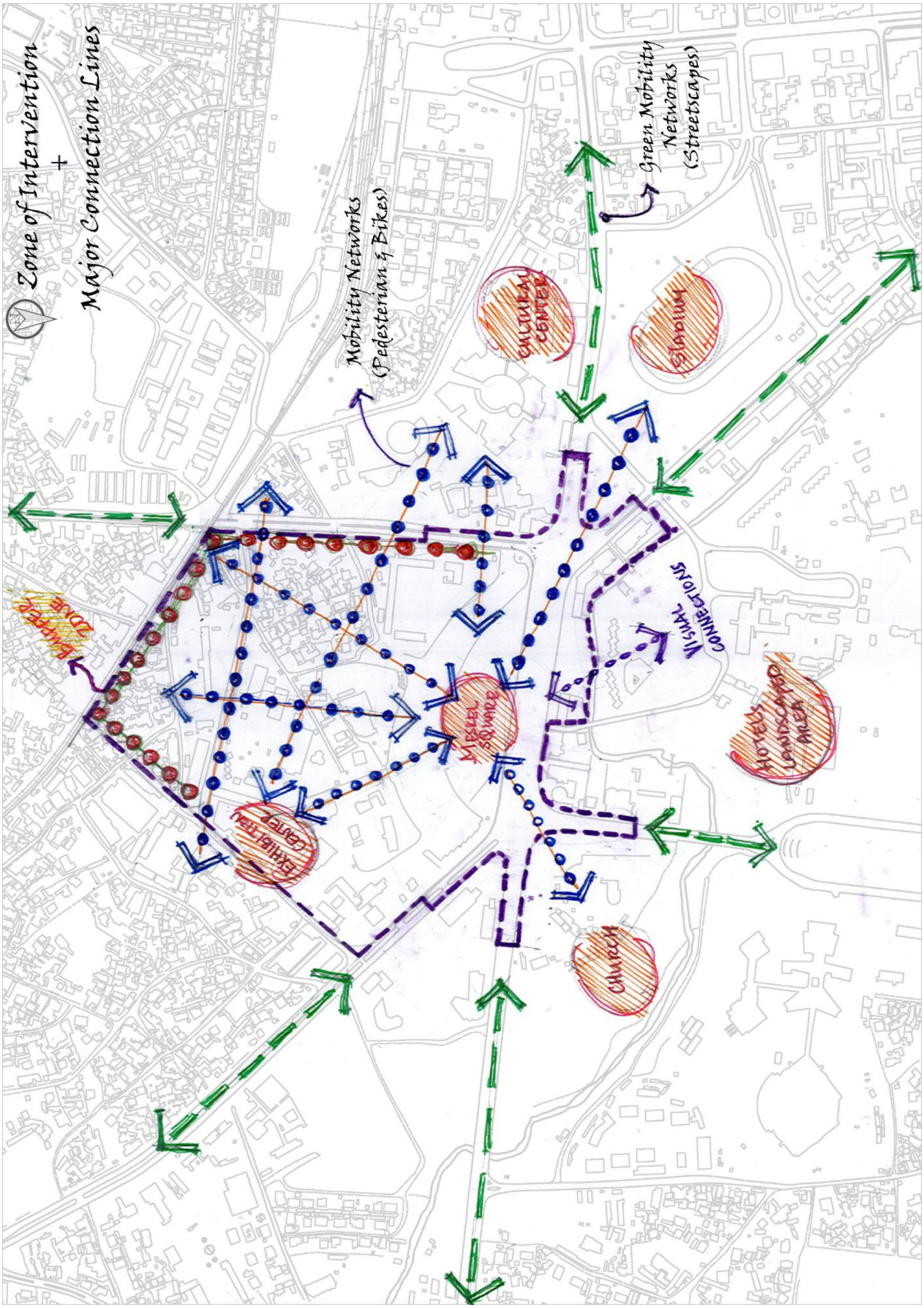
a/ Preliminary sketch

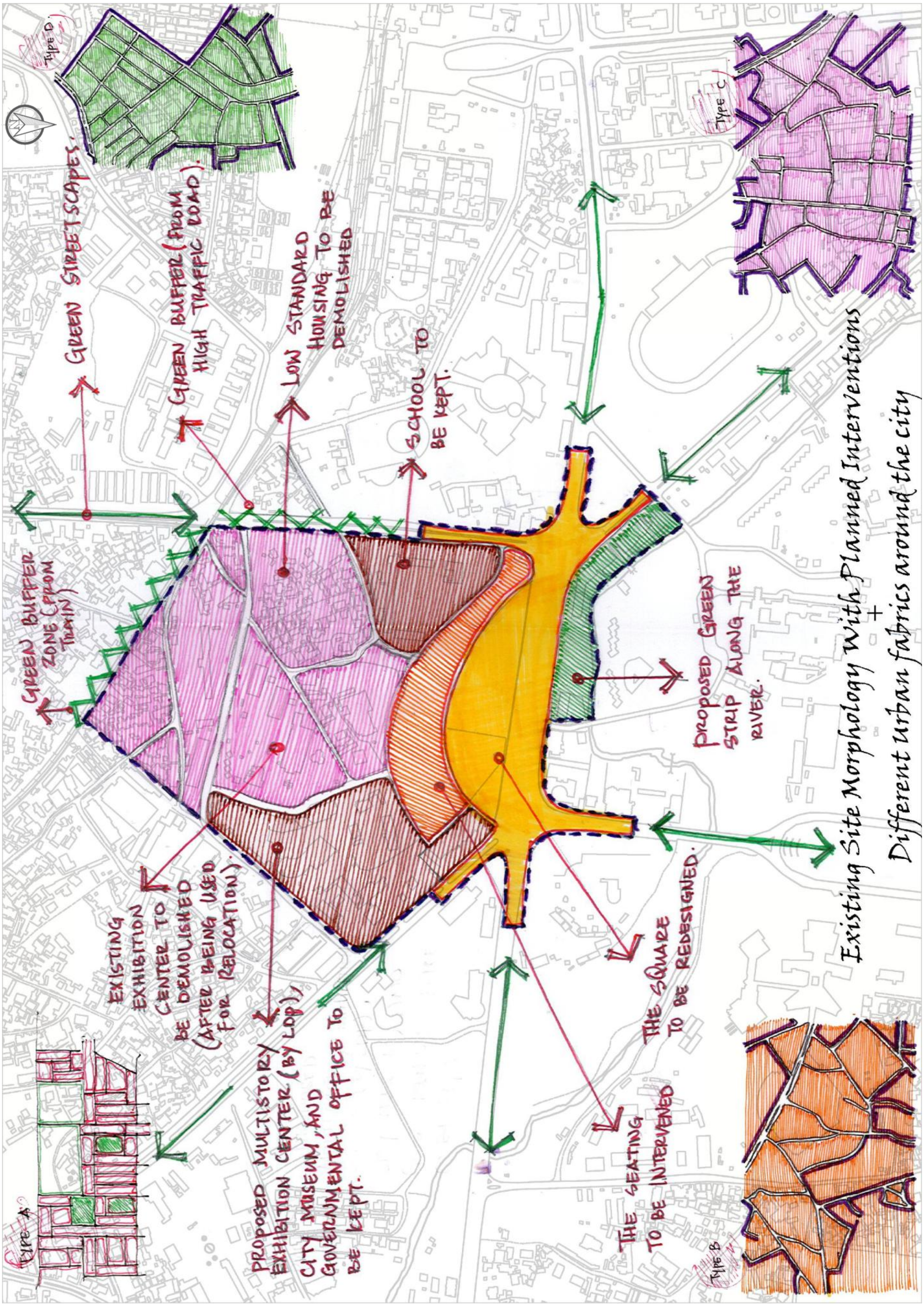
b/ Mobility network

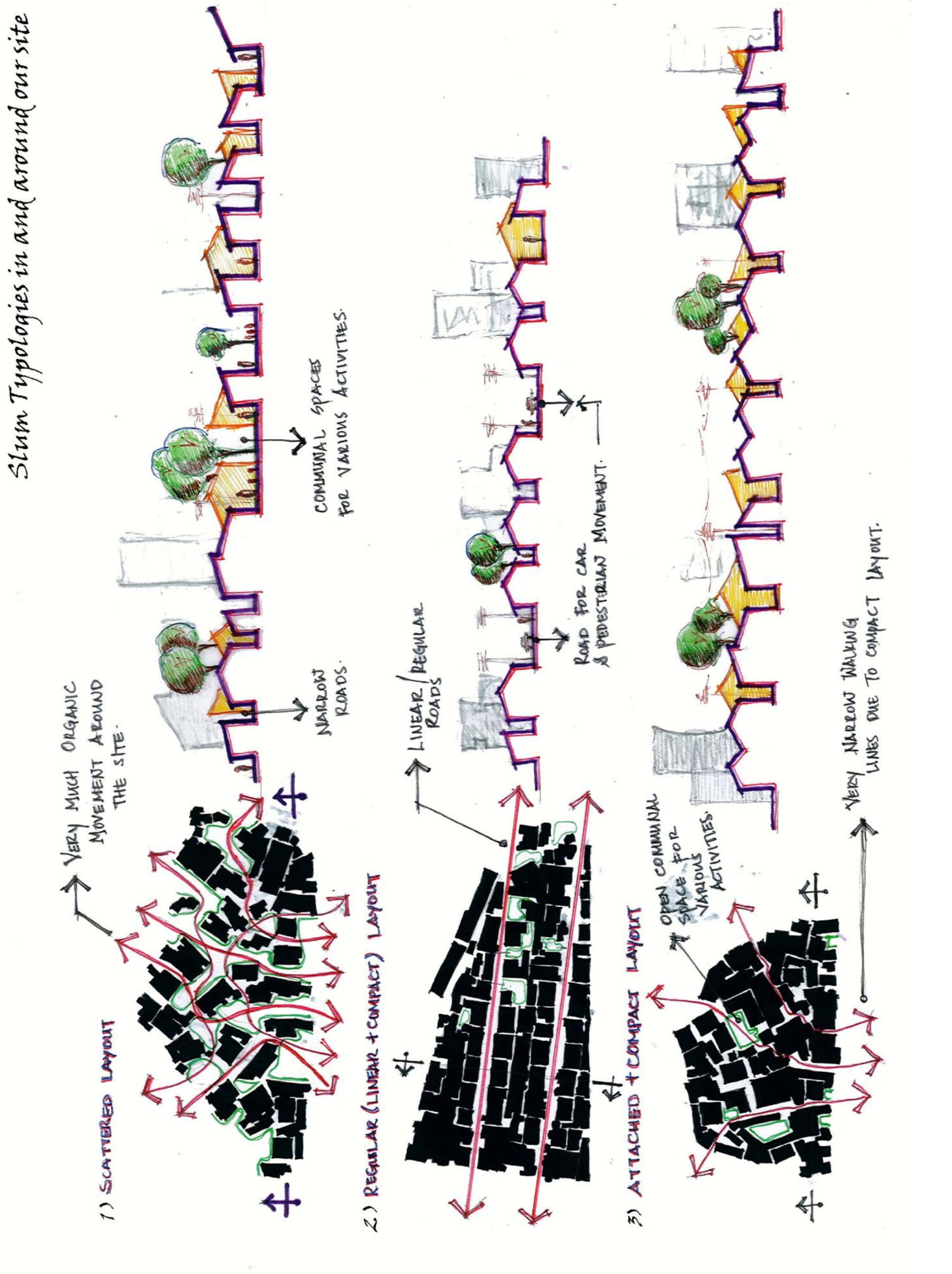
c/ Preliminary concept

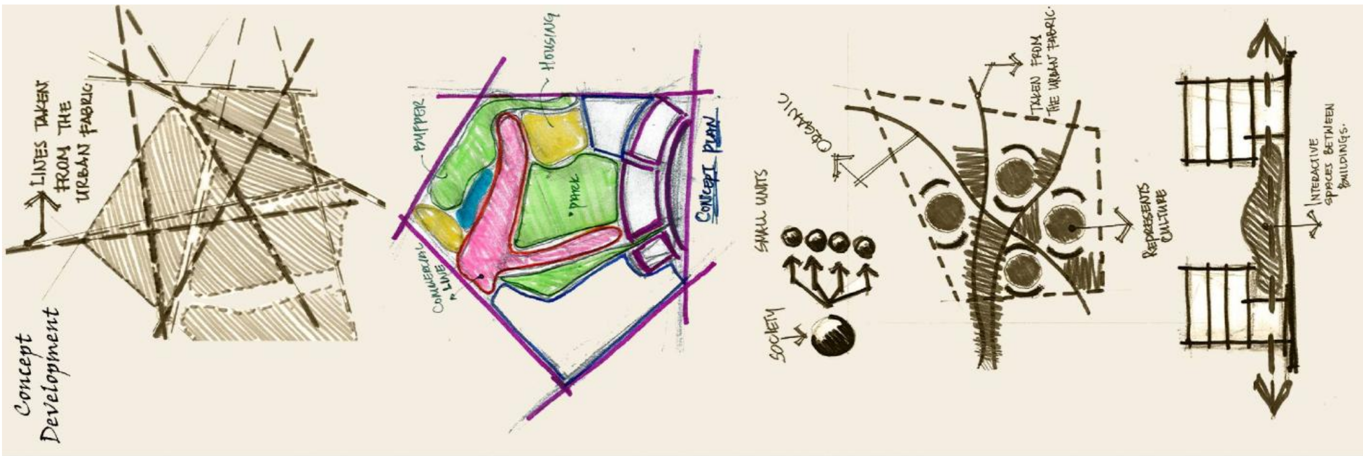
d/ Conceptual plan based on network

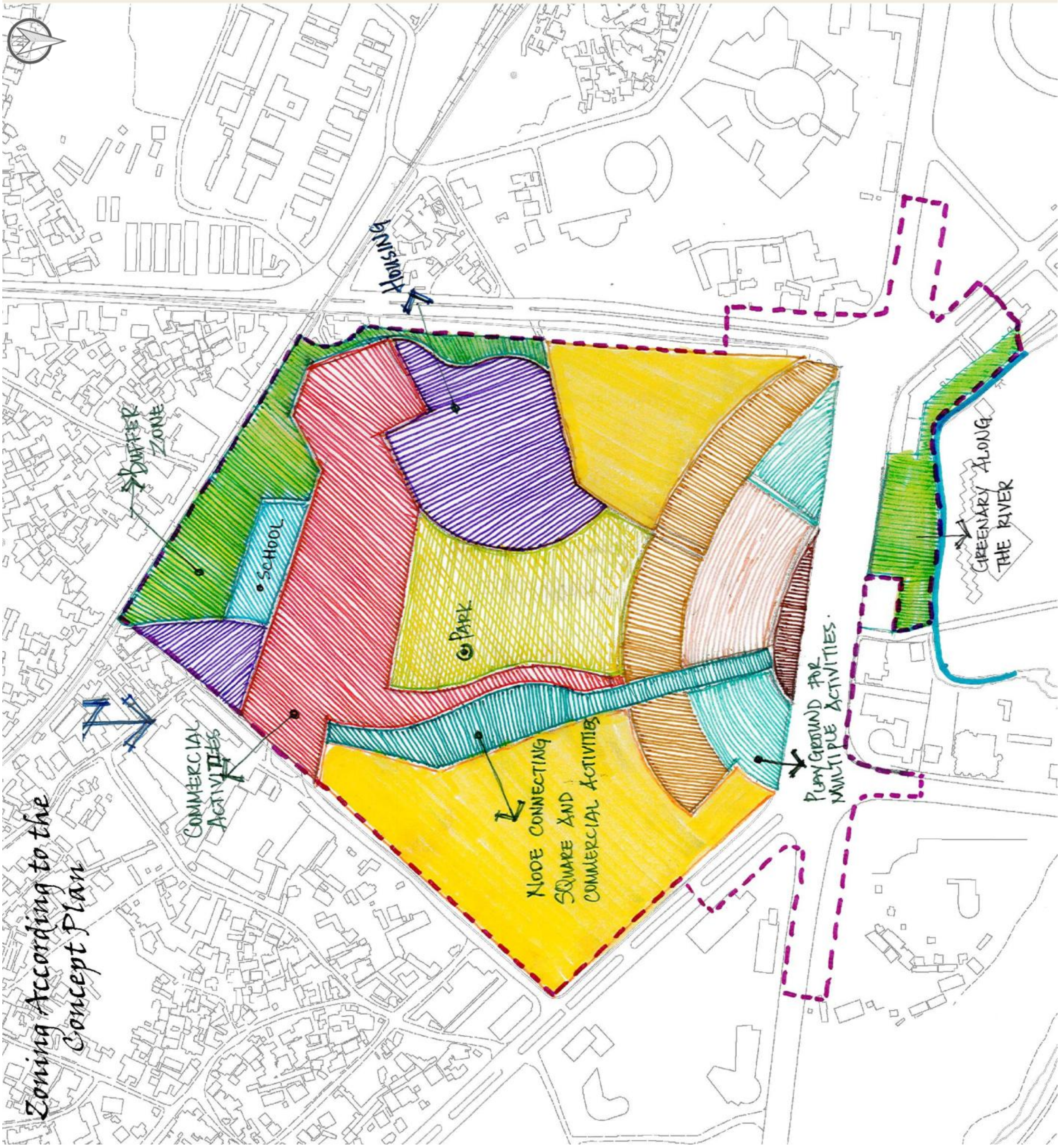

Functional Connection Analysis
Connecection between site and out of site elements
Connecection between two site elements
Connecection between two out of site elements
or
Connecection between two elements with indirect influence of one to the other
TRAIN'S BUS STATION
TO COMMERCIAL CENTER
CULTURAL CENTER
STADIUM
RESIDENTIAL ZONE
HOTEL
MESKEL SQUARE
EXHIBITION CENTER
AFRICA PARK
CHURCH
ECA
TO AIRPORT

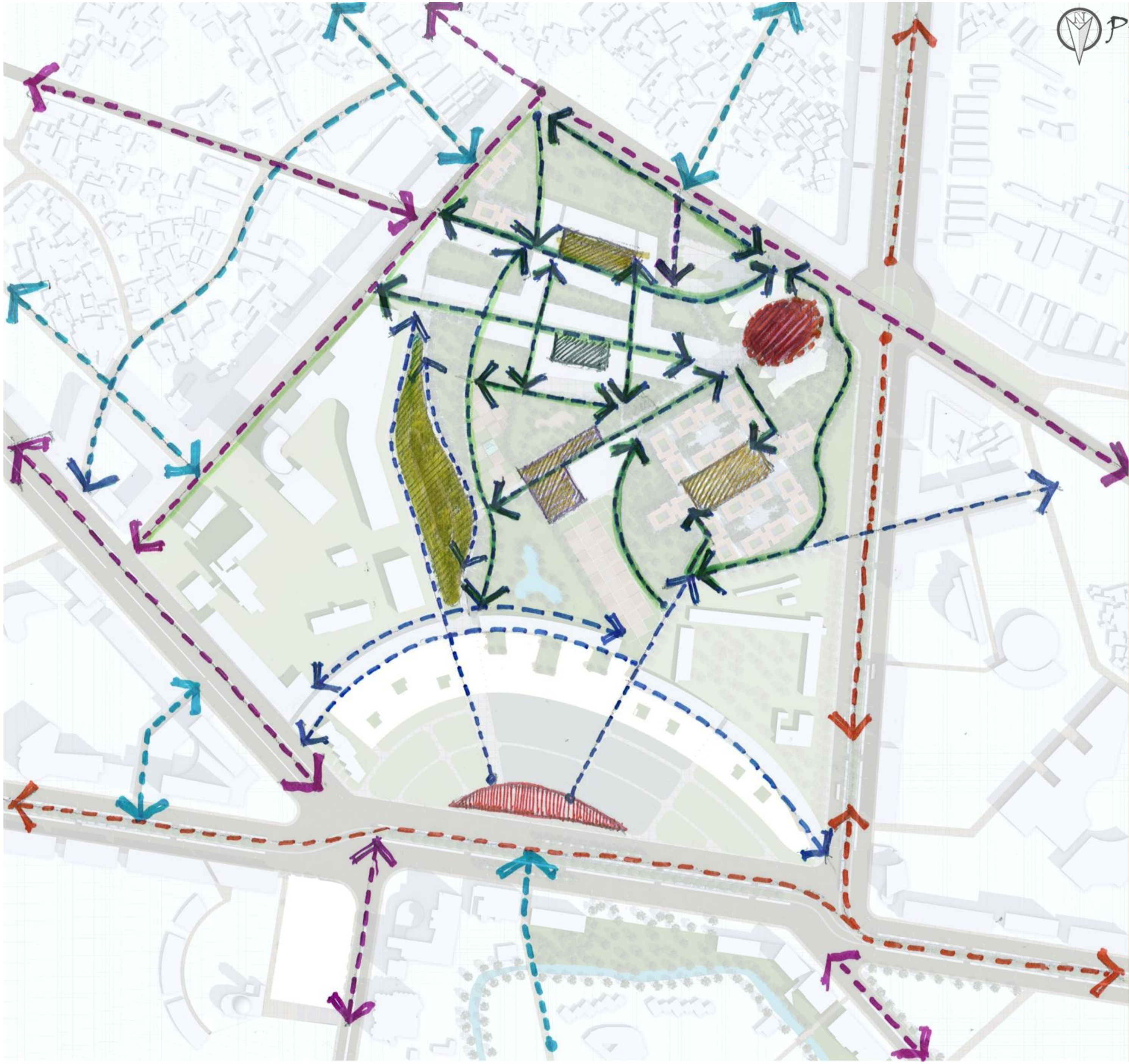

Zone of Intervention
+
Major Connection Lines
Mobility Networks
(Pedestrian & Bikes)
Green Mobility
Networks
(Streetscapes)
CULTURAL CENTER
STADIUM
VISUAL CONNECTIONS
HOTELS LANDSCAPED AREA
MESKEL SQUARE
EXHIBITION CENTER
CHURCH
BUFFER ZONE


TYPE D
GREEN STREETSCAPES.
GREEN BUFFER (FROM HIGH TRAFFIC ROAD).
LOW STANDARD HOUSING TO BE DEMOLISHED
SCHOOL TO BE KEPT.
TYPE C
GREEN BUFFER ZONE (FROM TRAIN)
PROPOSED GREEN STRIP ALONG THE RIVER.
EXISTING EXHIBITION CENTER TO BE DEMOLISHED (AFTER BEING USED FOR RELOCATION).
PROPOSED MULTISTORY EXHIBITION CENTER (BY LOP), CITY MUSEUM, AND GOVERNMENTAL OFFICE TO BE KEPT.
THE SQUARE TO BE REDESIGNED.
THE SEATING TO BE INTERVENED
TYPE A
TYPE B
Existing Site Morphology With Planned Interventions
+
Different urban fabrics around the city


Slum Typologies in and around our site
1) SCATTERED LAYOUT
VERY MUCH ORGANIC MOVEMENT AROUND THE SITE.
NARROW ROADS.
COMMUNAL SPACES FOR VARIOUS ACTIVITIES.
2) REGULAR (LINEAR + COMPACT) LAYOUT
LINEAR/REGULAR ROADS
ROAD FOR CAR & PEDESTRIAN MOVEMENT.
3) ATTACHED + COMPACT LAYOUT
OPEN COMMUNAL SPACE FOR VARIOUS ACTIVITIES.
VERY NARROW WALKING LINES DUE TO COMPACT LAYOUT.


Concept Development
LINES TAKEN FROM THE URBAN FABRIC
BUFFER
HOUSING
COMMERCIAL LINE
PARK
CONCEPT PLAN
SOCIETY
SMALL UNITS
ORGANIC
TAKEN FROM THE URBAN FABRIC
REPRESENTS CULTURE
INTERACTIVE SPACES BETWEEN BUILDINGS


Zoning According to the Concept Plan
HOUSING
BUFFER ZONE
SCHOOL
PARK
COMMERCIAL ACTIVITIES
NODE CONNECTING SQUARE AND COMMERCIAL ACTIVITIES
PLAYGROUND FOR MULTIPLE ACTIVITIES
GREENARY ALONG THE RIVER



Proposed Mobility Networks

- Vehicular + Light Rail (Tram)
- Pedesterian
- Pedesterian + Bike
- Out of site Pedesterian Connection
- Vehicular

Open Spaces

Commercial node aimed to attract people towards the site and it is encircled by two buildings with height that is proportional with the open space.

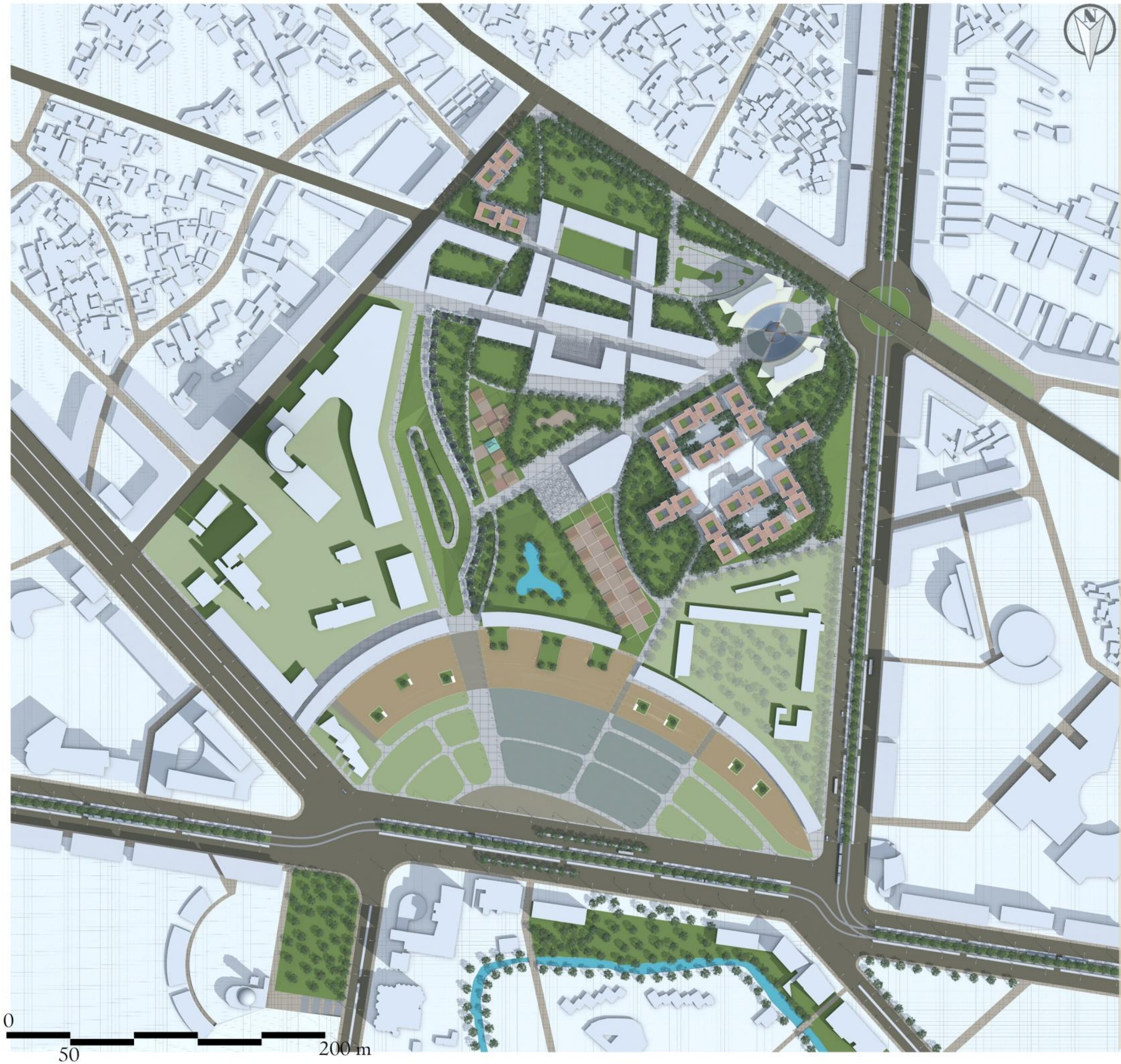
An open space in between the parks and connected with the proposed Library. Set to mediate between the Library and the park users.

A common space in the residential quarter for hosting various cultural activities, such as wedding ceremonies and the likes which need a large area to lay tents and the like. apart from that it serves as a playground for kids since it is surrounded by the residential buildings.

An open Space which is put to break the linear commerial lines. It is used as a resting place for customers while moving around the commercial buildings.

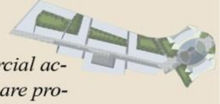
A large open space which is located in between the newly proposed exhibition center and the proposed local street market,i.e in our design. We proposed it this way so that it could accomodate the expected huge flow of people due to the presence of multifunctional activities and it is also a sloped landscaped area to serve as a playground and recreation area with various elements.

This open space infront of the proposed school will define the hierarchy of spaces, i.e.gradual transition from the road side towards the educational activities. It is somehow serving as a buffer space.



Master Plan

This segment of the masterplan mainly consists of the buffer zone which separates the site from the neighbouring high traffic activities. It also has a space for the newly proposed public school, parking space for the commercial activities and some part of the residential development.



This is where most of the commercial activities take place. The buildings are proposed in a way to attract potential visitors towards the site by providing various attraction points along the commercial line.

A zone for the residencial activities which is bounded by green spaces to serve as buffers and give privacy for the residents.We have also incorporated a big open space for communal activities such as wedding ceremonies and the like. Apart from this residents will have a rather small spaces for their day to day activities which require outdoor exposure.

The hub inside the masterplan for entertainment and recreative activities for the society. This is the kind of space which the city lacks currently due to lack of provision and mis-usage. It has a space for various cultural activities including a public library. This park will incorporate various sculptures and open air exhibition points based on the culture of the society. Since the city is the diplomatic capital of Africa we have also tried to provide spaces dedicated to display African culture.

A commercial line in close connection with the designed landscape and trees around dedicates itself for the local street marketing culture of the society. This spaces are useful in acknowledging the values of the residents that will be living in the residential quarters.

Node connecting the activities at Meskel square with those along the local street markets and the proposed multistory exhibition center. It has a huge significance in accomodating the expected large number of attendants of the various activities. It also serves as a playground for youngsters.

3.9. Master Plan

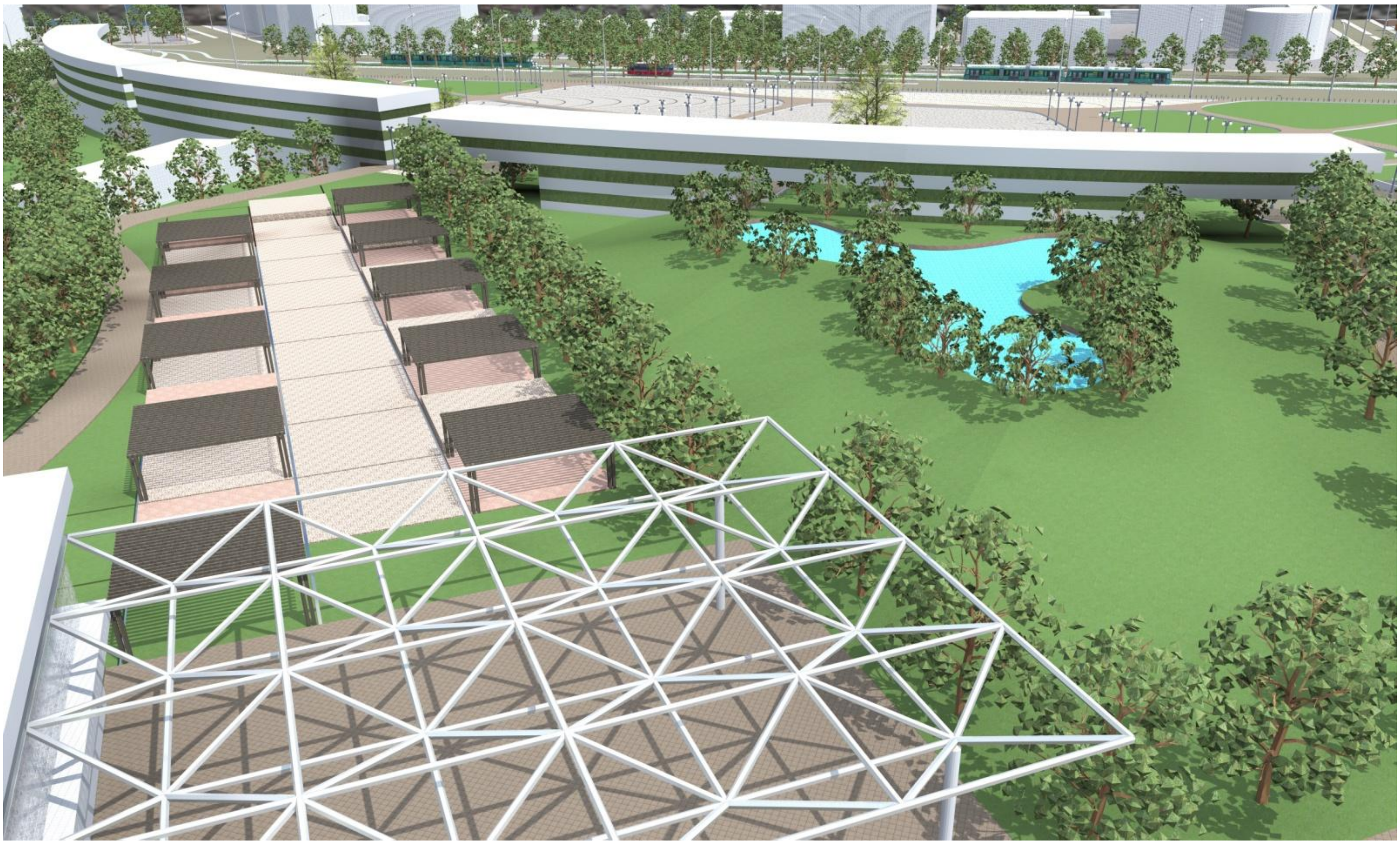
Based on our design goals and undertaken conceptual analysis we have come up with a master plan which tries to mediate between the different social values and activities taking place in and around our design area. In the urban design, we have tried to modify some parts of Meskel square to make it interactive throughout the year by providing various attractive spaces and functions. This include provision of simple structures integrated within the current seating area to accommodate kiosks, cafeterias and restaurants, game stops, and other functions which will enhance both the aesthetical and cultural values of the square.

Provision of this functions along the bold seating area of Meskel square not only will break the monotonous feeling that currently exists but also attracts members of the society on a regular manner. While doing this, we have also noticed the everyday users of the square for sports activities and given them proper spaces by providing segmented permeable finishes as playgrounds on the flat part of the square.

The other problem which made the square to be dull almost all round the year is the existing 16 lane high traffic road. For this problem we have tried to provide a proper solution by dividing the road into different parts, i.e. separate lanes for buses, cars and light rail (Tram) activities, and integrating green elements such as trees in between the different segments and a permeable surface along the tram line.

In the next few pages we have put various proposed road sections and 3D renders to visualize the design area.

3.10. 3D Renders



CHAPTER 4

ARCHITECTURAL DESIGN

4. Architectural Design

4.1. Introduction

The architecture of the project focuses in designing low cost housing for inhabitants residing in a slum area located behind Meskel Square as well as accommodating other low income families from different parts of the city. This is to be achieved by creating a residential zone on the existing slum area. The project area currently is occupied with substandard one storey slum housing units. According to the Local Development Plan (LDP), the plan is to carry out a relocation strategy. In fact the area now is proposed to be a cultural centre and relocate all the residence to a place away from the site.

Fig. 4.1 Architectural project location

4.2. Aim and Vision

Our aim is to create pleasing, harmonies and suitable social living space for the low income. This could be achieved by converting the area of the slum dwelling into a residential zone able to accommodate more inhabitants. Since the low-incomes are integral part of the overall social and economical aspect of the city, we should provide them with an appropriate living standard and create affordable design solutions. We convince ourselves that the residential zone could exist in harmony with other important function of the site like the proposed cultural centre, exhibition centre, mixed use buildings and others.

The current social housing is generally located away from the center of the city. The subject matter is how to integrate this housing zone for the poor in the centre without compromising the existence and vitality of other functions. This could be achieved by creating a design with a pleasing look which adheres well within the city and depicts an architectural identity.

4.3. Architectural analysis

4.3.1. Social Life

The families are used to live in neighborhoods living as close as possible. The social life of these families in general can be described as a closely interactive living culture. People spend much time together. The culture ties people together in their daily lives. The ideas of individual cultural concept rarely exist in these types of families rather a collective living style is adapted. "*They help each other, they drink coffee together they share whatever they have, and you cannot even express this in economic terms in numbers. It's is so immeasurable; the social interaction, the network, the relationship between the neighbors, the favors that they exchange, the way they help each other is something that you cannot put in to figures into numbers.*"[21]

Fig. 4.2 Neighbour's attending a traditional coffee ceremony

Are these type of style of living is due to economic reasons? It's hard to say. But that's not the critical point here to know, it's to how they live regardless of the reason behind. And it's also critical to think if this way of living would change if these people get the chance to change themselves in a positive way. Well let's say that there would be some disappearing social activities based on the some economic, social and political changes. We can study how these families create their own spaces to accommodate their needs. The spaces are very natural in nature - are not planned by architects or urban planners. They are more natural and true. People on their daily lives unknowingly create paths and these paths in turn create these default spaces. Therefore we tried to Analyze these spaces according to what they are and how they are.

Fig. 4.3 Families eating together

[21] *Architect Fasil Giorgis in a documentary titled ''Disappearing Spaces - a day in Addis Ababa informal city (Kebele Houses)*

4.3.2. Living Spaces

The types of spaces that exist within the slum area are below standards and not planned. They are settlements that flourished without an actual urban planning rule and regulations. Therefore we encounter houses which are way below standards. A closer look up in figure 4.4, illustrates intermix of living spaces among neighbor's.

Fig. 4.4 Intermix of slum living space

Open Spaces:-

In starting to analyze the functional spaces in and out the housing; we find open spaces scattered here and there existing in between narrow path's, shared among neighbors. They don't really have an owner or they don't really belong to any one in specific. They are just there serving the general by default. Sometimes we find spaces wide enough to serve all and this spaces diminish into being a narrow street. The streets are defined by irregular boundaries created by two bounding housings. The streets wind up undulating and end up in to another wider space. The open spaces exist or are defined by natural growing trees.

Fig. 4.5 Scattered open spaces in slum areas connected by irregular street path's.

In the open spaces that people actually created, it is used for traditional food preparation like spices washing of clothes, cooking, coffee ceremonies, playground for kids as well as taking a shower at some times. Among these activities we identify; the traditional food preparation process, the washing and drying of clothes, kids play ground and the celebrated coffee ceremony are social activities which are permanent. Other functions are likely developed due to lack and adequacy of interior spaces. Social gatherings are also an important part of the activities. Moments of mourning, celebrations, happy and sad moments are an important part of the open spaces which is shared throughout. Adequate spaces should be provided for all these social needs. Despite this fact, these places are not pleasant enough to live in. Problem of waste treatment, proper usage of domestic water and unpleasing scenery makes living there difficult and stressing. But this is all because of absence of proper urban planning and economy of the people. However the spaces exist side by side in a controversial way within.

Fig. 4.6 Social activities in open spaces

Internal Living Spaces:-

Fig. 4.7 Shared living and dining spaces among neighbours[22]

Living and dining spaces could be a point where nearby neighbors meet and interact. People spend time to dine play and drink coffee in these spaces. This is one good aspect that we think in the creation of spaces- Interactivity. Services like kitchen and toilet are mostly also shared among nearby family units. Sharing of space may be because of economy, but as a result it creates a highly interactive community.

Kitchens:-

Traditional way of preparing food is very complex and time taking in general. The tradition is there and would be also in the future. "Enjera" a food item that is used to eat other foods with, is basically in everyday food preparation of the society. Not only "Enjera" but also residents have the has tendency of preparing other food items made by using fire. It is said that the foods prepared with that technique are more delicious than one made with modern stoves. This is a culture which there and would also be in the future.

[23]
Fig. 4.8 Making "Enjera"- main traditional food

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[22], [23] *A documentary titled ''Disappearing Spaces - a day in Addis Ababa informal city (Kebele Houses)*

4.3.3. Slum Architecture

Most of the housings are single storey buildings. They are made in a very simple form, like the basic housing form, a pitched roof with an overhang. The geometry of the walls doesn't follow regular geometries. These slum houses are built using cheap and available materials that the people could find. The roof sheet is made from corrugated iron sheet. The rafters and purlins are built with a simple truss. 53 % of the slum housing has no proper ceiling. The walls are basically made from mud and wood. Plastering and paint can be applied in the interior to

Fig. 4.9 Typical slum housing

4.3.4. Case Studies

4.3.4.1. Build Our Nations- Taifa Letu Tujenge.

Build Our Nation is an innovative educational experience in Architecture. Taifa Letu Tujenge meaning - Build Our Nation in Swahili, is the first project involving multitude of students from four different Universities in Europe Including Politecnico Di Milano. As part of the educational process our group member, Gebriel A. Askabe took part in the process. The experience was to work together internationally to explore and develop a design for a women's community centre in the Democratic Republic of Congo. It is the first project under the umbrella of Build Our Nation which is involving architecture students internationally. Through workshops and events the students worked to explore and experiment with ideas, discuss and connect internationally, and build an empathy and awareness for design issues. The first stage of the workshop started in April 2011, and continued with stage 2, 3, and 4.

The project is related in with our context in that it focused in disadvantaged group of the society in both cases – the low incomes in Addis Ababa and the Women in DRC – Bukavu area. The multipurpose centre aimed to promote interaction and activities for local women, from different backgrounds (rural, urban, peripheral, etc.) as well as reducing the difficulty of inequalities in income and employment opportunities. It could be a catalyst for social change and should be a participatory and innovative action for the province in the new democratic period. Approximately 5,000 women and girls are potentially the direct potential beneficiaries of the project.

The Key ideas gained from the experience are;

- Recognition of local cultural and social spaces
- Local sustainable approach
- Easy self build technique
- Climate sensitive approaches
- Reuse and recycle of natural resources
- Use of local sustainable materials – Bamboo in the DRC context

- Avoiding social segregation
- Empowerment
- Participation of the actual users of the space (The women)

Fig. 4.10 The final prototype housing unit produced for the Women Centre through international participation.

4.3.4.2. The Grand Housing Project

To further know and identify our housing type we tried to look at existing social housing that is currently working in Addis Ababa. The Grand Housing program is one of the first large scale projects which has been launched by the government in collaboration with the German Gesellschaft fur Technische Zusammenarbeit (GTZ) in 2004.

Fig. 4.11 Grand Housing Project launched in 2004.

The design is being implemented in various areas of Addis Ababa. This production of housing has solved the major housing problem of the ever growing population of Addis Ababa. It is known that since the Italian occupation rural population has been migrating to one of the biggest urban centers of Ethiopia, Addis Ababa. The result is an increase of slum and informal settlement within the centre. After the condominium was planned to be implemented, it has been serving the wider population for living and job creation. The allocation of housing units is based on lottery.

The plan is regular and simple. A typical floor is composed of; Three bed, Two bed, One bed and Studio type with an approximate area of $75m^2$, $50m^2$, $31m^2$ and $22m^2$ respectively.

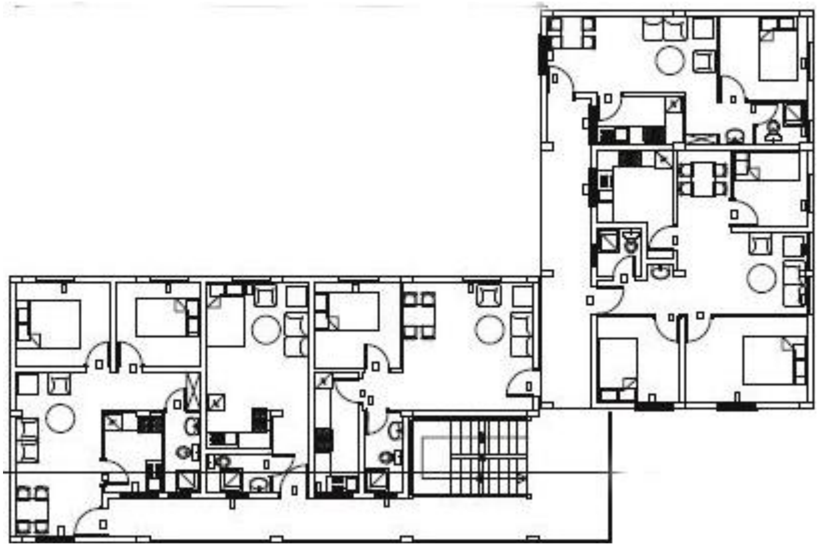


Fig. 4.12 Typical Grand Housing Project floor plan

Whereas the aesthetics of the volume is concerned, it has received negative critics throughout. The problems we think are the use of building materials; finishes and general treatment of the facades. The color, the texture creates a pictorial chaos in city. The treatment seems like a low cost design rather than being a low cost housing. Among the success of the grand housing project is establishing large amount of jobs for the urban poor. Some small business and shops were also created.

4.3.4.3. Elemental

Elemental is a profit company, with field of action is the city: the development of housing, public space, infrastructure and transportation projects that can perform as an effective and efficient upgrade in the quality of the life of the poor. Elemental operates in contexts of scarce resources, using the city as a source of equality and moreover as a shortcut to correct inequalities.[24]

Fig. 4.13 Elemental Housing projects for the poor

The projects relate to our idea of participation design aiming low-income people. Elemental identifies that the main problem of the poor is not shelter but the access to jobs, markets, education, health, recreation and social assistance.

[24] http://www.elementalchile.cl

4.3.5. Addis Ababa Housing Typologies

Fig. 4.14 Typical Housing Typologies in Addis [25]

4.3.6. Project Area Requirement's

The Local Development Plan of the area (LDP) suggests that in the project area the built up area ratio is 0.3-0.5 and Buildings shall be built of height ranging from G+0 to G+4. The aim of the project is to provide a low cost housing able to accommodate 129 families as well as more from other parts of the city.

Type	Number of houses
Kebele Owned	93
Private	31
Rent	5
Total	129

Table 4.1 Number of housing units in the current project area

[25] Building Ethiopia – Sustainability and Innovation in Architecture and Design, Vol. 1, 2012, Zegeye Cherenet, Helawi Sewnet

4.3.7. Design Goals

Communal space

A living space belongs to a single person or two or more depending on the person's own decision. Whether single, married or based on different relationships developed. However spaces also exist to serve and be owned by many. They are called communal spaces. The concept of integrating communal spaces within a living environment existed for centuries. The vision is minimizing the cost of providing a space for every individual as well as nurturing the interaction of people - in our case it's both.

Open Space

Open spaces are part of the daily life of the society. People utilize much of the area in the exterior of their house for daily activities. Activities like washing and drying clothes, dinning and cooking, traditional food preparation, coffee ceremony and recreation are among the many activities people use the open spaces. But these spaces are not originally intended for these purposes. They gradually evolve through the activities of the people. But why not we design open spaces as part of the housing structure itself?

Vertical densification

As part of the urban renewal process vertical densification has become an integral part of a city urban planning strategy. It has its own positives and negatives. As population grows a high demand of land for dwelling and form livelihood occurs. These in turn increase the value of land in terms of price and other factors. As a result low incomes or other groups who are not able to afford the price of the land would be forced to live and settle away from the centre. But if we are to apply the vertical densification strategy then we would be able to convince that even though the price of land is increasing there would be as many families living in certain area rather only on ground level. From the case study we had the number of floors given for one housing building is five. We find this viable for designing low cost housing since it's not required to provide lifts in a building with number of floor below five.

Social Mixity

It's an important concept to avoid social segregation. Segregation occurs mainly due to absence of proper planning strategies. In the absence individuals tend to group up in the location of their living. This is a natural process. The groups are created based on income level basically. Low income people tend to live near other low incomes and the same happens for high income. With this, smaller segregated zones are created occupied by similar income status groups. As result urban functions also flourish based on the neighboring groups within the area. This would create in the total unbalance of flows of material and capital in general. The development of one area would be overshadowed by the other. This concept can be overseen also in the level of architecture when designing a space within the building itself. For instance grouping bigger families together and segregating the single ones creates a negative psychological as well visible effect. There would also be missing an important part of a society which is social interaction within different economical group.

Vegetation gardens

A garden is a space provided in homes as a means of enjoyment of plants and other forms of natures. If what's being cultivated are part of vegetables then it would be a source of food or income to the community members. They could also absorb carbon dioxide and give away oxygen and as a result reduce air pollution. The tradition of vegetation garden or home garden has been part of the city residents. Nevertheless, the tradition is been fading away, one of the reasons being increase of land value. But we believe to preserve this tradition to its originality without compromising the value of land.

Interacting spaces

A living space can be interactive within itself but interactive spaces are two or more spaces allowing visual or verbal connections among people using them. The closeness of the social life of Ethiopians has been the focus of our design. If the architecture for a building defines and serves the people in it, it should in addition incorporate with it means of interaction with the architecture of other people in other buildings and the environment. This is possible by certain components of buildings. The window, balconies and terraces are among the components. Through these opening elements we should be able to strengthen the link among people.

Empowerment

The grand housing program accomplished one of its main goals by creating job opportunities and enabling members of the urban poor to establish their own business, workshops and corporative. Micro and small enterprises MSEs were formed with an average of ten to fifteen members each. About forty thousand jobs were created with fifteen hundred MSEs currently operating.[26] For the realization of a low cost housing especially targeting the low income people, the design should consider means of involving the people in the construction process enabling them to create their livelihood out of it.

Modular and Simple

Adapting simple and modular design strategies would be important to attain the above mentioned requirement. If the design to be proposed is geometrically simple in assembling and envisioning it, it in turn would create job opportunities for the families yet to live in. If the elements are to also be modular, meaning having easier specific dimensions, it would facilitate the construction process with regards to time and labor skill.

Low cost

Low cost housing has always been facing challenges starting from the design, implementation until its working life. It gives a feeling of being a low quality building. Especially the existing grand housing that is being implemented now in the city gives this sense. As being a low quality not only creates unpleasant living for the families but also it has a negative picture to the cityscape of the city. After having mentioned the above requirements comes with it the challenge of making the house a low cost. This involves the design in its form and functions and the building materials; roofing, wall component, flooring, finishing materials and structural component to be realized in less costly means. This is an aspect which we think sets the extent of architectural philosophies to a limit. Nevertheless, we think that we should compromise between a pleasing living and low cost design. In other words the architecture for a low cost housing is attained when the families dwelling in it are satisfied as the same way as other families living in other modern apartment. We can improve the living spaces and their environment of the low income families by giving them a pleasant housing working well with its surrounding and in turn we can give the city positive image and attractive sense.

[26] *Cities of Change*

Architectural Identity

Architecture beyond all the above mentioned aspects reflects the identity of the culture as well vise verse. It's a way of expression of inhabitant living in certain place at a time. In Referring to the Architecture of Ethiopia, one basically keeps in mind the ancient monolithic stone curved architecture of Aksum and the 11 rock hewn churches of Lalibela among the many traditional stone built churches. This invaluable identity seems to have being left in the past, when looking at the present variant architectural styles of Addis Ababa. Ever since Addis Ababa was established 125 years ago, the attempt of modernization is underway. As a result variant international styles now appear and the past architectural identity is left behind.

a/ *b/*

Fig. 4.15 Recent Projects that depict Ethiopian architecture, a) Netherlands embassy b) Stairs Office building

The Netherlands embassy and Stairs office building both depicted Ethiopian ancient architecture, by creating monolithic masses.

Participatory Design

Architecture in its contextual form should respond to the needs of the society. It is the architect who decides on the final output of the design in a normative way. The best architecture can be seen as the ones which responds if not fully but quite near to the needs of the majority. It starts with a simple idealization of space for use. The question is who uses it, how and why? Therefore a deep analysis and know how shall be embedded in the mind of the architect for the specific space creation in its own context. Or the use of contemporary analysis procedures shall be used. This procedure- "Participatory design and construction" is a way in which the individuals which are directly related to the space in question are involved in the design process as well as the construction besides the architects and the engineers. In involving the individuals the architect could learn better and have a closer outlook of their needs in real picture. And the individuals can envision their own individual spaces accordingly. The form of participation can differ by level and extent. For our project we listed important questions that could guide our design, and asked three representative individuals from the residents of the area. The following is a list of questions with answers.

	Questions	Person 1 - **Street shop owner/inhabitant** Condition - **Lives with his two sisters** Age - **28years old** Sex - **Male**	Person 2 - **Government worker** Condition - **Family with two kids** Age - **56 years old** Sex - **Male**	Person 3 - **Worker** Condition - **Lives with family and sisters** Age - **26 years old** Sex - **Female**
1	**Do you support the Idea of living on a condominium? Why?**	**Yes**, because it is a modern way of living and it is more clean and comfortable	**Yes**, because I dont want to rise my child in this neighbourhood, I want a better life for them than these (slum houses) and most importantly clean. And for me it is a my dream house. If people dont support condominium it is lack of education.	**yes**, it is a better way of life than the existing.
2	**How many floors for condominium do you think it is Good? Why?**	Maximum 3 floors and if there is lift 10 floors	Four floors, because in case of death it is difficult to get the body down and in case of Earthquake to get off more easly.	2 - 3 floors because it is difficult to move for ealders, there will be more space for common areas, it will be difficult to move things up and down and also freedom for childern to play
3	**What do you think about people who work and live at the same place?**	I my self work very near to my house. There should be a place for this kind of people to continue there life to support becuase if there is a transport cost life may became difficult .	Living on condominium will encourage to upgrade our way of living so to find a another way to support and to get in governmental development programs like Micro and small enterpises.	There is no option for them if there is, it is good but even to let them work on the ground floor is not possible because the ground floor of condominium will be leased for economically rich people for shop purpose.
4	**What do you think about permanent relocation? Why?**	**No**, because there is a transport shortage in the city and it is difficult to get transport, there are places where there is a luck of infrastructure, there may not have a place for enjoyment and I will lose my neighborhood and social contact.	-	**No**, because its a place where I grew up and adapt, it will not be comfortable for transportation and there are association (Eder and ekob) that we live together for long thats why i dont to relocate.
5	**What is your opinion about sharing a space for rooms like kitchen, living room, toilet? And if you have to share which rooms would you prefer to share?**	It is a good idea and I prefer to share kitchen and toilet	If its for the purpose of low cost i prefer to share toilet and kitchen and for people with out family for the purpose of cost sharing it is good if they share bed rooms also.	**No**, i dont want to share any rooms and if i have to share it will be toilet and kitchen but there will be a luck of freedom during service or any maintenance works because one person might use more frequantly than the other.
6	**What is your opinion for open space activities that may be lost if you move to condominium? What do you think if we provide a space for this activity on each floor?**	There must be a way to achive it like by going down to the ground open space because social value is important. On floor open space will be an important space	A small verenda must be provided on each floor, the existing condominium verenda is not enough. Depend on the conditions open areas must be provided. E.g. If some one die it needs a big space because all the building inhabitants will attend so a bigger open area is needed on the ground but if it is a coffee ceremony it may need only the floor inhabitants so it need a small space on the floor.	-

Table 4.2 Questionnaire - Answers to questions by residents in the project area

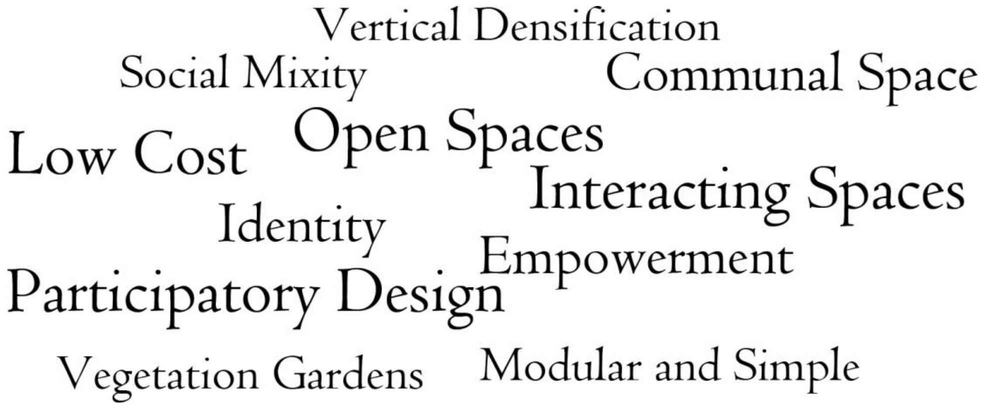
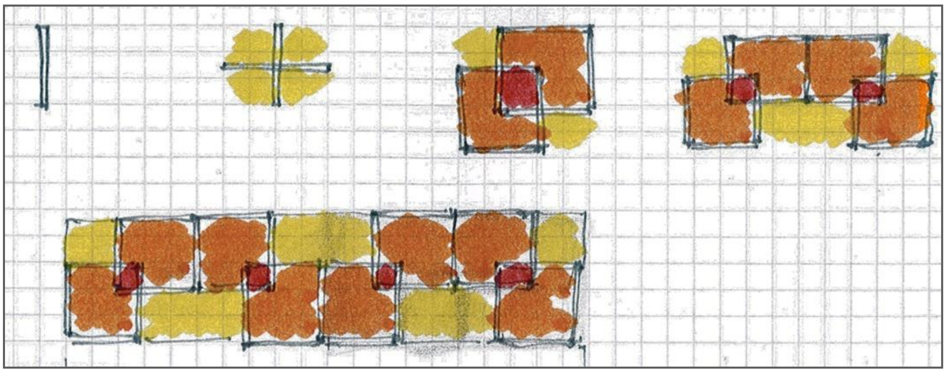
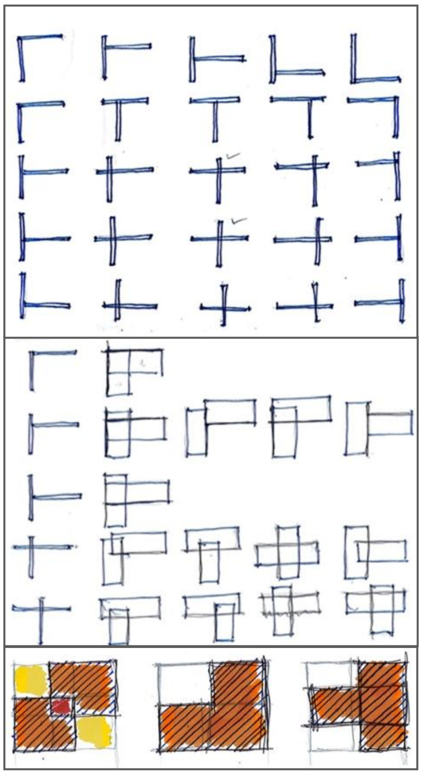


Fig. 4.16 Keywords

4.4. Concept Development



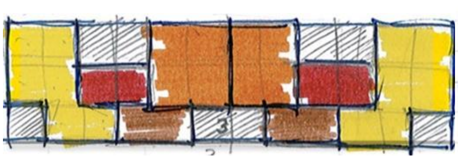
a)



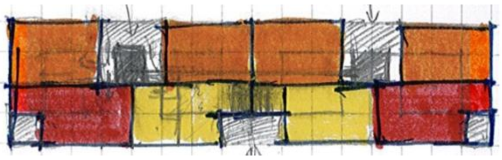
b)

Fig. 4.17 a) and b) initial concept development

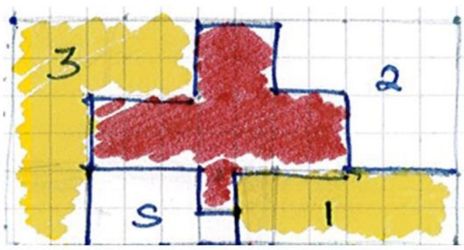
It all starts with a line to define an enclosure. Two lines touch or intersecting in different forms to define a space. The lines can then become shapes, with multitude options. The shapes in turn become volumes. The aim is to get three important types of spaces; Living, Shared and Open space.



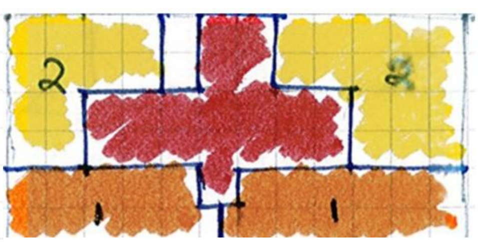
c)



d)



e)



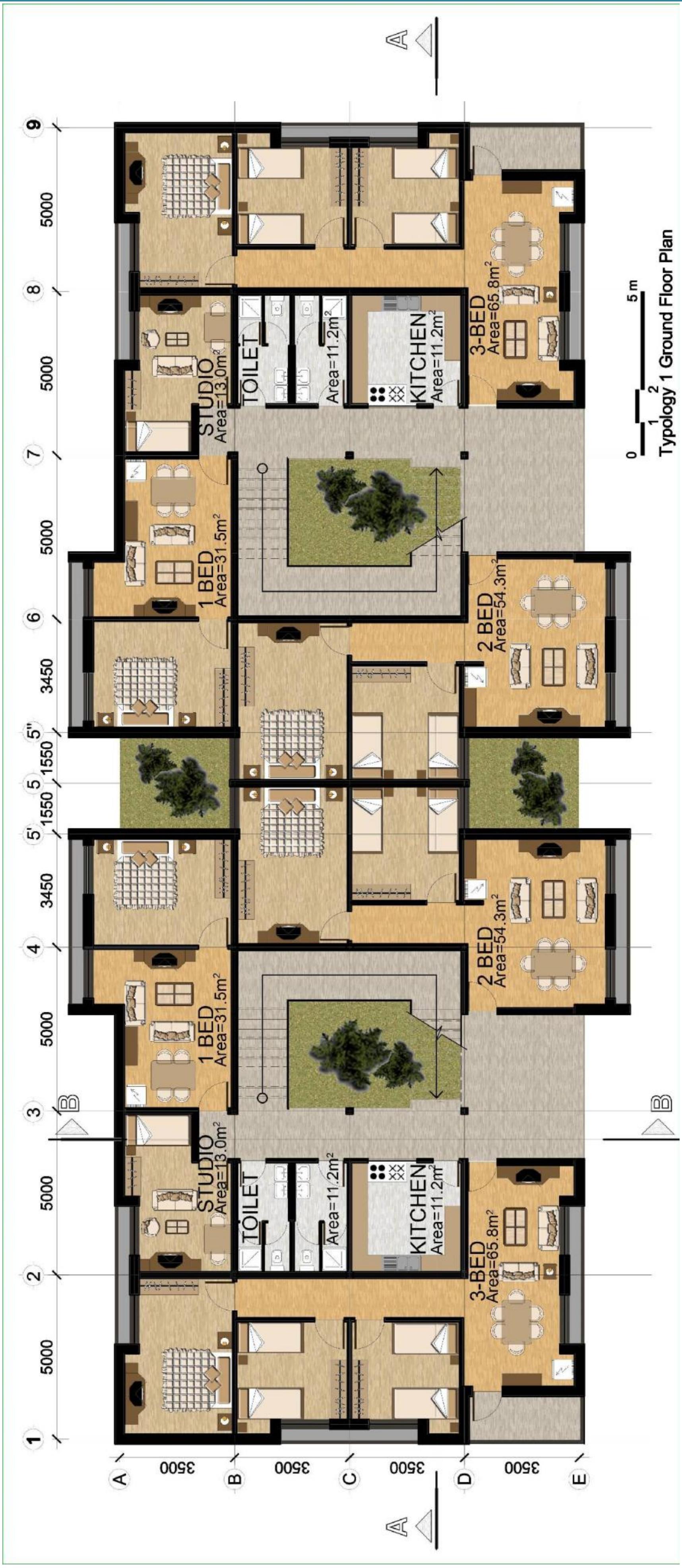
f)

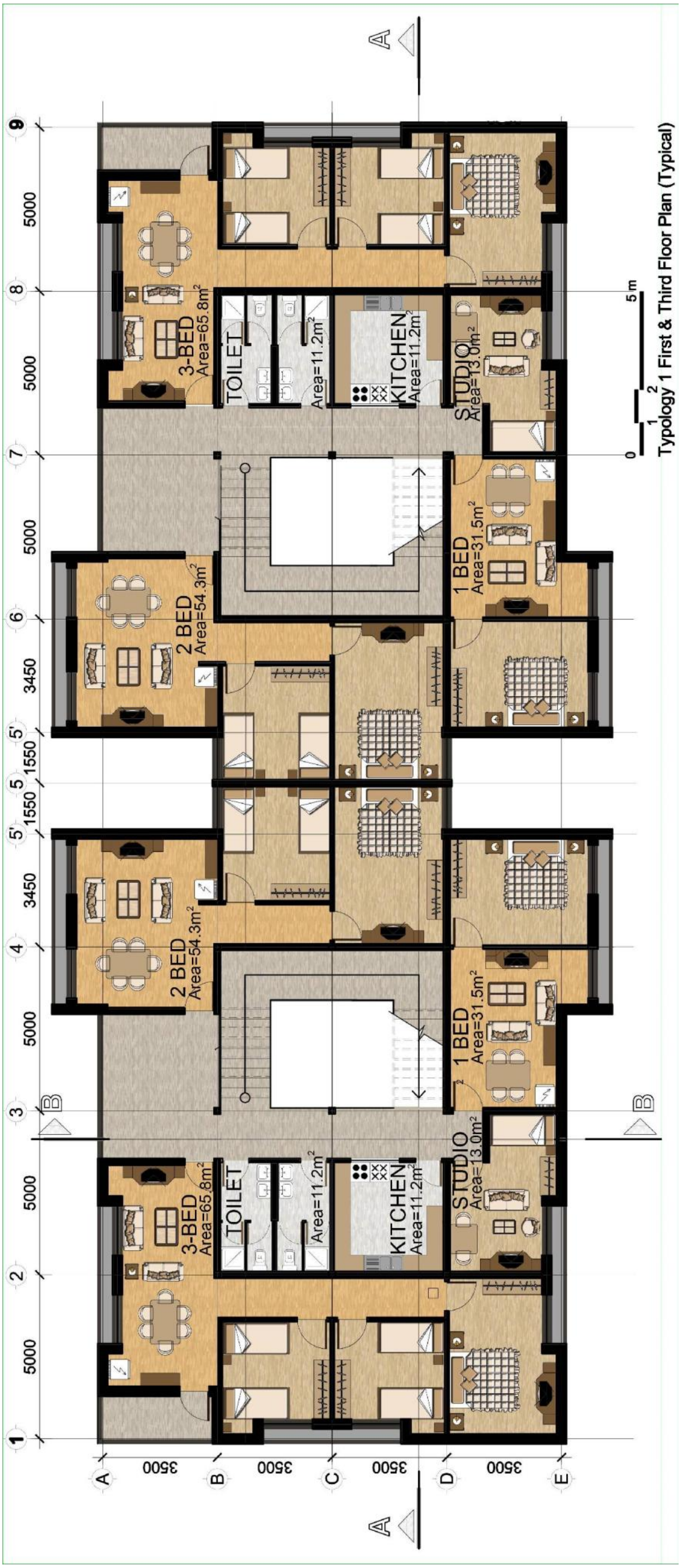
Fig. 4.18 c), d), e) and f) Concept development Process

The design development took series of steps to configure the three spaces for four different typology units; Three bed, Two bed, One bed and Studio. Even though the shared space in our design is realized as toilet and kitchen, it's open for the people to get involved and decide on what to share and what not. Sufficient open space has been thought for four families in addition to their own living spaces.

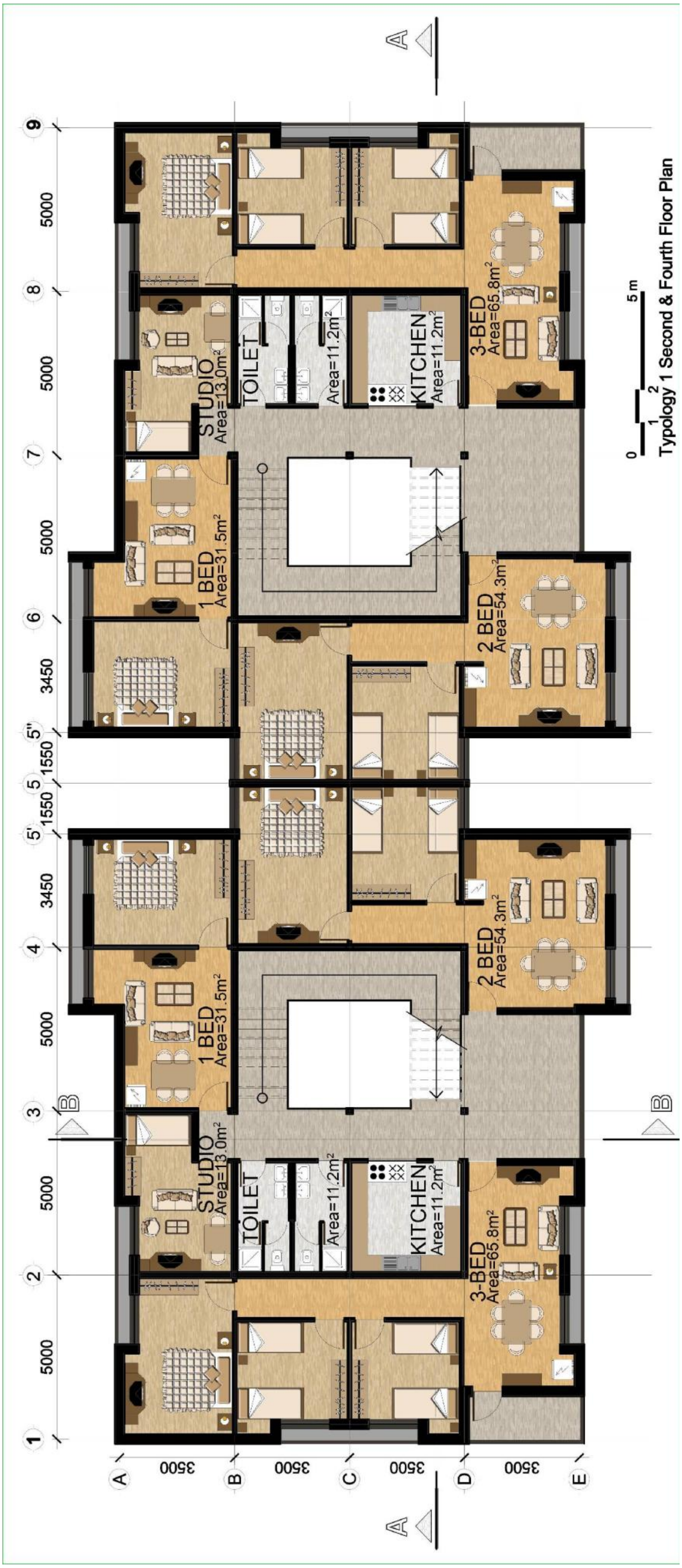
4.5. Architectural Drawings and Renders

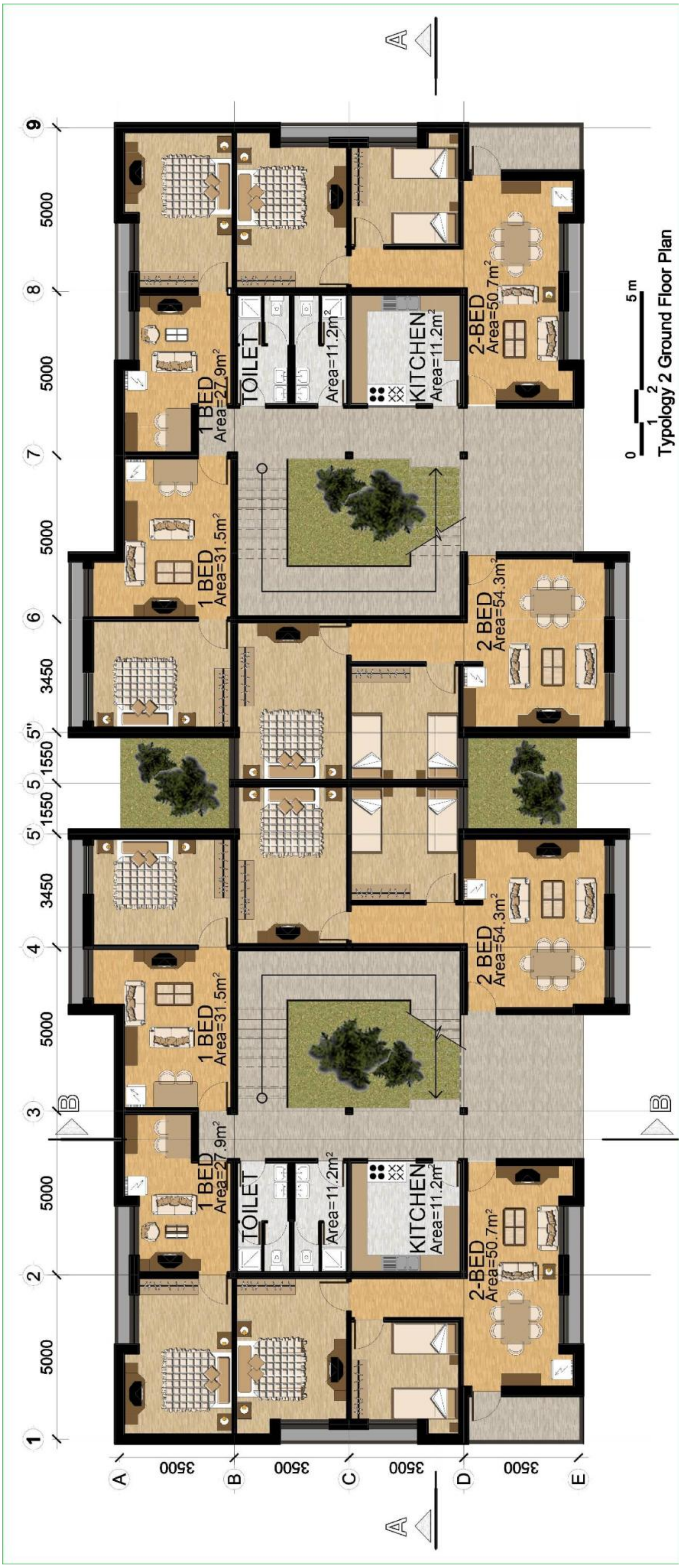
Site Plan
Typology 1
Ground Floor Plan
First and Third Floor Plan (Typical)
Second and Fourth Floor Plan (Typical)
Typology 2
Ground Floor Plan
First and Third Floor Plan (Typical)
Second and Fourth Floor Plan (Typical)
Roof Plan (Typical)
Elevations
Sections
Section A-A
Section B-B
Renders

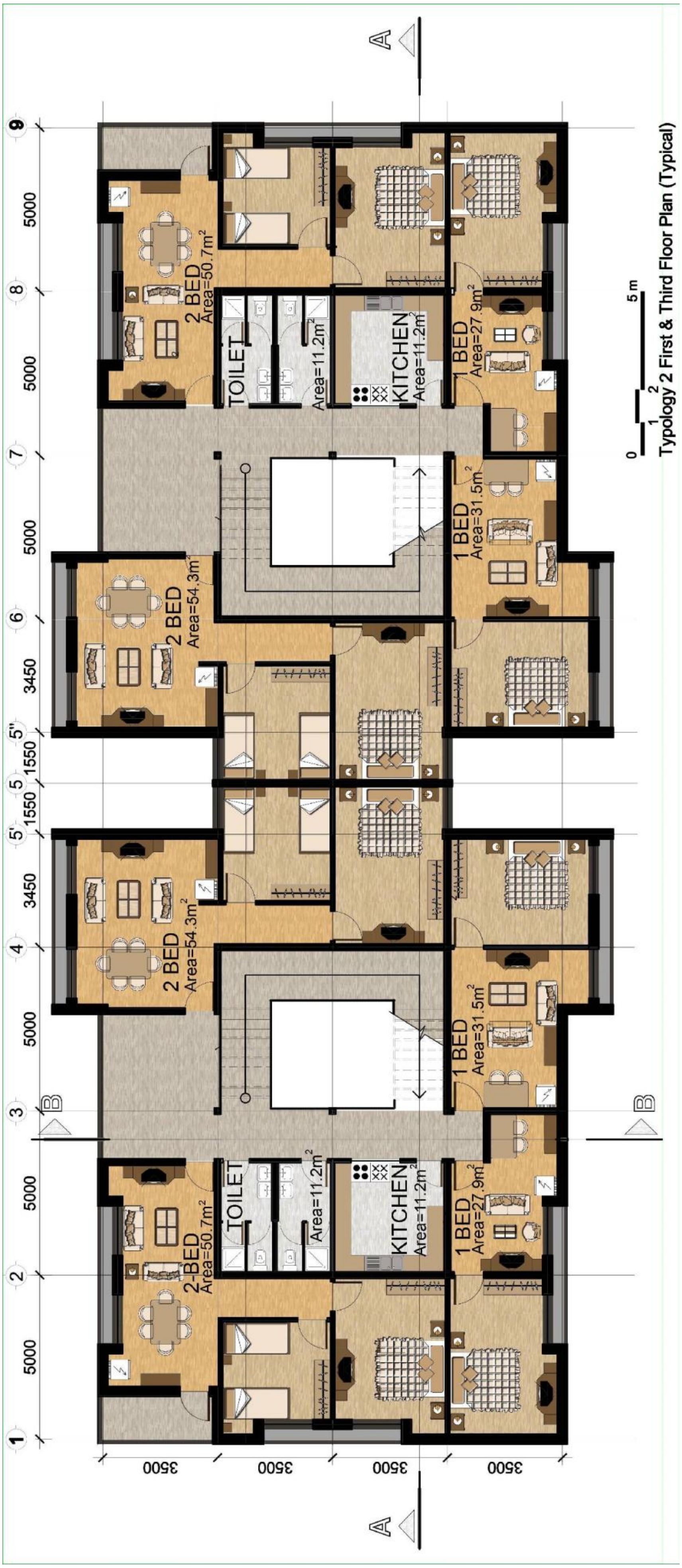

Typology 1 Ground Floor Plan
0 1 2 5 m
3-BED
Area=65.8m²
KITCHEN
Area=11.2m²
TOILET
Area=11.2m²
STUDIO
Area=13.0m²
1 BED
Area=31.5m²
2 BED
Area=54.3m²
A
B
C
D
E
1
2
3
4
5'
5
5"
6
7
8
9
3500
5000
3450
1550

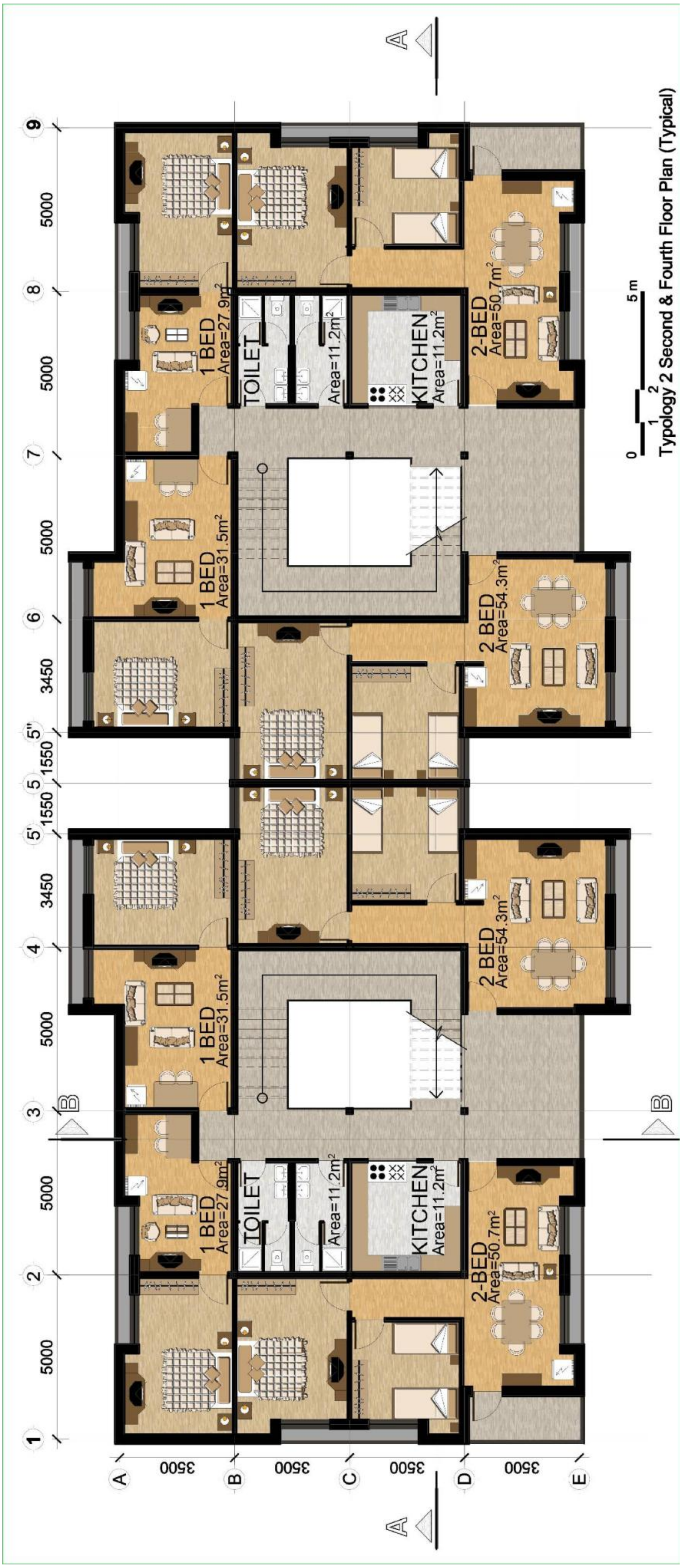


Typology 1 First & Third Floor Plan (Typical)

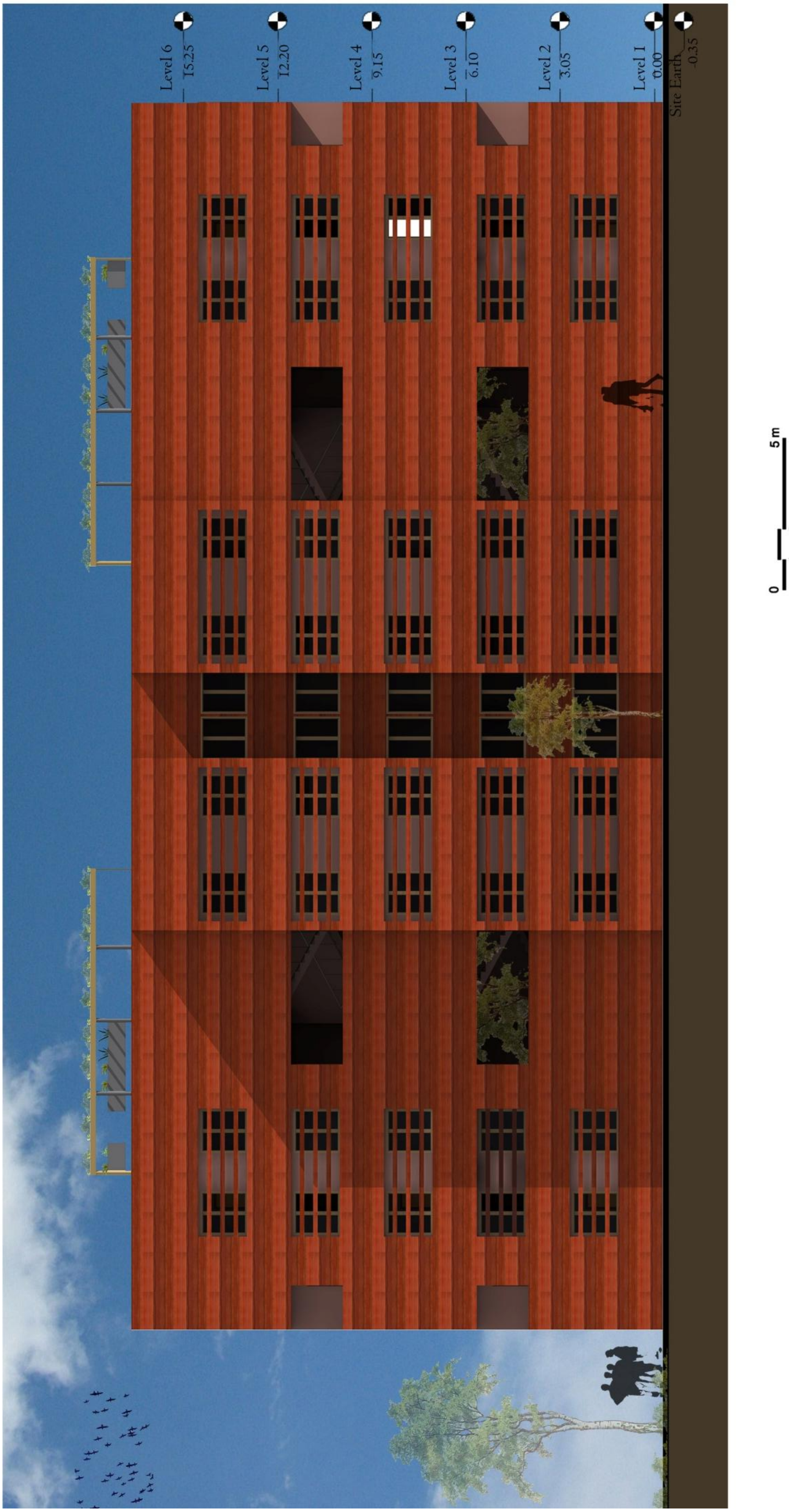

Typology 1 Second & Fourth Floor Plan
3-BED
Area=65.8m²
KITCHEN
Area=11.2m²
TOILET
Area=11.2m²
STUDIO
Area=13.0m²
1 BED
Area=31.5m²
2 BED
Area=54.3m²
5000
3450
1550
3500
0
1
2
5 m
A
B
C
D
E


Typology 2 Ground Floor Plan
0 1 2 5 m
1 BED
Area=27.9m²
TOILET
Area=11.2m²
KITCHEN
Area=11.2m²
2-BED
Area=50.7m²
1 BED
Area=31.5m²
2 BED
Area=54.3m²
5000
3450
1550
3500
A
B
C
D
E
1
2
3
4
5
5'
5"
6
7
8
9

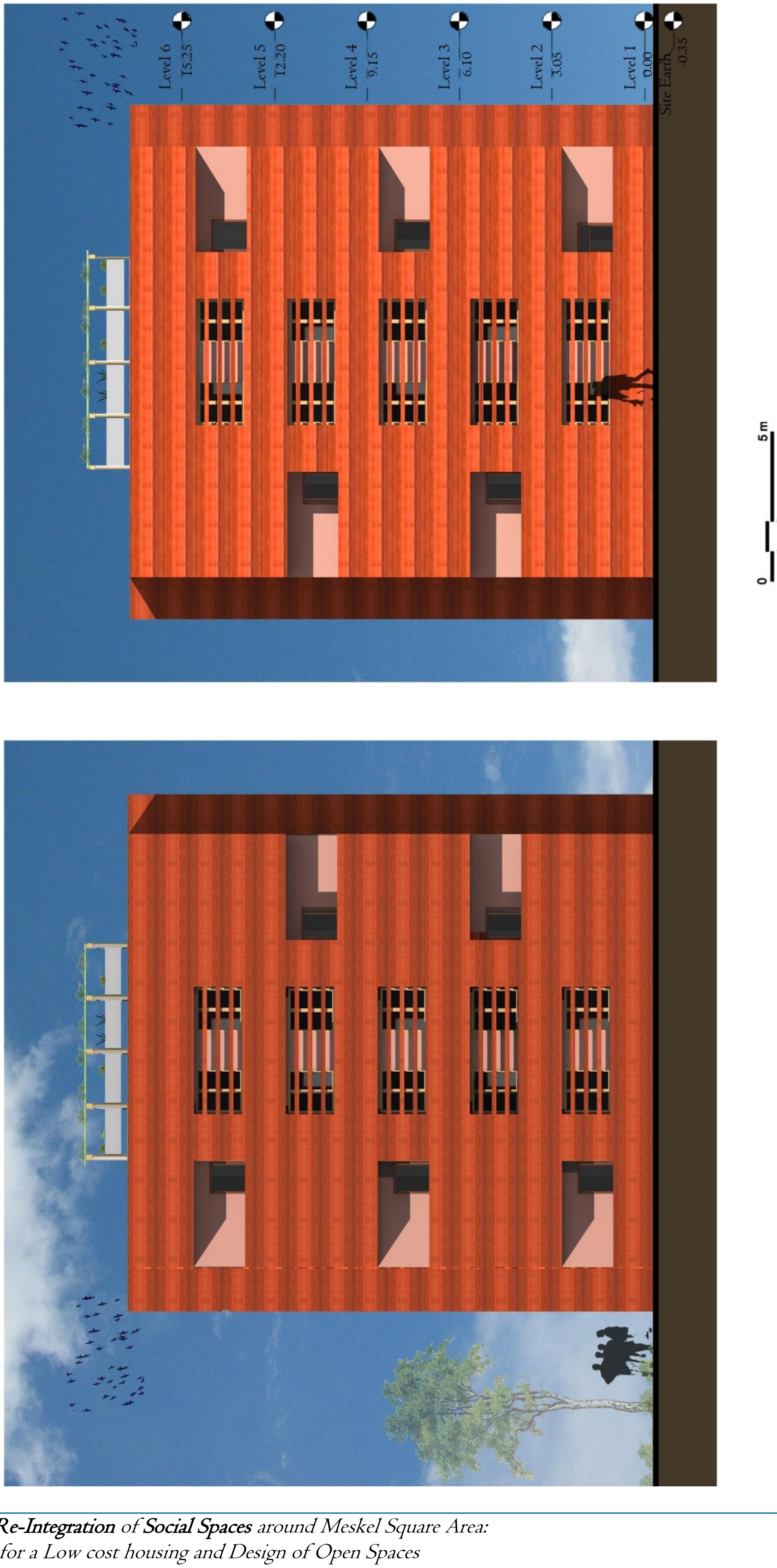

2 BED
Area=50.7m²
TOILET
Area=11.2m²
KITCHEN
Area=11.2m²
1 BED
Area=27.9m²
1 BED
Area=31.5m²
2 BED
Area=54.3m²
2 BED
Area=54.3m²
1 BED
Area=31.5m²
TOILET
Area=11.2m²
KITCHEN
Area=11.2m²
1 BED
Area=27.9m²
2 BED
Area=50.7m²
5000
5000
5000
3450
1550
1550
3450
5000
5000
5000
3500
3500
3500
3500
A
A
B
B
0 1 2 5 m
Typology 2 First & Third Floor Plan (Typical)


Typology 2 Second & Fourth Floor Plan (Typical)
0 1 2 5 m
1 BED Area=27.9m²
TOILET Area=11.2m²
KITCHEN Area=11.2m²
2-BED Area=50.7m²
1 BED Area=31.5m²
2 BED Area=54.3m²
1 BED Area=31.5m²
2 BED Area=54.3m²
1 BED Area=27.9m²
TOILET Area=11.2m²
KITCHEN Area=11.2m²
2-BED Area=50.7m²
A B C D E
3500 3500 3500 3500
1 2 3 4 5' 5 5" 6 7 8 9
5000 5000 5000 3450 1550 1550 3450 5000 5000 5000
A A
B B

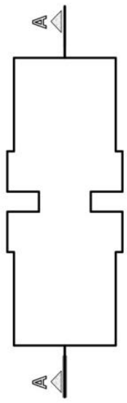
Front Elevation



Rear Elevation

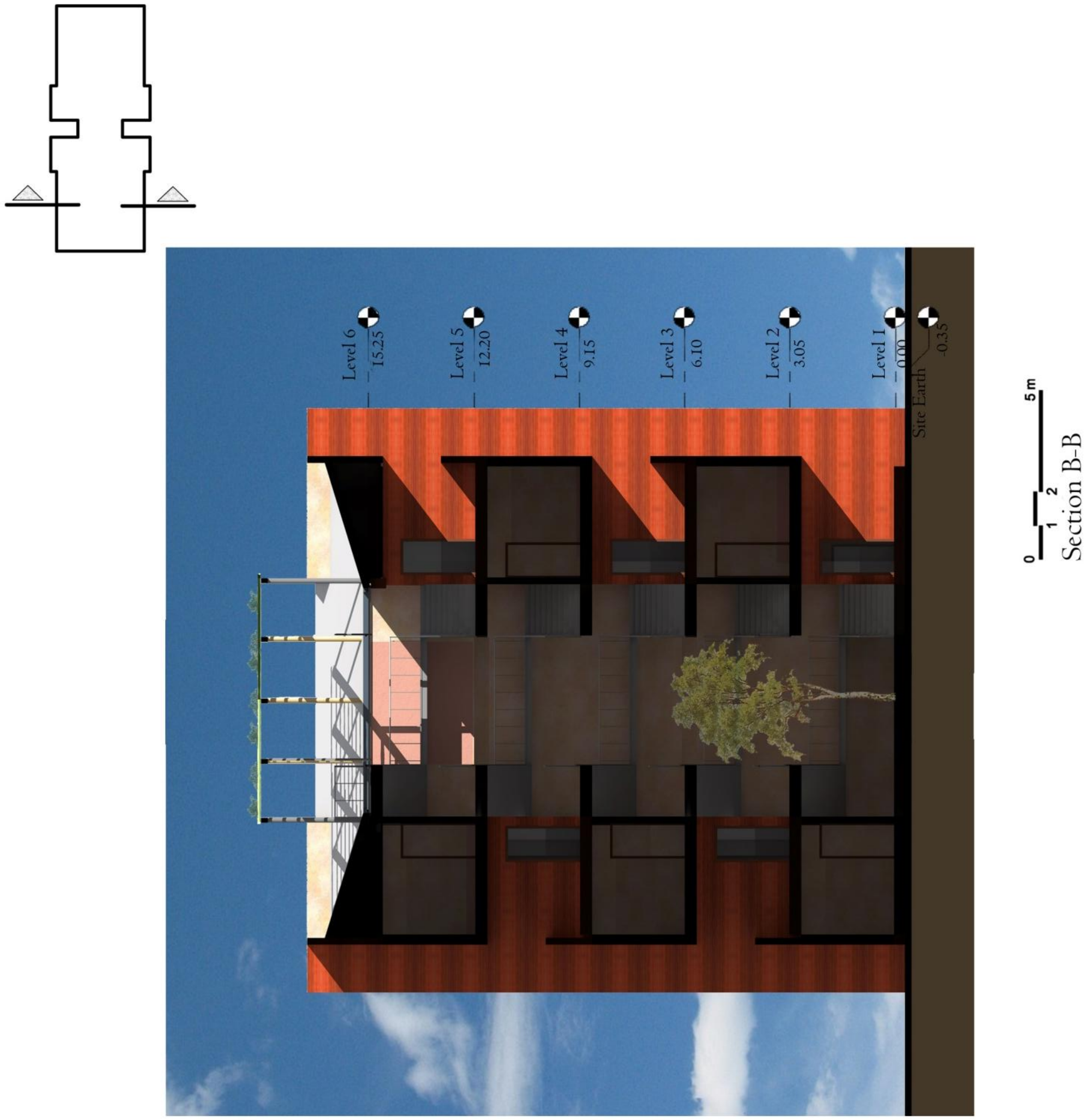


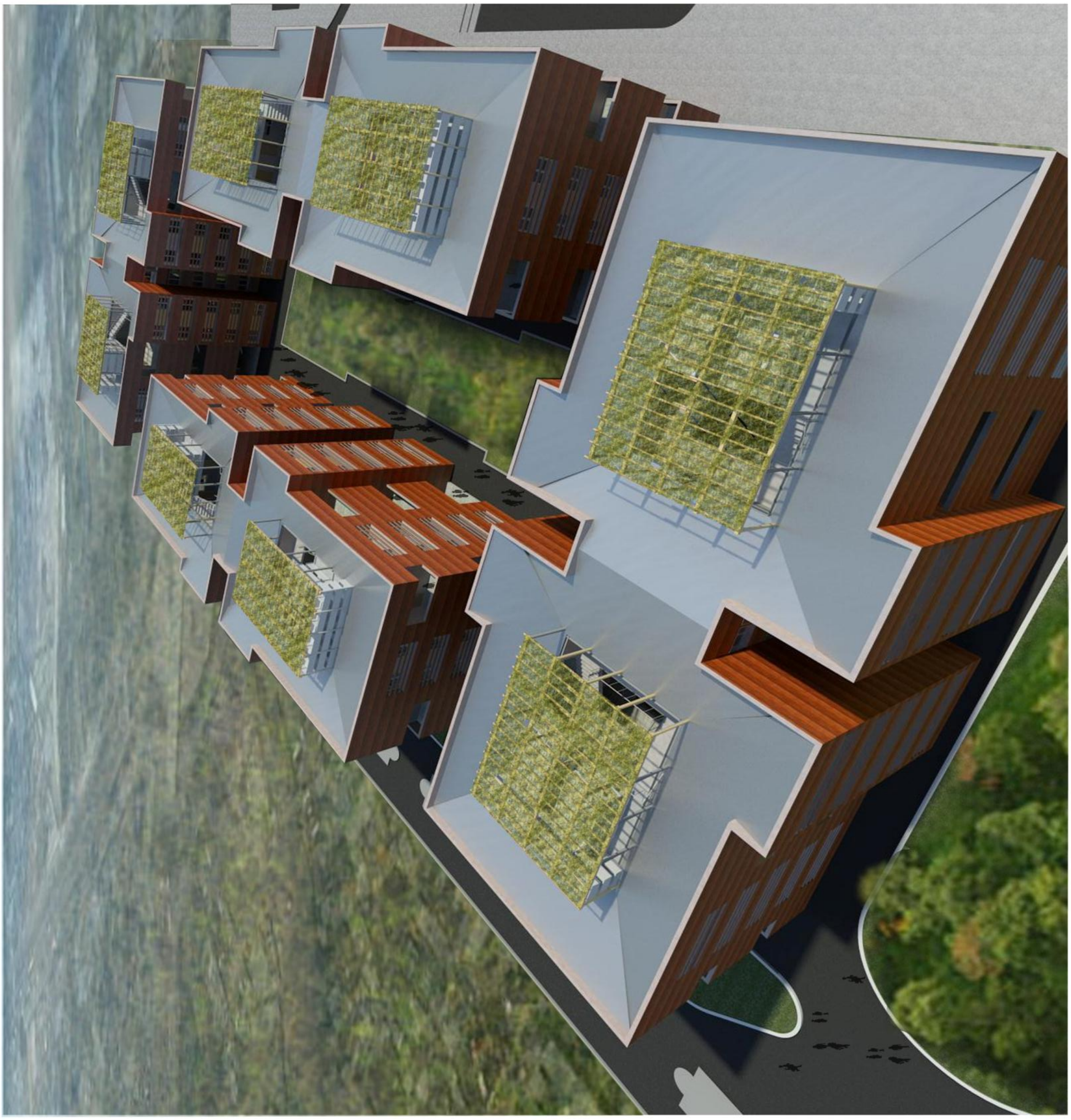
Right & Left Side Elevation

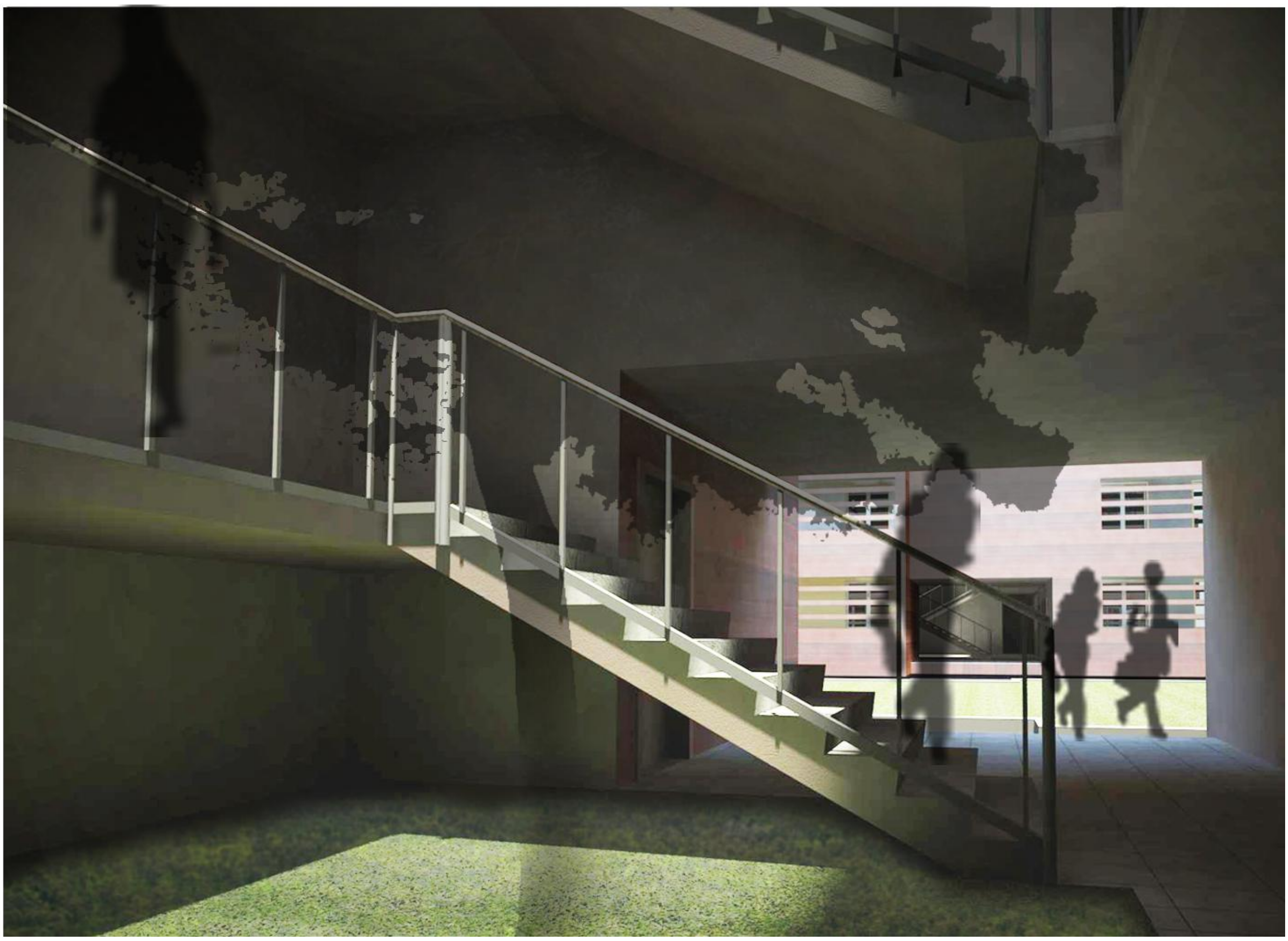


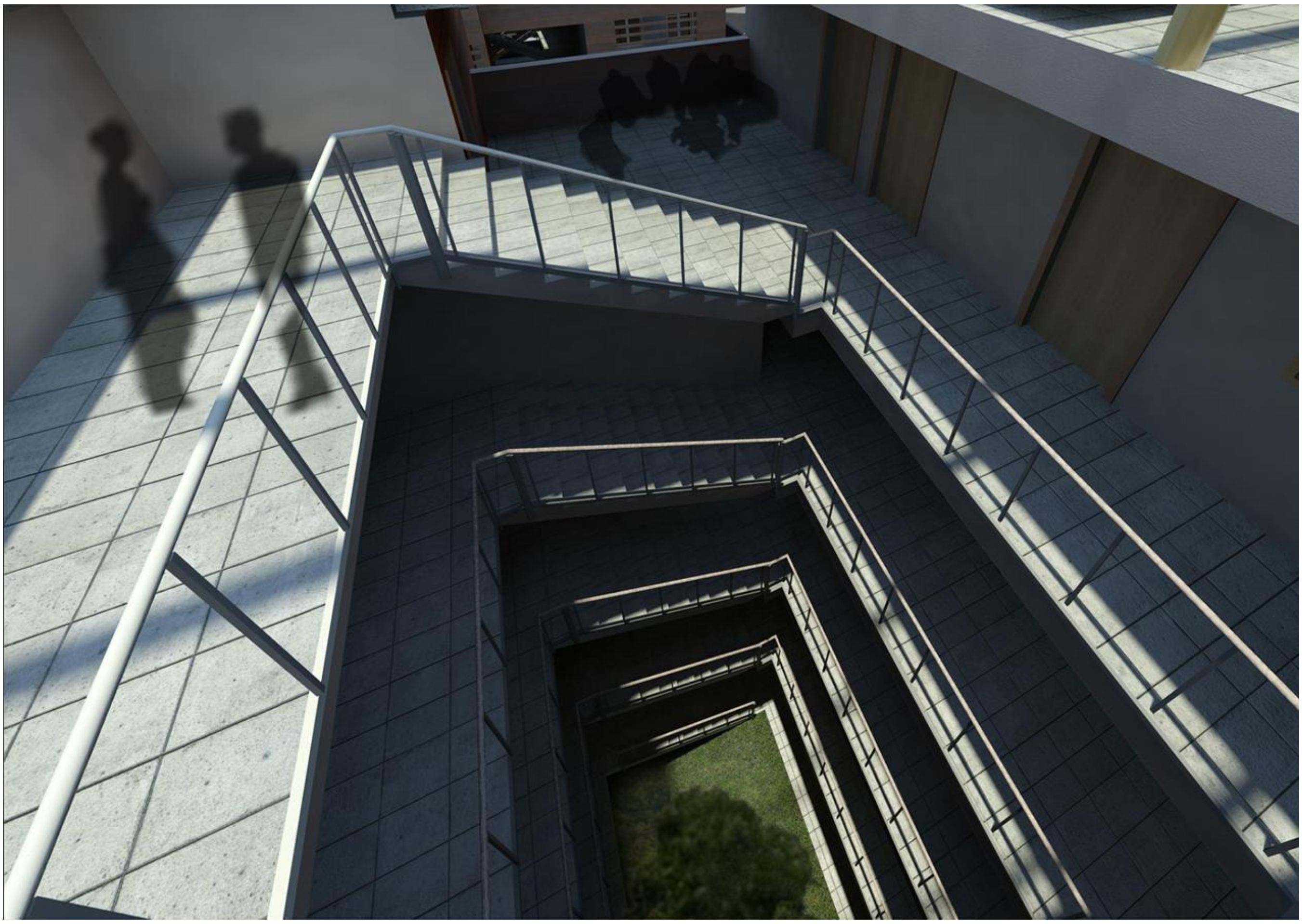
0 1 2 5 m

Section A-A

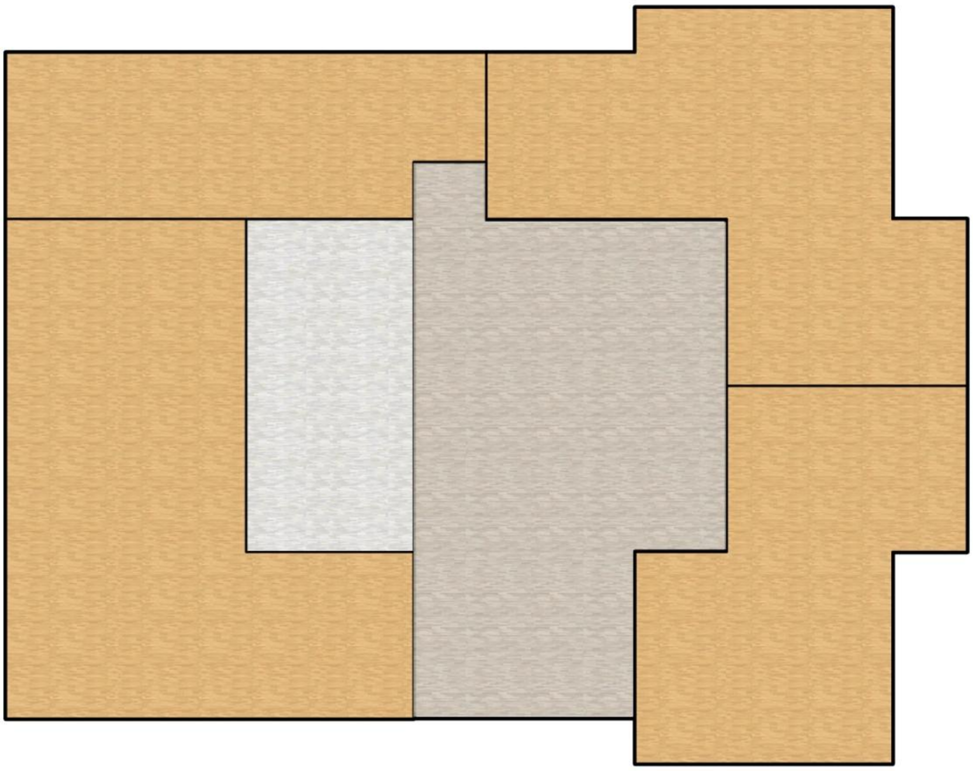

Level 6
15.25
Level 5
12.20
Level 4
9.15
Level 3
6.10
Level 2
3.05
Level 1
0.00
-0.35
Site Earth
0
1
2
5 m
Section B-B



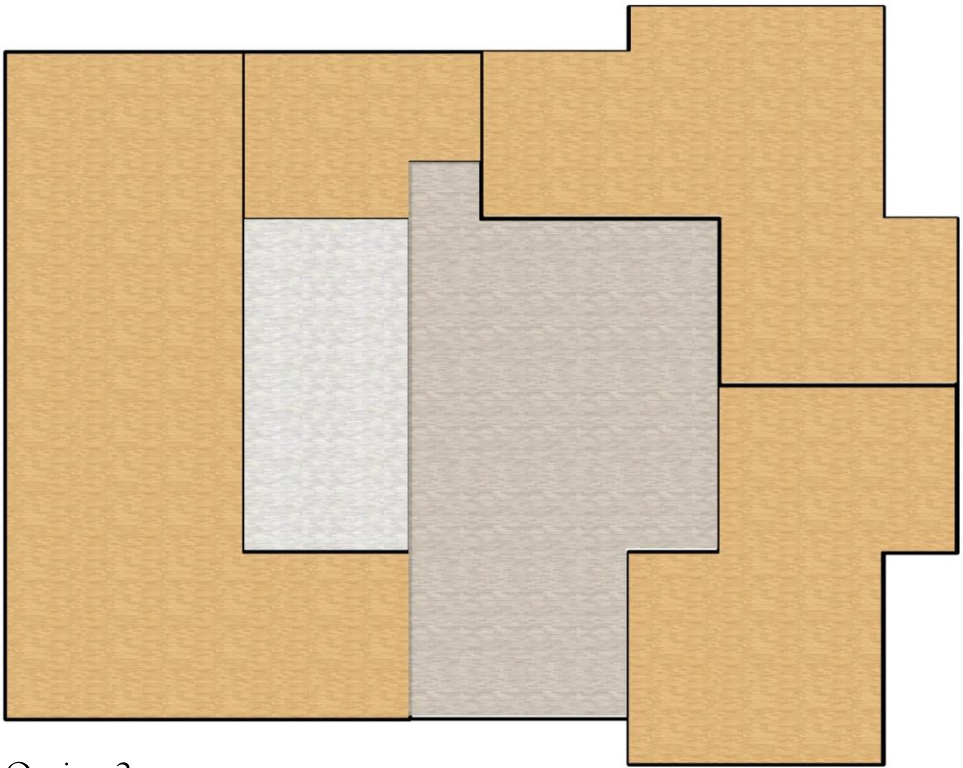




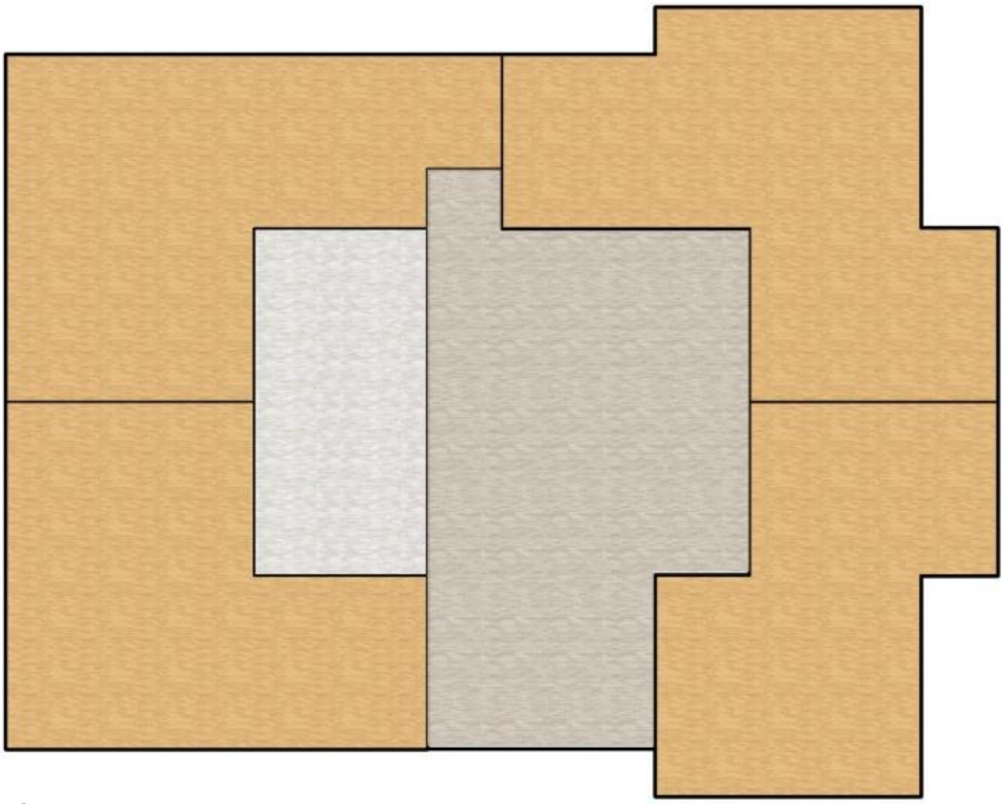
In the next two pages we have put the different spatial arrangements that could be attained with the proposed floor plan without changing the external look and aesthetics of the residential buildings. This flexibility of the floor plans gives an option for the residents to choose and modify according to their needs.



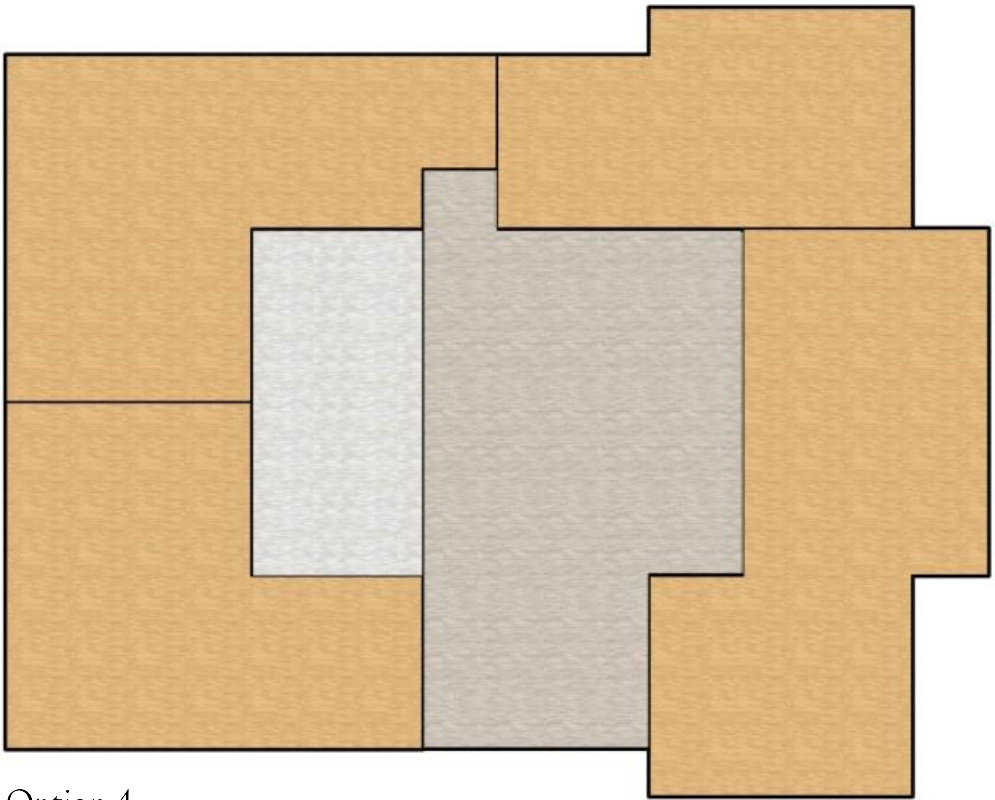
Option 1



Option 2



Option 3



Option 4

CHAPTER 1

INTRODUCTION

CHAPTER 2

KNOWLEDGE

CHAPTER 3

URBAN DESIGN

CHAPTER 4

ARCHITECTURAL DESIGN

CHAPTER 5

STRUCTURAL DESIGN

CHAPTER 6

TECHNOLOGICAL DESIGN

5. Structural Design

5.1. Description

The structure is a 5 story building; the structural system is composed of frame system and wall system working together. The frame is composed of reinforced concrete and the wall is a rammed earth which is only a load bearing wall.

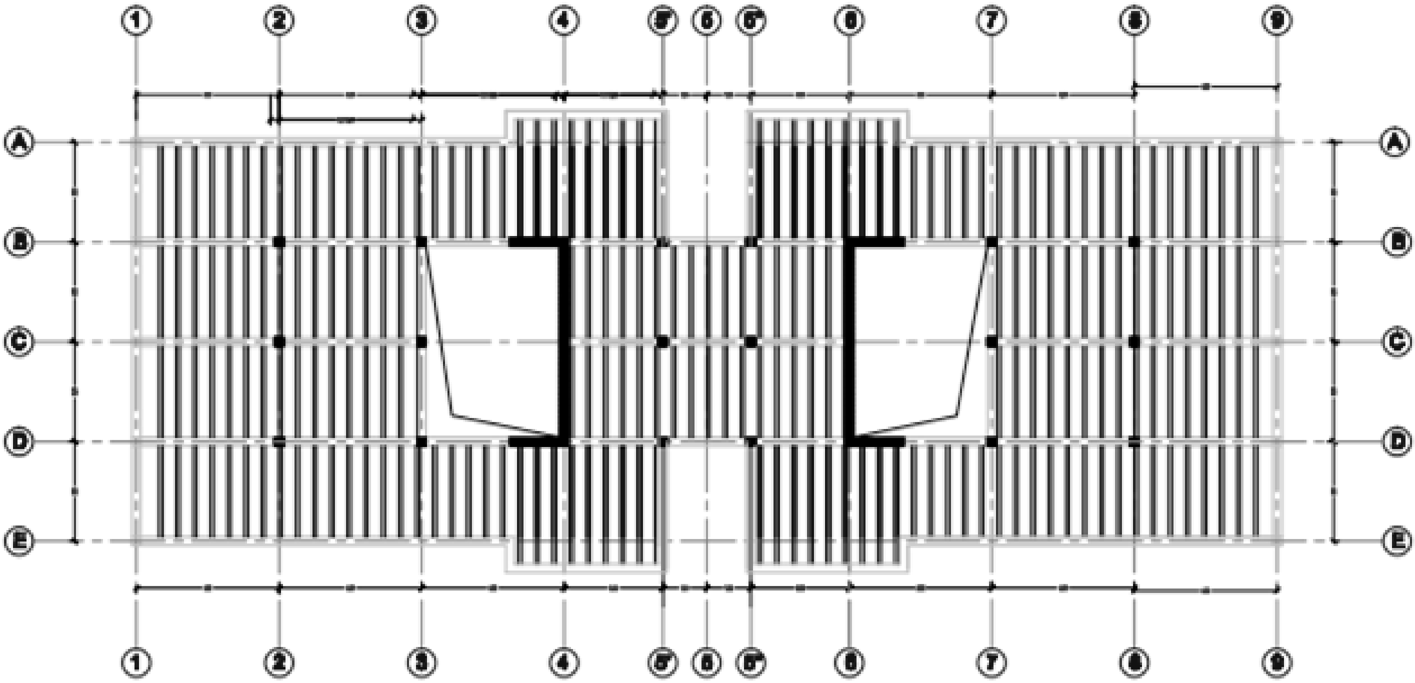


Fig. 5.1 1st to 4th floor Structural Plan

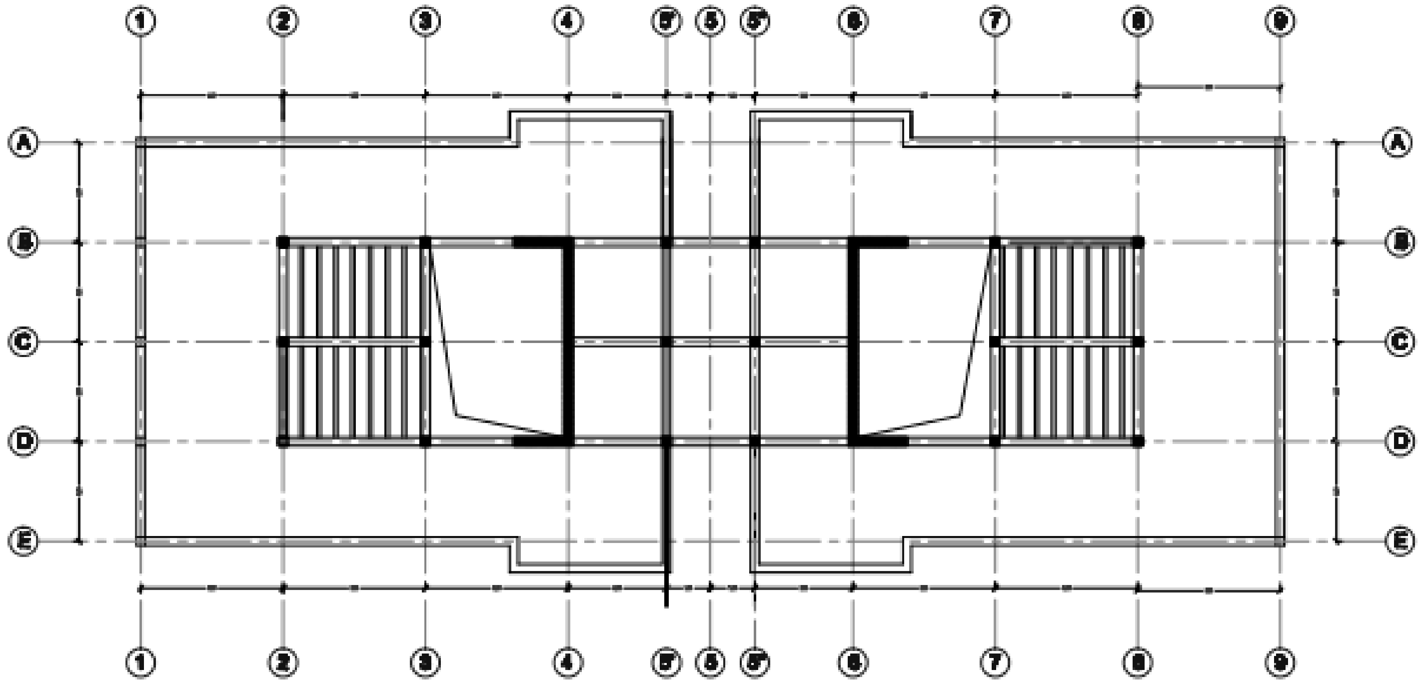


Fig. 5.2 Roof Plan

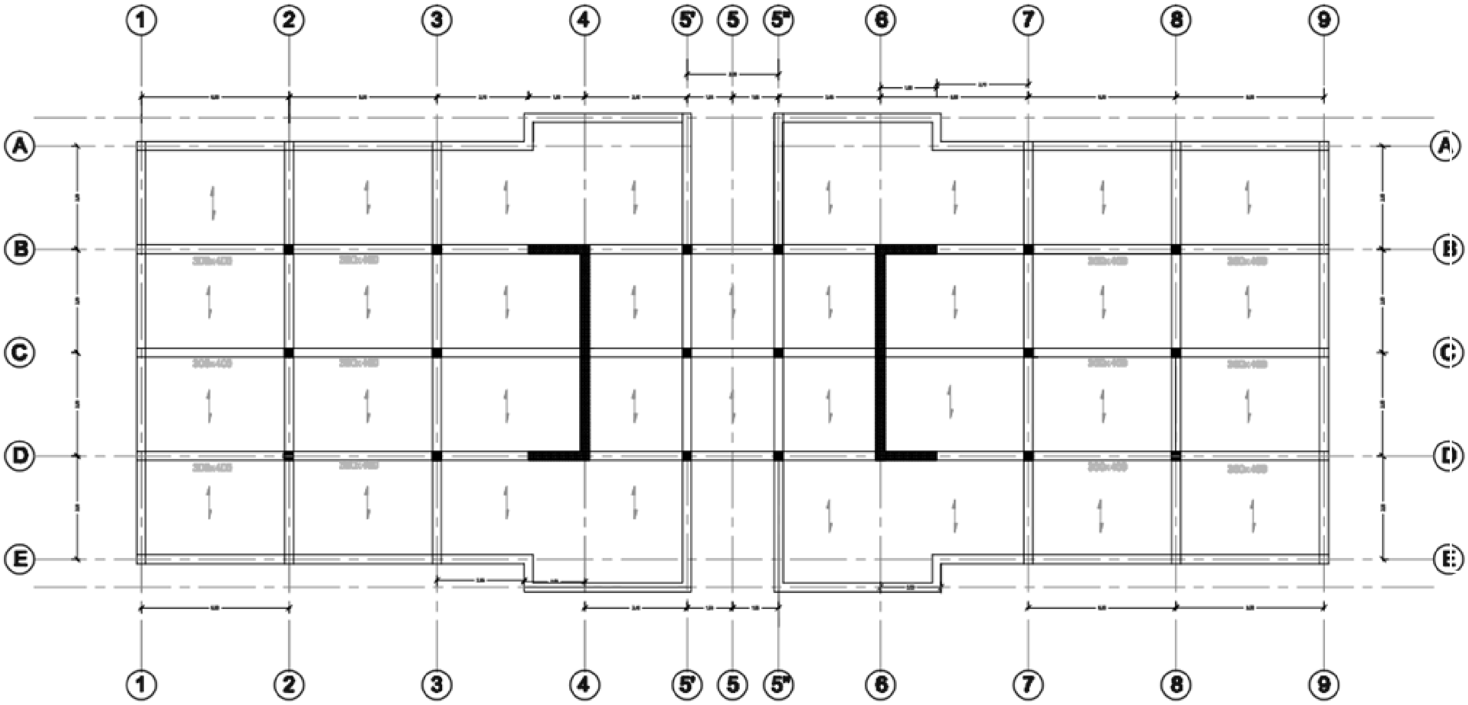


Fig. 5.3 Ground Floor Structural Plan

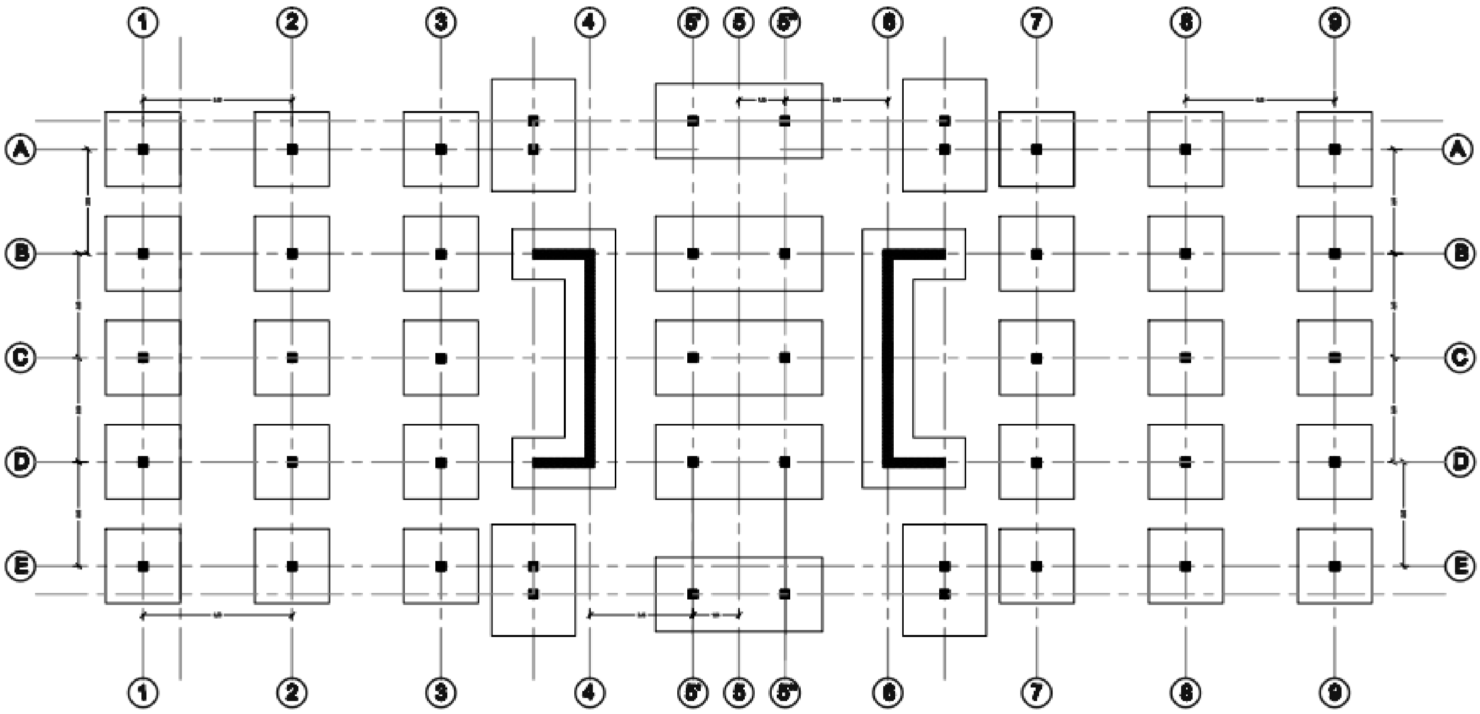


Fig. 5.4 Foundation Plan

5.2. Material Properties

5.2.1. Stabilized Rammed Earth

Structural Performance Requirements

Strength Design

In keeping with structural masonry design the primary ultimate limit states for rammed earth walls are compression failure, including buckling, lateral bending failure, and shear failure. Current limit state philosophy codes (NZS 4297:1998 1998; Standards Australia, 2002) use 95% characteristic material strengths (f_k) based on either rather limited published data or experimental test results. Given the very limited data recommended design values for characteristic design strengths are generally believed to be conservative. For example in absence of experimental data flexural tensile and shear strengths are often assumed to be zero.

Compressive Strength Design

Wherever possible the *characteristic compressive strength of rammed earth* (f_c) should be established by experimental testing. Testing of cylinders will provide a *characteristic unconfined material compressive strength* (f_{uc}). The design compressive strength is given by:

$$f_c = \varphi * f_{uc}$$

where φ is the capacity reduction factor (also known as the partial safety factor for materials) applied to the experimental characteristic value. In the New Zealand Standard for engineering design of earth buildings (NZS 4297:1998, 1998) the capacity reduction factor for axial compression and bearing is taken as 0.60, whilst the Australian earth building handbook (Standards Australia, 2002) takes a factor between 0.4 and 0.45.

In the absence of experimental data the Australian earth building handbook (Standards Australia, 2002) suggests values for design compressive strength between 0.40 N/mm^2 and 0.60 N/mm^2. The New Zealand Standard for engineering design of earth buildings (NZS 4297:1998, 1998) uses a design compressive strength equal to 0.5 N/mm^2.

In Bulletin 5 (Middleton, 1992), a safe working, rather ultimate limit state, compressive stress of 0.25 N/mm^2 for stabilized rammed earth is recommended; however, the value should also reflect the importance of the structure and the expected variations of the construction quality. King (1996) proposes an allowable compressive stress in stabilized rammed earth walls equal to 20% of material compressive strength.

Flexural Bending Strength

As in the case of compressive strength, characteristic bending strength of rammed earth (f_t) should be established by experiment. To establish design bending strength a capacity reduction factor between 0.60 and 0.80 is adopted by the Australian (Standards Australia, 2002) and New Zealand (NZS 4297:1998, 1998) design documents. If no experimental results are available, but testing for compressive strength has been carried out, the New Zealand Standard (NZS 4297:1998, 1998) proposes taking the characteristic bending strength as equal to 10% of the characteristic compressive

strength, for materials with compressive strength less than 6 N/mm2. As general guidance with no available test results the New Zealand standard proposes taking a value of characteristic bending strength equal to 0.1 N/mm^2. More conservatively the Australian earth building handbook recommends ignoring any material strength in bending in the absence of test data (Standards Australia, 2002). For permissible stress design King (1996) proposes taking an allowable flexural
compressive stress in a stabilized rammed earth wall equal to 45% of the material compressive strength, whilst Easton (1996) suggests a value of 33% of the compressive strength for stabilized rammed earth.

Shear Strength

When experimental data are available, the characteristic basic shear strength of rammed earth (f_v) should be equal to the product of the capacity reduction factor times the unconfined shear strength of the material. The recommended capacity reduction factors for shear should be either 0.70 (NZS 4297:1998, 1998) or not greater than 0.60 (Standards Australia, 2002). If experimental data for compressive strength are available then according to the New Zealand Standard (NZS 4297:1998, 1998) the shear strength of rammed earth can be taken as the greater of:

$$f_v = 0.07\ f_c$$

or

$$f_v = [70 + (5 \times h)]\ kPa$$

Where h is the height of the earth wall in meters above the plane under consideration. If there are no available test data the code proposes a value of shear strength for wind loading with elastic respond equal to 0.08 N/mm^2. Whereas without test data the Australian earth building handbook (Standards Australia, 2002) adopts zero basic shear strength, shear resistance developed along horizontal joints may be checked assuming a coefficient of friction equal to 0.20.

In a permissible stress design approach, the allowable shear stress in the wall may be taken as the square root of the compressive strength of the stabilized rammed earth (Easton, 1996; King, 1996).

Modulus of Elasticity

In the absence of direct experimental data the New Zealand Standard (NZS 4297:1998, 1998) takes the modulus of elasticity for earth wall construction as three hundred times the characteristic compressive strength value (E = 300 x f_c). The Australian earth building handbook takes the modulus of elasticity E for rammed earth as 500 N/mm^2 (Standards Australia, 2002). Permissible stress approach used in USA recommends taking the modulus of elasticity as 750 times the rammed earth compressive strength (Easton, 1996; King, 1996).

Serviceability Limit State

Serviceability limit states for rammed earth walls are concerned with appearance (cracking due to excessive deflection or shrinkage) and functional performance (rainfall or frost erosion) of the structure.

Deflection

All structural rammed earth members should be designed to have adequate stiffness to limit deflections and associated cracking under compressive service loads. In addition cracking due to deflection can also occur due to in-plane forces acting on the walls e.g. wind loading. In this case cracking is dependent on the wall thickness (Middleton, 1992) but with some empirical guidelines for minimum wall thickness, maximum wall

slenderness and provision of openings is usually sufficient for low rise earth building under wind loading.

(a) Minimum Wall Thickness

Minimum recommended thicknesses for rammed earth walls vary depending between design codes. A summary of the main recommendations is presented in Table 5.1 below:

Reference	Thickness of Wall	
	Internal	External
Standards Australia (2002)	125mm	200mm
New Mexico Code (Tibbets, 2001)	12”(305mm)	18”(457mm)
New Zealand Code (NZS 4297:1998, 1998)	250mm	
Zimbabwe Code (SAZS 724:2001 2001)	300mm	

Table 5.1 Minimum Wall Thickness for Cement stabilized Rammed Earth

While the Australian, New Zealand and Zimbabwean recommended external values are broadly similar, the New Mexico Code proposes significantly larger values for the minimum wall thickness as a result of the considerable seismicity of the region. The lower values proposed by the Australian earth building handbook reflect a wider use of *cement stabilized rammed earth* construction.

(b) Maximum Wall Slenderness

Recommendations for maximum wall slenderness limit both the likelihood of excessive cracking under service load and compression buckling under ultimate limit state conditions. The New Zealand Standard for engineering design of earth buildings (NZS 4297:1998, 1998) requires that the maximum unsupported clear height and length shall not exceed the following values (where *t* is wall thickness):

- *Simply supported- Height and Length not greater than18t*
- *One end continuous- Height or Length not greater than 21t*
- *Both ends continuous- Height or Length not greater than 22t*
- *Cantilever- Height or Length not greater than 8t*

For the similar configurations the Australian earth building handbook (Standards Australia, 2002) recommends that height of a freestanding wall should not exceed 10t. For a wall laterally restrained top and bottom its height shall not exceed 18t. In both cases the unsupported clear length of the wall should not exceed 30t. Similar values for unrestrained walls are proposed by the Zimbabwe Standard Code of Practice for Rammed Earth Structures (SAZS 724:2001 2001). A number of other publications (Easton 1996; King 1996; McHenry 1984; Earth Building Association of Australia 2001, Middleton 1992, Tibbets 2001) recommend similar maximum wall slenderness values based on typical wall thickness. Both the New Zealand Code and Australian earth building handbook (NZS 4297:1998, 1998; Standards Australia, 2002), following masonry design standards, determines a wall slenderness ratio (S_r) based on ratio of effective height to thickness. Effective height depends on end restraints and are defined as follows:

- *0.75H for a wall laterally supported and rotationally restrained both at the top and the bottom; or*
- *0.85H for a wall laterally supported both top and bottom and rotationally restrained at one of these; or*
- *1.00H for a wall laterally supported but rotationally free both top and bottom; or*
- *2.00H for a wall laterally supported and rotationally restrained only along its bottom edge.*

In addition to the above limitations on wall height and length, for unreinforced load bearing rammed earth walls the maximum slenderness ratio required according to the New Zealand code shall be not exceed 6, whilst for unreinforced columns the limiting value is 3.

(c) Provisions for Openings

Recommendations for openings in earth walls may be summarized as follows:

- *Total combined horizontal length of openings in a wall should normally not exceed one-third of the total wall length ((Standards Australia, 2002; Easton, 1996; McHenry 1984, King, 1996) ;*
- *The minimum distance between openings for a load bearing wall of minimum thickness should be between 600mm-1000mm ((Standards Australia, 2002; SAZS 724:2001, 2001; Middleton, 1992; King, 1996);*
- *Openings should be at least 750mm from the corner of the wall and with minimum 450mm of wall above the crown (SAZS 724:2001 2001); and*

- *For heavily loaded walls the total area of the openings should not exceed 20% of the total area of the wall (Standards Australia, 2002).*

Further recommendations for small arched openings in rammed earth walls are published by Keable (1996) following listing by Lilley & Robinson (1995).

Shrinkage

To limit the possibility of cracking due to drying shrinkage and movements arising from thermal expansion and contraction, control or movement joints are normally provided. The horizontal spacing of the joints depends on the soil properties. In general, the control joints in wall panels should be spaced between 2.5 and 5.0 meters (Standards Australia, 2002).

Water Penetration & Frost Resistance

Rammed earth walls should be detailed in a such way that the effects of water and moisture penetration, including frost, do not unduly affect the durability of the structure. These conditions are controlled by appropriate material selection and architectural detailing.[1]

5.2.2. Concrete

Concrete strength class: C25/30

Characteristic cylinder compressive strength

$$f_{ck} = 25\ N/mm^2$$

Design compressive strength [EC2 – 3.1.6(1) and Table 2.1N for γ_C]

$$f_{cd} = \alpha_{cc}\frac{f_{ck}}{\gamma_c} = 0,85\cdot\frac{25}{1,5} = 14,2\ N/mm^2$$

Allowable compressive stress under characteristic combination of actions [EC2 – 7.2(2)]

$$\sigma_{c,adm} = k_1\ f_{ck} = 0,6\cdot 25 = 15\ N/mm^2$$

Medium tensile strength [EC2 – Table 3.1]

$$f_{ctm} = 0,3(f_{ck})^{2/3} = 0,3\cdot(25)^{2/3} = 2,6\ N/mm^2$$

Characteristic tensile strength [EC2 – Table 3.1]

$$f_{ctk;0,05} = 0,7\ f_{ctm} = 0,7\cdot 2,6 = 1,8\ N/mm^2$$

Design tensile strength [EC2 – 3.1.6(2) and Table 2.1N for γ_C]

[1] *May 2003, A Review of Rammed Earth Construction for DTi Partners in Innovation Project*

$$f_{ctd} = \alpha_{ct} \frac{f_{ctk;0,05}}{\gamma_c} = 1,0 \cdot \frac{1,8}{1,5} = 1,2\ N/mm^2$$

Secant modulus of elasticity [EC2 – Table 3.1]

$$E_{cm} = 22\left(\frac{f_{cm}}{10}\right)^{0,3} = 22\left(\frac{f_{ck}+8}{10}\right)^{0,3} = 22 \cdot \left(\frac{25+8}{10}\right)^{0,3} \approx 31000\ N/mm^2$$

From EC Table 3.1: Nominal values of yield strength f_y and ultimate tensile strength f_u for hot rolled structural steel we choose EN 10025-2 & S350.[2]

Characteristic yield strength

$$fyk \geq 355N/mm2$$

Design yield strength [EC2 – 3.2.7 and Table 2.1N for γs]

$$fyd = \frac{fyk}{\gamma s} = \frac{355}{1.15} = 308.7N/mm2$$

Admissible stress under characteristic combination of actions [EC2 – 7.2(5)]

$$\sigma s, adm = k3 * fyk = 0.8 * \frac{355N}{mm2} = 284N/mm2$$

Modulus of elasticity [EC2 – 3.2.7(4)]

$$E_s = 200000\ N/mm^2$$

5.3. Loads

Self weight of structural and non structural elements

External wall *(Rammed earth)*

Layer	*Thickness*	*Specific weight(KN/m³)*	*Weight (KN/m²)*
Rammed earth	*30cm*	*16*	*4.8*
		Total	*4.8KN/m²*

Table 5.2 Material parameters for Rammed Earth

[2] *BS,EN 1993-1-12005 Eurocode*

5.3.1. Stabilized Rammed Earth

For a floor height of 3.05m including slab thickness and 35 cm slab, the clear height is 2.7m so the linear weight of the wall is

$$2.7\text{m} * 4.8\text{KN/m}^2 = 12.96\text{KN/m}$$

Assuming 20% of openings

$$12.96*0.8 = 10.37\text{KN/m}$$

This is the total linear weight of the wall. The load of the external walls is directly applied on the beams along the perimeter and it is not shared out with slabs.

5.3.2. Internal Partition - Compressed Straw Board Panels

For inside partition we used straw board with wooden frame filled with straw bale

Layer	Thickness (cm)	Specific weight(KN/m³)	Weight (KN/m²)
Straw board	3	16	0.44
Wooden frame	5	8	0.02
Straw bale	5	10	0.475
		Total	0.935KN/m²

Table 5.3 Material parameters for Straw Board wall

The clear height is 2.70m so the linear weight of the wall will be

$$\mathbf{2.7m*0.935KN/m^2 = 2.52KN/m}$$

EN 1991-1-1 [§ 6.3.1.2(8)] permits to consider an equivalent uniformly distributed load all over the floor, instead of the free action of movable partitions, if the slab can well redistribute the load transversally. The nominal value of this uniform load is given in function of the linear self-weight of the wall considered:

- for movable partitions with a self-weight ≤ 1.0 kN/m wall length: $q_k = 0.5$ kN/m²
- for movable partitions with a self-weight ≤ 2.0 kN/m wall length: $q_k = 0.8$ kN/m²
- for movable partitions with a self-weight ≤ 3.0 kN/m wall length: $q_k = 1.2$ kN/m²

In case of partitions with linear self-weight exceeding 3,0 kN/m EN 1991-1-1 [§ 6.3.1.2(9)] recommends to consider the effective position of the load on the slab.

However, the load of inside walls is hereby considered to be uniformly distributed in order to avoid further calculations in case of a possible change of disposition of partitions during the design working life of the building.

The linear weight of the partition wall will be the product of the total partition wall in ml by the total linear weight

171.51m*2.52KN/m = **432KN**

And if we distribute this load to a floor area of 553m²

The distributed load of the partition wall will be : 432KN/553m² = **0.78KN/m²**

It has to be specified that this equivalent uniform load has to be considered as a live load with partial safety factor $\gamma_Q = 1,5$ (=0 where favourable) for Ultimate Limit State (ULS) combinations and coefficients $\psi_0 = \psi_1 = \psi_2 = 1,0$ for Serviceability Limit State (SLS) combinations.

5.3.3. Slabs

Self weight: In order to compute the dead load of the slab, it is preferable to assume percentage of the cross section hence there are heterogeneous composition.

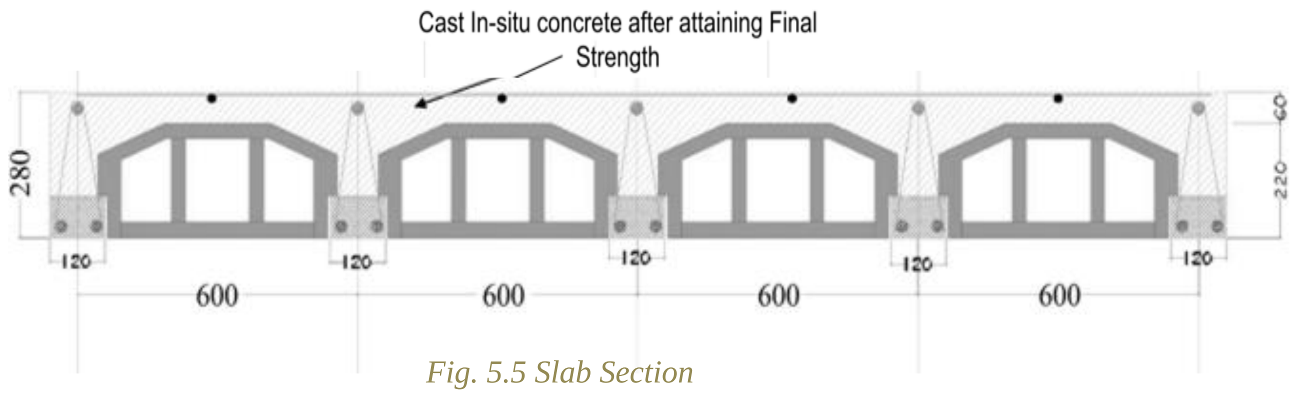


Fig. 5.5 Slab Section

Total cross sectional area = A_t = 120*28= 3360 cm²

Empty = 94.4*18 = 1692cm² percentage 50%

HCB = 16*22 = 352cm² percentage 10.5%

Concrete = 3360 –2044= 1316cm² percentage 39.5%

So the load of the slab will be

$(0.336m^2*39.5*0.01*25KN/m^3)/1.2m = 2.765KN/m^2$

$(0.336m^2*10.5*0.01*14KN/m^3)/1.2m = 0.4116KN/m^2$

Total load of the slab per square meter is $2.765KN/m^2 + 0.4116KN/m^2 =$ **$3.177KN/m^2$**

5.3.4. Floor Finishes

Cement mortar $3cm*23KN/m^3 = 0.69KN/m^2$

Plastic finish $2cm* 12KN/m^3 = 0.24KN/m^2$

Total floor finish $0.69KN/m^2 + 0.24KN/m^2 =$ **$0.93KN/m^2$**

5.3.5. Imposed Load

The imposed load for floors in residential buildings is [EN 1991-1-1 §6.3.1.2, Tables 6.1 & 6.2, in accordance with National Annex] **2.00 kN/m²**

5.3.6. Design Seismic Load

Identification of earthquake zone

The national territory has been divided into seismic zones, each marked by a different value of the

Parameter g, maximum horizontal bed rock acceleration for Addis Ababa which is located in zone 2 that is 0.05g.

Classification of the type of subsoil

For the purposes of the definition of the seismic design, Euro code 8 defines several categories of stratographic profile of the soil foundation. The readings on the ground, performed with measurement of Shear wave velocity V S 30, define belonging to the category of soil *type C* (average deposits of sands and gravels thickened or clay of medium texture with thickness of several tens of meters), [EC8 - - 3.1.2]. The value of the parameter S is: S = 1.15.

Ground types A, B, C, D, and E, described by the stratographic profiles and parameters given in Eurocode 8 Table 3.1 and described hereafter, may be used to account for the influence of local ground conditions on the seismic action. This may also be done by additionally taking into account the influence of deep geology on the seismic action.

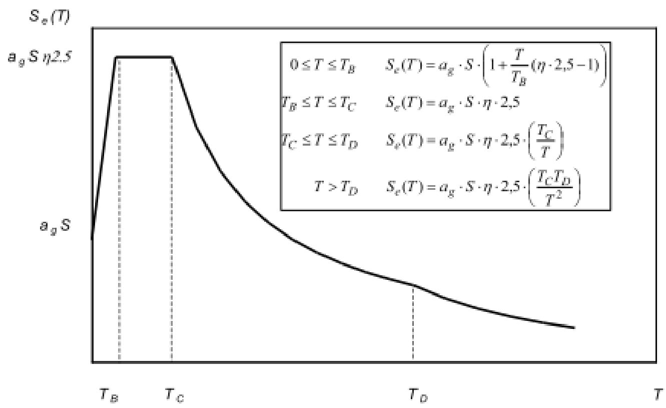
Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0
E	1.4	0.15	0.5	2.0

Type 1 elastic response spectra

Table 5.4 Parameter of elastic response spectrum [3]

For ground type C we have S=1.15, $T_b(s) = 0.2$, $T_c(s) = 0.6$, $T_d(s) = 2$

The motion due to a seismic event at a given point on the surface of the soil can be represented by elastic response spectra of acceleration of the ground. The elastic response spectrum consists of a spectral form considered independent at the level of seismic activity, multiplied by the maximum value at the ground that characterizes the site $a_g \cdot S$.



T : vibration period of a linear SDOF system

a_g	design ground acceleration on type A ground ($a_g = \gamma_I * a_{gR}$);
T_B	lower limit of the period of the constant spectral acceleration branch;
T_C	upper limit of the period of the constant spectral acceleration branch;
T_D	beginning of the constant displacement response range of the spectrum;
S	soil factor;
η	damping correction factor (η = 1 for 5% viscous damping).

Fig. 5.6 Horizontal elastic response spectrum

Buildings are classified in 4 importance classes, depending on the consequences of collapse for human life, on their importance for public safety and civil protection in the immediate post-earthquake period, and on the social and economic consequences of collapse. The importance classes are characterized by different importance factors as described in EN-1998 2.1(3).

[3] *Eurocode 8*

Importance class	Buildings
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.
II	Ordinary buildings, not belonging in the other categories.
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.

Table 5.5 Importance class for buildings

From this table our building is Importance class II and value of γ =1.0

Lateral Force Method of Analysis

This type of analysis may be applied to buildings whose response is not significantly affected by contributions from modes of vibration higher than the fundamental mode in each principal direction and for buildings which full fill both of the two following conditions.

- They have fundamental periods of vibration T1 in the two main directions which are smaller than the following values:

$$T1 \leq 4Tc \text{ or } 4s$$

- They meet the criteria for regularity in elevation,

NOTE: For the building we are considering, from the geometry it is regular both in plan and elevation. For buildings with heights of up to 40 m the value of T1(in s) may be approximated by the following expression:

$$H=2.7*5+0.35*5 =15.25 \ [m]$$

$$\text{Natural period } (T1) = C * H^{3/4} = 0.05* 15.25^{3/4} = 0.38 \ [s]$$

Where

C : is 0,085 for moment resistant space steel frames, 0,075 for moment resistant space concrete frames and for eccentrically braced steel frames and 0,050 for all other structures;

H is the height of the building, in m, from the foundation or from the top of a rigid basement.

For $T_B \leq T_I \leq T_c$ $\quad S_d(T_I) = a_g*S*\eta*2.5$ $\quad$ where $a_g = 0.05g = 0.05*9.81m/s^2 = 0.49$

$S_d = 0.49*1.15*0.05*2.5$ $\quad$ S_d= **0.0704m/s²**

Base shear force

The seismic base shear force F_b, for each horizontal direction in which the building is analyzed, shall be determined using the following expression:

$$F_b = S_d (T1) * M_{tot} * \lambda$$

$$M_{tot} = M_{GF} + M_{1stfloor} + M_{2nd\ floor} + M_{3rdfloor} + M_{4thfloor}$$

- M_{tot} is the total mass of the building, above the foundation or above the top of a rigid basement, as computed above.
- λ is the correction factor, the value of which is equal to: $\lambda = 0,85$ if $T_1 < 2\ T_C$ and the building has more than two storey, or $\lambda = 1.0$ otherwise.

Except the 4th floor which has additional roof weight, all the other floors have the same weight.

Mass of ground floor

- Rammed Earth = 10.37KN/m*123.2m*100 = 127,758.4Kg
- Partition =0.78KN/m2*545m^2*100 = 42,510Kg
- Slab =3.177KN/m2*545m^2*100 = 138,975Kg
- Finishing = 0.93KN/m2*545m^2*100 = 50,685Kg
- Beams = 3KN/m*242.55m*100 = 72,765Kg
- Column = 6.07KN*21*100 = 12,757.5Kg

Total weight of ground floor is **445,451kg**

For the 4th floor including the 10,845Kg roof weight we will have a total of 456,296Kg.

M_{tot} = 445,451kg + 445,451kg + 445,451kg + 445,451kg + 456,296Kg = **2,238,100Kg**

$F_b = S_d (T_1) * M_{tot} * \lambda$

= 0.0704m/s^2*1*2,238,100Kg = **157.65KN**

Distribution of the horizontal seismic forces

The fundamental mode shapes in the horizontal directions of analysis of the building may be calculated using methods of structural dynamics or may be approximated by horizontal displacements increasing linearly along the height of the building.

$$F_i = F_b \cdot \frac{z_i \cdot m_i}{\sum z_j \cdot m_j}$$

Where

z_i, z_j are the heights of the masses m_i ,m_j above the level of application of the seismic action.

$\sum Zj * mj$ = 3.1m*445,451kg +6.2m*445,451kg +9.3m*445,451kg + 12.4m*445,451kg +15.5m*456,296kg

= 20,881,569Kg.m

$$Froof = 157.65KN * 15.5m * \frac{456296Kg}{20881569Kg.m} = 53.4KN$$

$$F4th\ floor = 157.65KN * 12.4m * \frac{445451Kg}{20881569Kg.m} = 41.7KN$$

$$F3rd\ floor = 157.65KN * 9.3m * \frac{445451Kg}{20881569Kg.m} = 31.27KN$$

$$F2nd\ floor = 157.65KN * 6.2m * \frac{445451Kg}{20881569Kg.m} = 20.85KN$$

$$F1st\ floor = 157.65KN * 3.1m * \frac{445451Kg}{20881569Kg.m} = 10.43KN$$

Dead Loads

Before starting the load combination let us summarize the loads that have been calculated in the previous sections:

- Rammed earth = 12.96KN/m to be applied along the external beam
- Partition = 0.78KN/m^2
- Slab = 3.177KN/m^2
- Finishing = 0.93KN/m^2
- And live load = 2.0KN/m^2

5.4. Structural Analysis

The structural analysis will be carried out using linear analysis based on the theory of elasticity, considering the combination of actions for Ultimate Limit States [EC2 – 5.1.3(1)P] that is [EC0 – Expression 6.10]

$$\sum_{j\geq 1}\gamma_{Gj}\, G_{kj} + \gamma_{Q1}\, Q_{k1} + \sum_{i>1}\gamma_{Qi}\,\psi_{0i}\, Q_{ki}$$

The most unfavourable condition results in considering the live load Q_1 as the leading variable action and the load due to inside partitions with its combination value $\psi_{02}\ Q_2 = Q_2$ ($\psi_{02} = 1{,}0$ according to National Annex).

Considering the earthquake

Effects of actions due to the combination of horizontal action earthquake can be evaluated using the following combinations: Linear-elastic analysis may be performed using two planar models, one for each main horizontal direction.

EE_{dx} "+" 0.30 EE_{dy} [EC8 - 4.3.3.5.2 (4)]

0.30 EE_{dx} "+" EE_{dy}

Where,

"+" Means "must be combined with";

EE_{dx}= represents the effects due to application of the seismic action along horizontal axis x of the structure;

EE_{dy} =represents the effects of the action due to application of the same seismic action along the horizontal axis y orthogonal structure.

Tests carried out considering the limits concerning the horizontal actions implemented separately to consider the combined effect plus the maximum values obtained in one direction with 30% of the maximum obtained by the action applied in the other direction.

Possible combinations:

1) COMB 1 = 1.4 DL + 1.5 LL
2) COMB 2 = 1 DL + 1 LL + 0.3 EE DX + EE DY ………(for analysis along Y direction)
3) COMB 3 = 1 DL + 1 LL + EE DX + 0.3 EE DY ………(for analysis along X direction)
4) COMB 4 = ENV(COMB 1, COMB 2, COMB 3)

ETABS Modelling

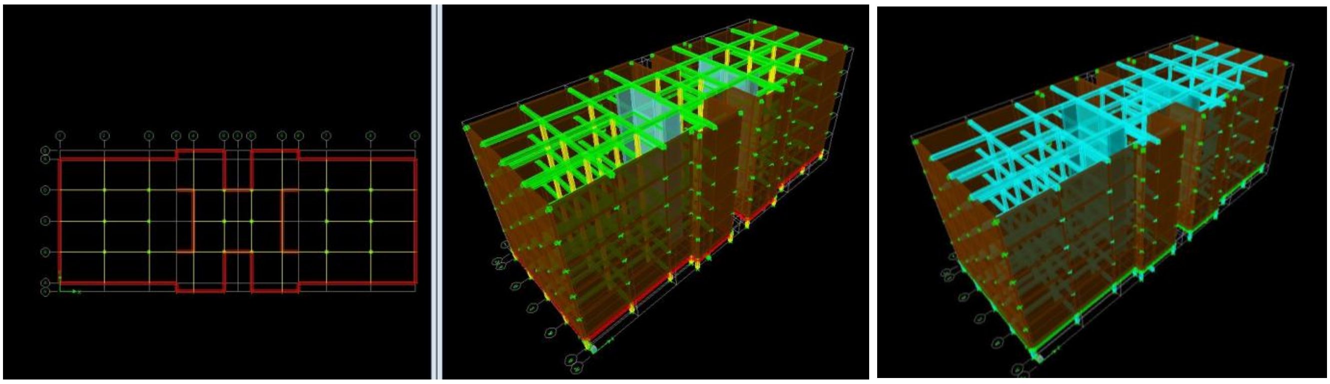


Fig. 5.7 Structural Models generated with ETABS

In terms of structural material composition the main components are rammed earth and reinforced concrete.

5.4.1. Design of Slab

For designing a slab we took a segment form the slab along the short axis of the slab as shown on the drawing below. And make analysis based on the two type of modelling.

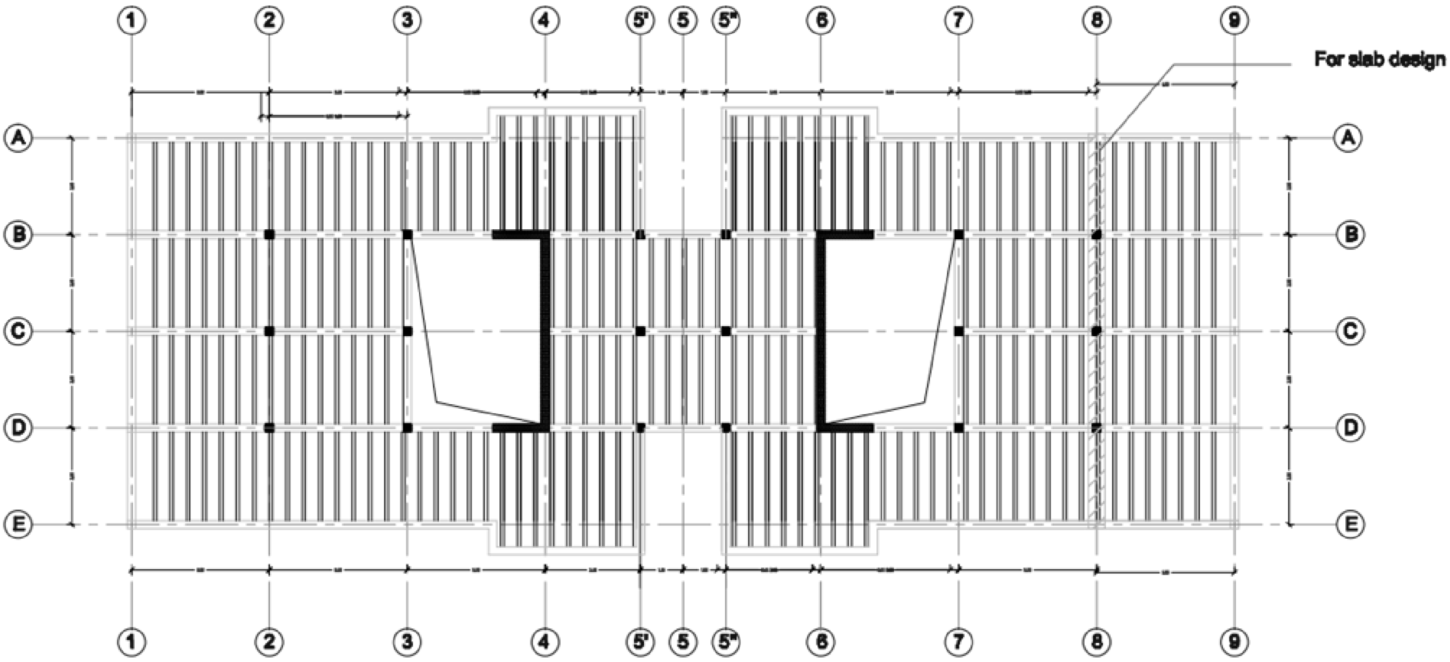
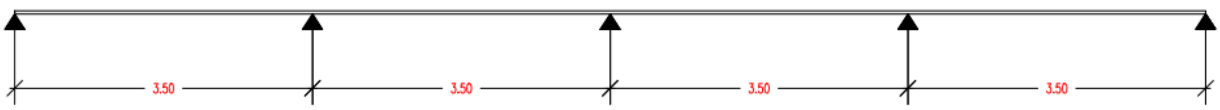


Fig. 5.8 Typical Structural Plan

There are two way of modelling the slab. One is to consider fixed end at axis A and E. The other is assuming simply support ends at axis A and E.

Modelling I



Modelling 2

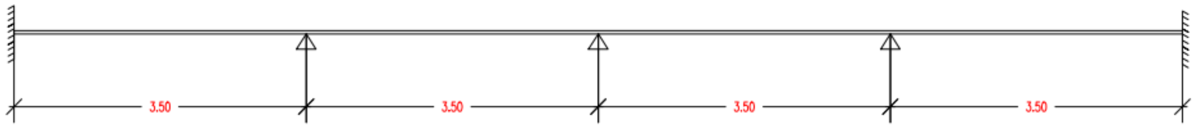


Fig. 5.9 Fixed end support

After having both the analysis using simply support end have a maximum value of both bending moment and shear force. So the design will be performed by using simply supported model.

ETABS out put

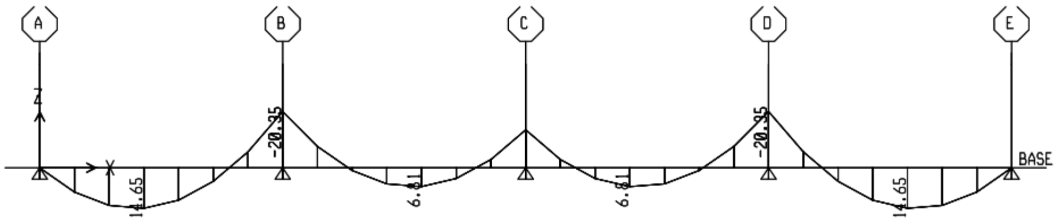


Fig. 5.10 Bending moment diagram

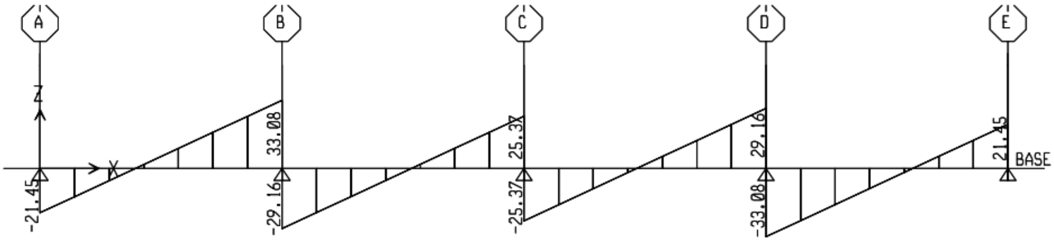


Fig. 5.11 Shear Force Diagram

i *Ribbed Spacing:* *600* *mm c/c*

ii *Slab Topping :*

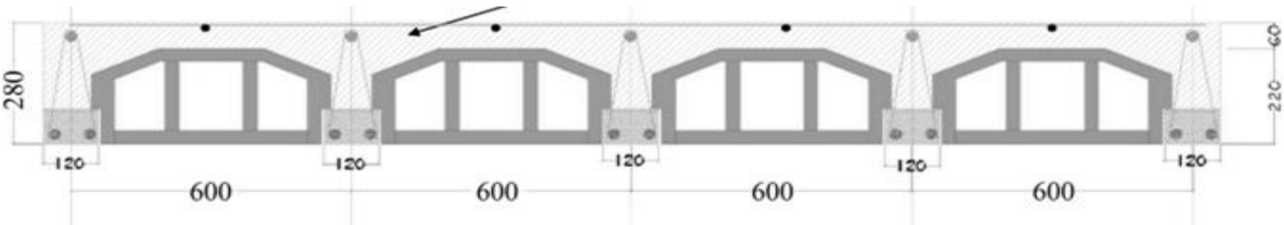
thickness of topping, t ≥ *40mm*

1/10 clear distance b/n ribs

Clear distance b/n ribs = 480 mm, and

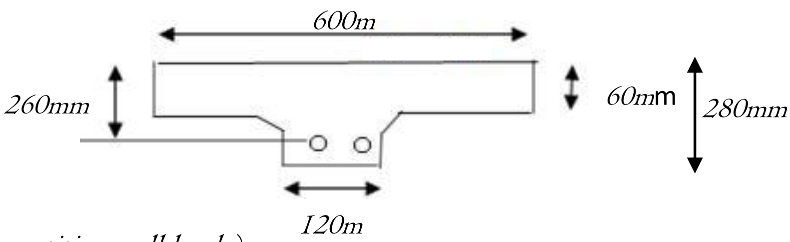
*1/10 ** *480* *=* *48* *mm*

take t = 60 mm



iii Effective Depth

Using Φ 10 mm 15 mm cover: d = 260 mm



iv Loading (Including partition wall loads)

Partition	*0.78*	*KN/m2*
Finishing	*0.93*	*KN/m2*
Slab	*3.177*	*KN/m2*

- *Dead load including partition wall = (1.2 x 4.877) = 5.864*

(For residential building live load is 2 KN/m²)

- *Live load = 2.000 KN/m²*

Dead Load :	*5.864*	*KN/m²*	*Factored dead load*	*8.210*	*KN/m²*
Live Load :	*2*	*KN/m²*	*Factored dead load*	*3*	*KN/m²*

Total Ultimate Load:

=1.4(Dead load + Partition load) + 1.5(live load) = 11.21 KN/m²

But in a 600mm width of the beam the load per meter is :

Dead Load:	*4.9261*	*KN/m*
Live Load:	*1.8*	*KN/m*
Total Ultimate Load:	*6.7261*	*KN/m*

Using ETABS the frames in the structural element are analyzed. In the analysis, all the loads and different load combinations are considered. In addition, maximum forces are selected by alternating the selected by alternating the loads in different spans of the beams.

$$\rho_{req} = \frac{1}{m}\left[1 - \sqrt{1 - \frac{2mR_n}{f_{yd}}}\right] \qquad m = \frac{f_{yd}}{f_{cd}} \qquad R_n = \frac{M_u}{bd^2}$$

$\rho_{min} = 0.0016901141$ $\qquad \rho_{max} = 0.04$

$A_s = \rho_{max} * b * d$

Description		Design Moment	R_u	ρ_{req}	ρ	Area of steel	Bar	Reinforcement
Strip		(KN-m)				As (mm²)	Φ(mm)	per rib
Strip at axis 8	Support A	0	0	0.000	0.002	52.732	10	1
	Span A-B	14.65	1805.97	0.006	0.006	199.935	14	2
	Support B	20.35	2508.63	0.009	0.009	290.226	14	2
	Span B-C	6.61	814.842	0.003	0.003	85.542	10	2
	Support C	13.7	1688.86	0.006	0.006	185.710	12	2
	Span C-D	6.81	839.497	0.003	0.003	88.238	10	2
	Support D	20.35	2508.63	0.009	0.009	290.226	14	2
	Span D-E	14.65	1805.97	0.006	0.006	199.935	14	2
	Support E	0	0	0.000	0.002	52.732	12	1

V. Check depth for deflection

$d = (0.4 + 0.6f_{yk}/400)Le/\beta_a$

$d = 0.85*L/30$ $\quad$ $L = 3.50m$

$d = 99.17$ $\quad$ OK!

Vi. Check depth for maximum moment

$M_{max} = 20.35KN\text{-}m$

$$d = \sqrt{\frac{M}{0.8bf_{cd}\ \rho m(1-0.4\rho m)}}$$

$\rho = (0.75 * 0.8\ \epsilon_{cu}/\epsilon_{cu}+\epsilon_{yd})*f_{cd}/f_{yd}$ $\quad$ $\epsilon_{cu} = 0.0035$

$\rho = \mathbf{0.020124717}$ $\quad$ $\epsilon_{yd} = \frac{308.7}{2E+07} = 0.0015$

$b_{eff} \leq b_w + le/5 = \text{Actual Width}$ $\left\{ \begin{array}{l} 820\ mm \\ 600\ mm \end{array} \right.$

$f_{cd} = 14.2\ Mpa$

$f_{yd} = 308.7\ Mpa$

$f_{yk} = 355\ Mpa$

$\mathbf{b_{eff} = 600\ mm}$

$m = f_{yd}/0.8f_{cd}$ $\quad$ 27.174

$$d = \sqrt{\frac{20.35*10^6}{0.8*600*14.26*0.0201*27.17(1 - 0.4*0.0201*27.17)}} = 83.59\ mm$$

d = 83.59 mm < 260 mm ....OK!

Check for shear

First of all the resistance of the slab without shear reinforcement is calculated [EC2 – Expression 6.2a]

At negative moment(support)

$$V_{Rd,c} = \frac{C_{Rdc}}{\gamma_c}\left[\left(1+\sqrt{\frac{200}{d}}\right)(100\,\rho_l\, f_{ck})^{1/3}\right] b_w\, d$$

$$\rho l = Asi/b*d = 0.01 \qquad Asi = 2\Phi 14mm$$

$$V_{Rd,c} = 20.55KN$$

At positive moment (mid span)

$$V_{Rd,c} = \frac{C_{Rdc}}{\gamma_c}\left[\left(1+\sqrt{\frac{200}{d}}\right)(100\,\rho_l\, f_{ck})^{1/3}\right] b_w\, d$$

$$\rho l = Asi/b*d = 0.005 \qquad Asi = 2\Phi 10mm$$

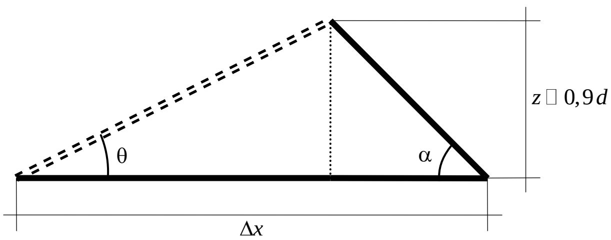
$$V_{Rd,c} = 16.31KN$$

From the above results we can conclude that the section will have to be provided with reinforcement.

Shear reinforcement at near continuous support

$V_{Ed} = 33.08$

Inclined shear reinforcement (α = 45°) will be provided where needed in order to bear the applied shear. Assuming an inclined compression chord for a value at $\cot\theta = 2$, the portion of slab intersected by the reinforcement is



$$\Delta x = 0.9*260(1+2) = 702mm$$

Assume reinforcement $A_{sw} = 2\Phi 12$

$$Vrds = \frac{Asw}{\Delta x} * z * fywd(\cos\theta + \cot\alpha)\sin\alpha$$

$$= 49.4KN > V_{Ed}\ ....OK!$$

Shear reinforcement near End support

V_{Ed} = 21.45KN and assuming reinforcement A_{sw}= 2Φ10, we will have $V_{Rd,s} = 34.45KN > 21.....Ok!$

5.4.2. Design of Beams

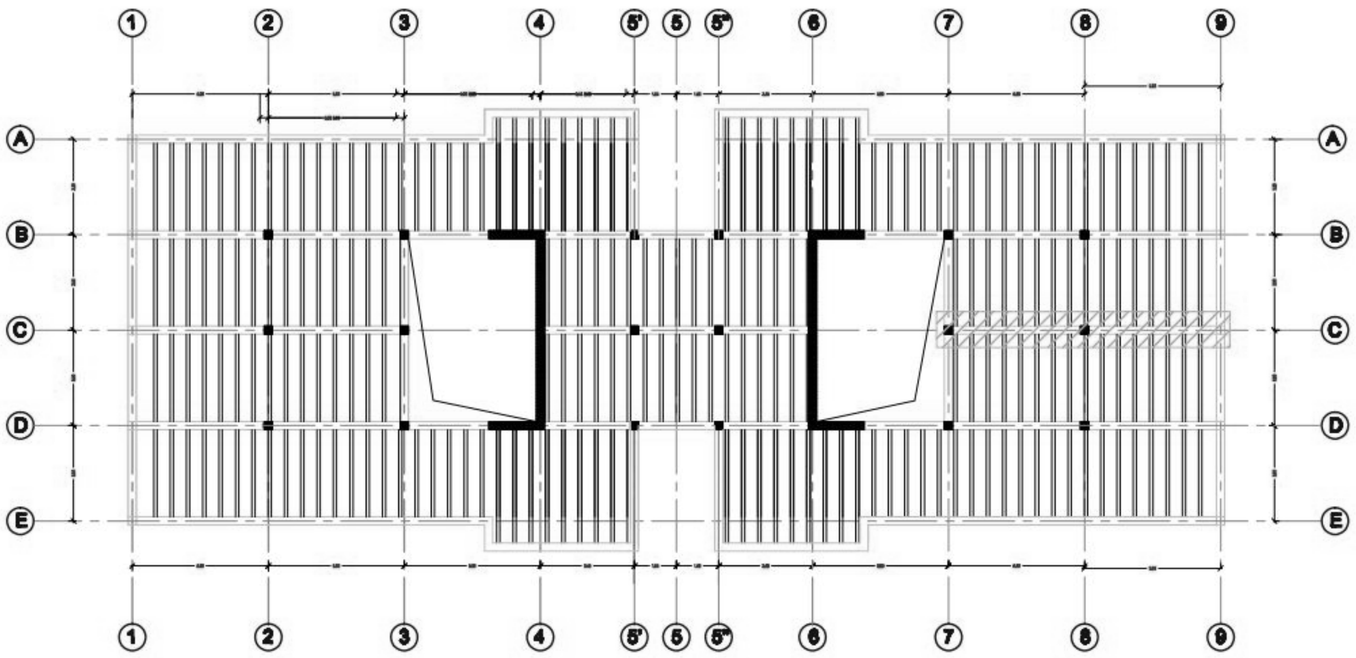


Fig. 5.12 Typical Structural plan

For beam design we considered a strip of beam which can represent the other 6 beams and based on that we will perform a design calculation for this representative beam.

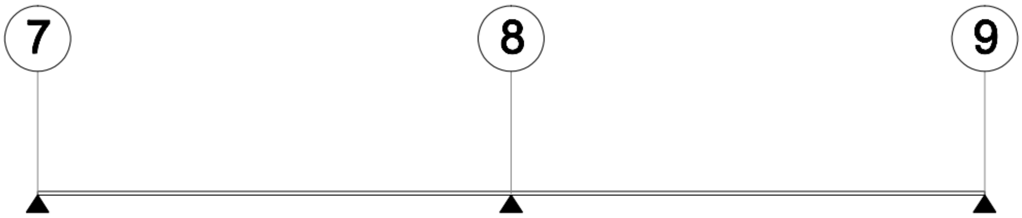


Fig. 5.13 Simply supported beam

For design purpose we consider the beam to be simply supported and calculate for bending moment and shear force.

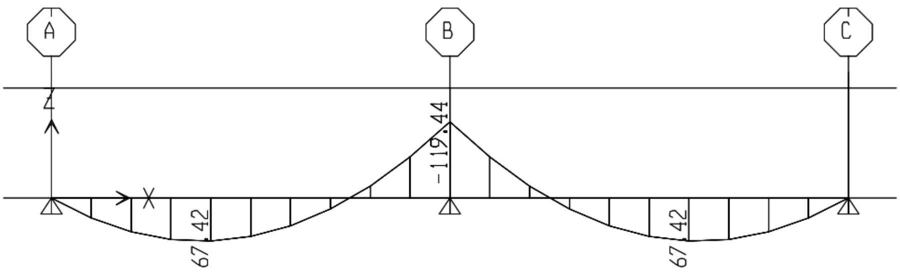


Fig. 5.14 Bending moment Diagram

The pre-dimensioning of longitudinal reinforcement is carried out. The cross section of the beam is *300x400mm.*

The rotational equilibrium gives the position of the neutral axis, x.

$$0,8b\,x\,f_{cd}\left(d-0,4x\right)=M_{Ed}$$

whereas through the translational equilibrium the required reinforcement area can be evaluated.

$$A_s=\frac{0,8b\,x\,f_{cd}}{f_{yd}}$$

The following limit for the depth of the neutral axis applies.

$$\varsigma=\frac{x}{d}\leq\frac{\varepsilon cu}{\varepsilon cu+\varepsilon yd}=\frac{3.5}{3.5+1.54}=0.69$$

So determined reinforcement needs to be not less than the minimum recommended [EC2 – 9.2.1.1, Expression 9.1N]

$$A_{s,\min}=0,26\frac{f_{ctm}}{f_{yk}}b_t\,d$$

The effective depth of the section in the end is

d = h – $c_{nom\ trasv}$ - ϕ_{strasv} - ϕ_{slong} /2 = 400mm-25mm = 375 mm

The results of such calculations are reported where the final provided reinforcement is shown too.

Section	*M_{Ed} (kNm)*	*b(mm)*	*x(mm)*	*x/d*	*$A_{s,req}$(mm^2)*	*b_t (mm)*	*A_{smin} (mm^2)*	*n° ϕ*	*A_s (mm^2)*
Span A- B	*67.42*	*300*	*56.25*	*0.15*	*618*	*300*	*215*	*4ϕ16*	*804.24*
Support B	*-119.44*	*300*	*106.25*	*0.28*	*1173*	*300*	*215*	*6ϕ16*	*1206.37*
Span B-C	*67.62*	*300*	*56.25*	*0,15*	*618*	*300*	*215*	*4ϕ16*	*804.24*

Table 5.6 ULS pre-dimensioning of longitudinal reinforcement

Bending: Ultimate Limit State verification

Assuming yielded steel and a rectangular stress block for concrete the translational equilibrium is:

$$0.8\ b\ x\ f_{cd} = A_s\ f_{yd}$$

The neutral axis then is

$$x=\frac{A_s\ f_{yd}}{0,8b\ f_{cd}}$$

Through the rotational equilibrium about the centre of either the compressions or tensions, the resisting moment can be easily determined.

$M_{Rd} = A_s f_{yd} (d\text{-}0.4x) = 0.8\ bxf_{cd} (d\text{-}0.4x) \geq M_{Ed}$

Results of such calculations are shown

Section	*A_s (mm^2)*	*b (mm)*	*x (mm)*	*ξ*	*M_{Rd} (kNm)*	*$\lvert M_{Ed} \rvert$ (kNm)*	*M_{Rd}/M_{Ed}*
Span A-B	*804.24*	*300*	*72.85*	*0.194*	*85.87*	*67.42*	*1.27*
Support B	*1206.37*	*300*	*109.3*	*0.29*	*123.4*	*119.44*	*1.03*
Span B-C	*804.24*	*300*	*72.85*	*0.194*	*85.87*	*67.42*	*1.27*

Table 5.7 ULS Verifications

Design for shear

Out put of the analysis:

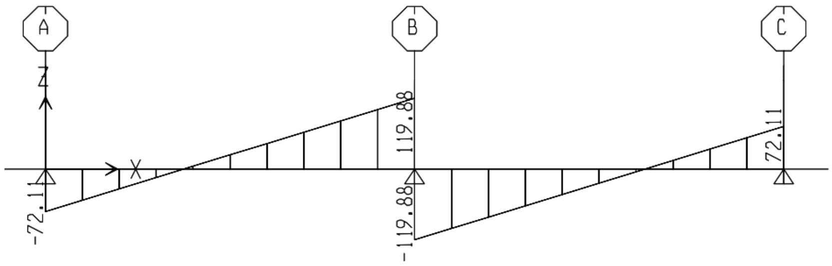


Fig. 5.15 Shear Diagram of the specified beam

The transversal reinforcement ratio needs to comply with the following limit [EC2 – 9.2.2(5) and Expression 9.5N],

$$\rho_{sw} = \frac{A_{sw}}{b_w\, s} \geq 0.08 \frac{\sqrt{f_{ck}}}{f_{yk}} = 0{,}0011$$

where appropriate numeric value for concrete and steel strengths have been adopted (C25, S355). The maximum longitudinal spacing between stirrups is [EC2 – 9.2.2(6) and Expression 9.6N]

$$Sl, max = 0.75d(1 + cot\alpha) = 0.75 * 375 = 281mm$$

Whereas the transverse spacing of the legs of stirrups needs not to exceed the value [EC2 – 9.2.2(8) and Expression 9.8N]

$$St, max = 0.75d = 0.75 * 375 = 281mm \leq 600mm$$

Assuming stirrups ϕ8/200 mm with two legs , the result will be:

$$\rho_{sw} = \frac{100.50}{300 * 200} = 0{,}00167 > \rho_{swmin}$$

The corresponding value of the shear resistance then is [EC2 – Expression 6.8]

$$V_{Rd,s} = 0.9\, d \frac{A_{sw}}{s} f_{ywd}\, ctg\,\theta = 0.9*375*\frac{100}{200}\, 308.7*2 = 104.8kN$$

Overlapping the design shear with the resistant shear diagram it can be easily noted that the provided shear reinforcement is not sufficient near the support (0.5m from support B). The required trasversal reinforcement can be then evaluated with the following expression: $\rho_{sw} \geq \rho_{sw\,rqd} = \dfrac{V_{Ed}}{0.9\, d\, b_w\, f_{ywd}\, ctg\theta}$

where the design shear V_{Ed} can be computed at a distance $\overline{x}$ from the ideal support equal to the semi-width of the column. The results of such calculations and verifications in accordance with EC2 – Expression 6.8 as shown below. The maximum shear force is near at the support B which is 120KN and using this value I can calculate the required shear reinforcement near support B extended to 0.5m to the span.

$$V_{Ed} = 120KN$$

$$\rho_{sw\,rqd} = \frac{V_{Ed}}{0.9\, d\, b_w\, f_{ywd}\, ctg\theta} = 120/(0.9*375*300*308.7*2) = 0.00192$$

Using two bars of ϕ8 the area of reinforcement will be $100.5mm^2$.

$s = \dfrac{A_{sw}}{b_w\ \rho sw} = 100.5/(300*0.00192) = 174mm,$ so e have to use *ϕ8 c/c 160mm* spacing near support.

$$V_{RD,s} = 0.9*0.0021*375*300*308.7*2 = 131.3KN$$

According to EC2 – Expression 6.9

$$V_{RD,max} = \alpha cw * bw * z * v1 * fcd * (cot\theta + cot\alpha)/(1 + cot2\vartheta)$$

$$= 300*0.9*375*0.62*14.2*2/(1+4) = 356.56KN > V_{ED}.....OK!$$

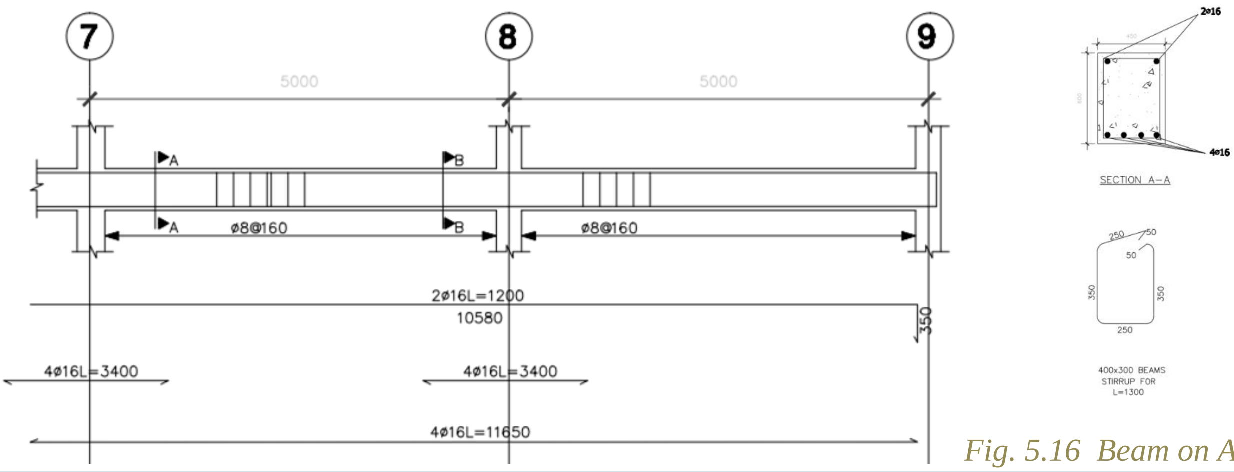


*Fig. 5.16 Beam on Axis C(300*400)*

5.4.3. Design of Column

An inside column will be analysed in this section. This column is subjected to axial load. The "influence areas" method will be used in order to determine the axial load to be taken into account during the pre-dimensioning of reinforcement.

Influence area: $3.5 * 5\ m^2 = 17.5\ m^2$

Modified influence area (redundancy coefficient = 1,4): $1.4 * 17.5\ m^2 = 24.5\ m^2$

Roof loads:

- *Roof slab* — *24.5/2*4.11+24.5/2*7.18 = 135.5 kN*
- *Weight of the rib of the beam (redundancy coefficient = 1,2)* — $1.2 * 0.3\ m * 0.4\ m * 5\ m \cdot 25\ kN/m^3 = 18\ kN$
- *Variable loads* — *24.5KN/m*2KN/m2 = 49KN*

Typical floor loads:

- Slab self-weight — $4.11\ kN/m^2 * 24.5\ m^2 = 100.7\ kN$
- Variable loads (inside partitions included): — $2.78\ kN/m^2 * 24.5\ m^2 = 68.11\ kN$
- Weight of the rib of the beam (redundancy coefficient = 1,2) — $1.2 * 0.3\ m * 0.4\ m * 5\ m \cdot 25\ kN/m^3 = 18\ kN$

For the calculation of columns only, a reduction factor can be applied to variable loads [EC1-1 – 6.3.1.2(10) – National Annex]

$$\alpha_A = \frac{5}{7}\psi_0 + \frac{A_0}{A} \leq 1,0$$

, where: $\psi_0 = 0.7$, $A_0 = 10\ m^2$, A is the influence area of the column considered , *For column P13:* $\alpha_A \cong 0.91$.

Loads on every storey are:

▪Roof level

- Permanent loads 153 kN
- Variable loads 49 kN

▪4° floor

- Permanent loads 118.7 kN
- Variable loads 62kN *(= 0.9·68.11 kN)*

▪3° floor

- Permanent loads 118.7 kN
- Variable loads 62 kN

- 2° floor
  - Permanent loads 118.7 kN
  - Variable loads 62 kN
- 1° floor
  - Permanent loads 118.7 kN
  - Variable loads 62 kN
- Ground floor
  - Permanent loads 193.91kN (*solid slab with 25cm thick*)
  - Variable loads 62 kN

For the ULS combination of actions, a single multiplicative factor will be referred to, as a simplification: γ_F* is obtained as weighted mean of the coefficients $\gamma_G = 1.35$ and $\gamma_Q = 1.5$, respectively concerning permanent actions and variable actions.

$$\gamma_f^* = \frac{\gamma_G\, G_k + \gamma_Q\, Q_k}{G_k + Q_k} = \frac{1.35 * 118.7\, kN + 1.5 * 62\, kN}{118.7 kN + 62\, kN} \cong 1.40$$

The pre-dimensioning of the geometry of column at axis 8D is shown.

Column	F_k *(kN)*	*N (kN)* $N = \Sigma F_{kj}$	$N_{Ed} = \gamma_F * N(kN)$	$A_{c0} = \frac{N_{Ed}}{f_{cd}}$ *(mm²)*	*b x h(mm)*	A_c*(mm²)*
4° floor	*202*	*202*	*282.8*	*19,916*	*300 x 300*	*90,000*
3° floor	*180.7*	*382.7*	*535.78*	*37,731*	*300 x 300*	*90,000*
2° floor	*180.7*	*563.4*	*788.76*	*55,547*	*300 x 300*	*90,000*
1° floor	*180.7*	*744.1*	*1041.74*	*73,362*	*300 x 300*	*90,000*
Ground	*180.7*	*924.8*	*1294.72*	*91,178*	*400 x 300*	*120,000*
Foundation	*256*	*1180.8*	*1653.12*	*116,417*	*400 x 300*	*120,000*

Table 5.8 Column at axis 8D - pre-dimensioning for centred axial load

Then we have to make an adjustment to the load by adding self weight of the column.

*4th floor - 1st floor – 0.3*0.3*2.7*25KN/m³ = 6.075KN*

*Ground and basement – 0.4*0.3*2.7*25KN/m³ = 8.1KN*

Column	*F_k (kN)*	*N (kN) $N = \Sigma F_{kj}$*	*$N_{Ed} = \gamma_F * N$(kN)*	*$A_{c0} = \frac{N_{Ed}}{f_{cd}}$ (mm²)*	*b x h(mm)*	*A_c(mm²)*
4° floor	208	208	291.2	20507	300 x 300	90,000
3° floor	186.7	384.7	538.58	37928	300 x 300	90,000
2° floor	186.7	581.4	813.96	57321	300 x 300	90,000
1° floor	186.7	768.1	1075.34	75728	300 x 300	90,000
Ground	188.8	956.9	1339.66	94342	400 x 300	120,000
Foundation	264.1	1221	1709.4	120380	400 x 300	120,000

Table 5.9 Column at axis 8D - pre-dimensioning for centred axial load

It is then necessary to dimension the longitudinal reinforcement. According to EC2 the following limits apply:

- *Technological limit: at least one bar needs to be placed at each corner of a polygonal column, whose diameter needs to be not less than 12 mm [EC2 – 9.5.2(4) and 9.5.2(1) – National Annex]*
- *Geometrical limit: $A_s \geq 0.003\, A_c$ [EC2 – 9.5.2(2) – National Annex]*
- *Static limit: $A_s \geq 0.10\, N_{Ed}/f_{yd}$ [EC2 – 9.5.2(2)]*

Column	*A_c (mm²)*	*$A_{s\,min}$ (mm²) $\rho_s = 0.3\%$*	*$A_{s\,min}$ (mm²)= $0.10\, N_{Sd}/f_{yd}$*	*4 ϕ 12(mm²)*	*n° x ϕ*	*A_s (mm²)*
4° floor	90,000	270	92	**452**	4 ϕ 12	452
3° floor	90,000	270	174	**452**	4 ϕ 12	452
2° floor	90,000	270	256	**452**	4 ϕ 12	452
1° floor	90,000	270	**338**	452	4 ϕ 12	452
Ground	120,000	360	**420**	452	4 ϕ 14	616
Foundation	120,000	360	**536**	452	6 ϕ 14	923

Table 5.10 Column at axis 8D - pre-dimensioning of longitudinal reinforcement

Check for ultimate limit state and serviceability limit state

The translational equilibrium of the cross-section for SLS is

$$N = \sigma_c A_c + \sigma_s A_s$$

Under the hypothesis of plane sections (Euler-Bernoulli), same strain in steel and surrounding concrete ($\varepsilon_c = \varepsilon_s$) and elastic materials, it is $\sigma_s = \alpha_e \sigma_c$, where the ratio between the modulus of elasticity α_e is assumed equal to 15 in order to take into account the time-dependent behaviour of concrete.

$$N = \sigma_c (A_c + \alpha_e A_s) = \sigma_c A_{ie}$$

Obviously it needs to be

$$\sigma_c = \frac{N}{A_{ie}} \leq \sigma_{c\,adm} = 0.6 f_{ck} = 15\ N/mm^2$$

Column	A_c (mm^2)	A_s (mm^2)	A_{ie} (mm^2)	N (kN)	σ_c (N/mm^2)	< $\sigma_{c,adm}$?
4° floor	90,000	452	141980	208	1.5	Yes
3° floor	90,000	452	141980	384.7	2.7	Yes
2° floor	90,000	452	141980	581.4	4.1	Yes
1° floor	90,000	452	141980	768.1	5.41	Yes
Ground	120,000	616	190265	956.9	5.03	Yes
Foundation	120,000	923	224995	1221	5.4	Yes

Table 5.11 Column at axis 8D- SLS verification

The translational equilibrium for ULS is

$$N_{Rd} = A_c f_{cd} + A_s f_{yd}$$

Column	A_c (mm^2)	A_s (mm^2)	N_{Ed} (kN)	N_{Rd} (kN)	N_{Rd} / N_{Ed}
4° floor	90,000	452	291.2	1417.5	4.87
3° floor	90,000	452	538.58	1417.5	2.63
2° floor	90,000	452	813.96	1417.5	1.74
1° floor	90,000	452	1075.34	1417.5	1.32
Ground	120,000	616	1339.66	1894.16	1.41
Foundation	120,000	923	1709.4	1988.93	1.16

Table 5.12 Column at axis 8D- ULS verification

In Eurocode 2 some prescriptions on transversal reinforcement are outlined.

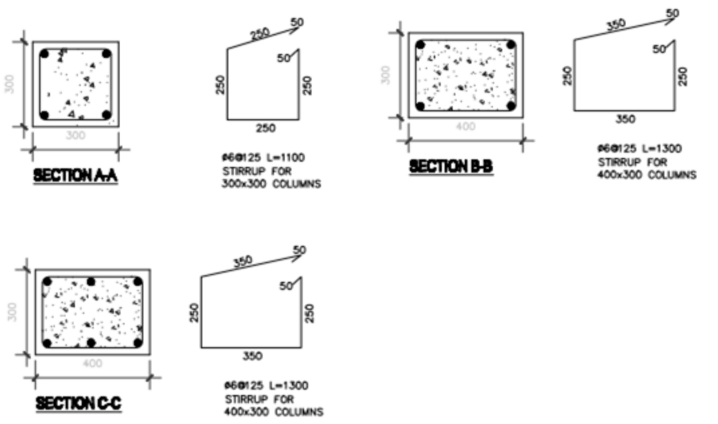
The minimum diameter of transversal bars needs to be not less than ¼ of the longitudinal diameter and however not less than 6 mm.

The spacing of the transverse reinforcement along the column needs not to exceed the following limits:

- *20 times the longitudinal bar size*
  (20 · 12 = 240 mm; 20 · 14 = 280 mm)
- *The smaller dimension of the column*
  (at most, 300 mm)
- *400 mm*

In those sections within a distance equal to the larger dimension of the column cross-section above and below beams and slabs the previous limits are reduced by a factor 0,6 (0,6 · 240 = 144 mm).

Stirrups ϕ6/200 will be provided along all the columns, whereas at the bottom and the top of the columns for a distance equal to 500 mm stirrups ϕ6/125 will be provided.



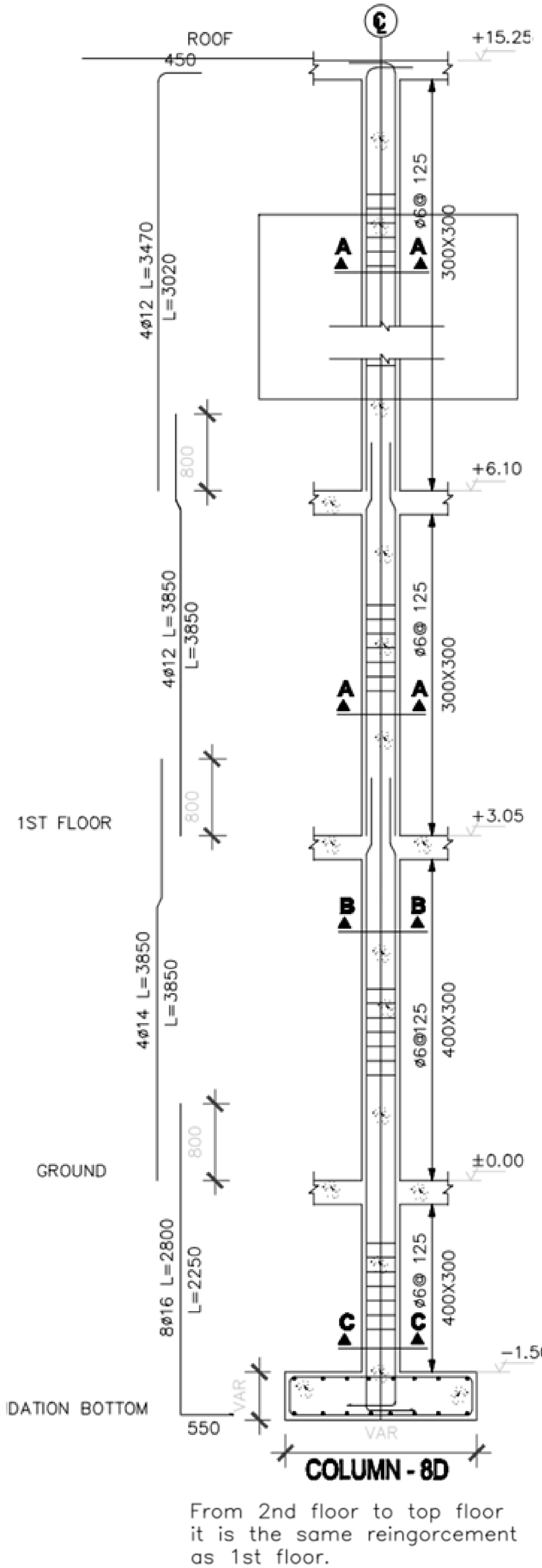


Fig. 5.17 Column 8D detail: Plan and Section

5.4.4. Check for Bearing Capacity of Rammed Earth

For the design of rammed earth along the perimeter of the building, the proper modeling for structural analysis is to assume a uniformly spring supported element. But the analysis is beyond the scope of this thesis so we analyze it as it is supported simply at cross sectional beams coming perpendicular to the perimeter beam.

To calculate the reaction on the perimeter beam and to find out the maximum load that will be imposed on the rammed earth we modeled the structure on ETABS and the maximum compressive force occurs at Axis E' between 5" and 6'.

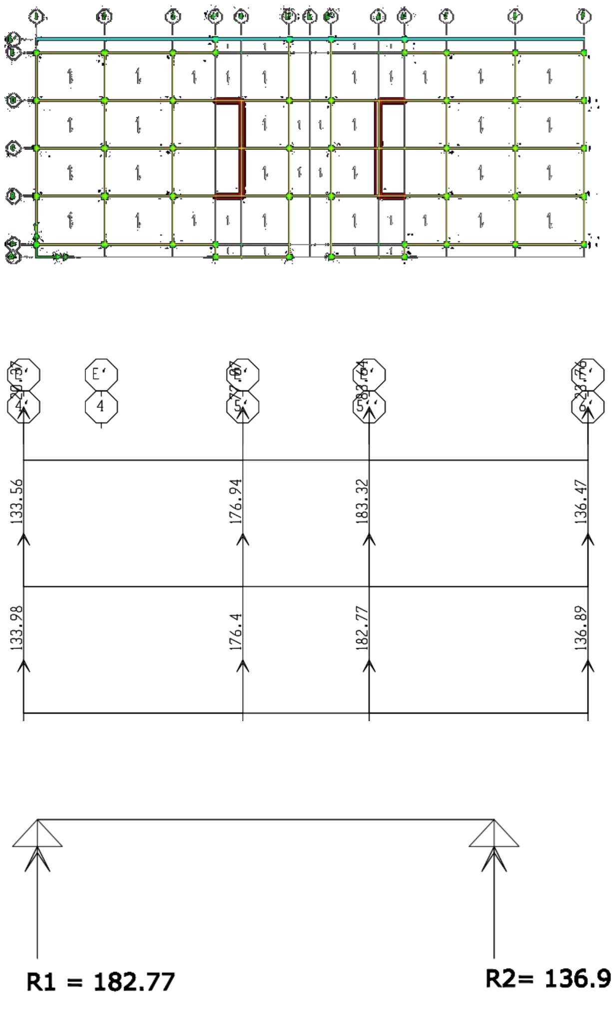


Fig. 5.18 Results from ETABS analysis for Rammed Earth

The applied load from rammed earth considered to be concentrated at beams perpendicular to the rammed earth or perimeter beam.

$F_E = R_1+R_2 = 182.77KN + 136.9KN = 319.70KN$

Since rammed earth is only designed for load bearing we need to calculate the compressive strength of the material.

$F_d \leq k_b*f_c*A$

F_d = Design compressive strength

k_b = concentrated bearing factor

$k_b = 1.00$

f_c = characteristic compressive strength of rammed earth

$f_c = \Phi* f_{cu}$

Φ - capacity reduction factor

0.4 - 0.6 so average is 0.5

$F_d = k_b*f_c*A$

$= 1*10^3KN/m^2*(0.3m*5.65m)$

(Where 5.65m is beam span)

$F_d = 16.05*10^3KN >> 320KN$…….ok

Check at axis E for the longer span

$F_E = 127.20 + 194.53 + 310.84 + 126.43$

= <u>759KN</u>

$F_b = 1*10^3KN/m^2*0.3m*13.4m$

(where 13.4m total beam length)

$F_b = 40.2*10^3KN >> F_E = 759KN$………..Ok!

From the result, we can conclude that a rammed earth wall with a thickness of 30 cm is highly adequate to bear the incoming load.

CHAPTER 1

INTRODUCTION

CHAPTER 2

KNOWLEDGE

CHAPTER 3

URBAN DESIGN

CHAPTER 4

ARCHITECTURAL DESIGN

CHAPTER 5

STRUCTURAL DESIGN

CHAPTER 6

TECHNOLOGICAL DESIGN

6. Technological Design

6.1. Building Technology in Ethiopia

Ethiopia is in a rapid change. The development and demand of housing and urbanization progress is rapidly growing. Ethiopia's sustainable design alternatives have not yet advanced in a scientific methodology yet but buildings seem to function well with the exception of some visible or sensible defects. As mentioned earlier in Ethiopia the use of renewable resources for energy demand is not yet utilized to a certain degree. Many aspects of building technology beginning form the choice of design strategies, to its construction time up until the buildings overall life time cycle, there hasn't been significant approach that enables to design a sustainable building. There are some design standards that are followed in order to make the building respond to the climate and the demand. But these approaches had not seen any measurable methodologies for a proof. Architects and engineers are trained in such a way to adapt certain principles in regards to the response of the building to the environment and vice versa. The immense renewable resources have not been utilized in to the building sector. The choice of certain materials and there assemblage for construction have become a general trend of designers and contractors. Scientifically assessment and labeling of buildings is in its infant stage. The reason could be due to the presence of a very moderate climate all throughout the year. The trend of design methodology has been established and is being implemented for decades. Living in this climate would also completely lessen the energy demand for heating and cooling of spaces inside the buildings. There is no any housing unit that uses air conditioning or any other mechanical equipment for modifying neither the internal temperature nor that there is a need. For exception's like office space's, factories and other buildings which generate high internal heat gain created by the presence of people or equipments, the demand of cooling units are required. Generally, the progress of technology in buildings is hindered by lack of available budget and absence of research and development institutes in the country. Recently however there is research and development carried out by EIABC (Ethiopian Institute of Architecture, Building Constructions and city development) in collaboration with international institute to device a research based sustainable design solutions which is related to the city and the context. However, for the housing project, we analyzed, hypothesized and provided sustainable and energy efficient solutions as a response to climate and the environment, having in mind the context.

6.2. Aim and Vision of the project

The need for making climate sensitive and environmentally sound buildings comes with the responsibility of designing a low energy building by reducing the CO_2 emissions and the impact on the environment. The aim of the project is to devise a low cost sustainable solution for a low cost housing in Addis Ababa. For envisioning a sustainable low cost housing which has a low impact to the environment, requires the systematic development of aspects like proper orientation of the housing with respect to climatic components, the use of local low energy building materials with low impact to the environment, the use of renewable resource as means of generating the energy demand of the housing shall be given priority. In addition the proper provision of daylight levels by using techniques to reduce overheating and improving ventilation and thermal comfort systems in the internal environment shall be considered.

6.3. Solar Analysis

Studying the behavior of the sun path for a particular design in a place is crucial in providing proper solution for optimizing the use of sunlight and solar energy of a building. The knowhow of sun path of a place is required in the design stage. This knowledge helps us in analyzing three aspects; the available daylight and energy, reduction of glare and overheating of a space. It's critical to know how the passage of the sun would affect the building and how the building would affect other vicinity structures. The passage is complex and differs from hour to hour throughout the year, changing its altitude and azimuth angle within a specific declination angle.

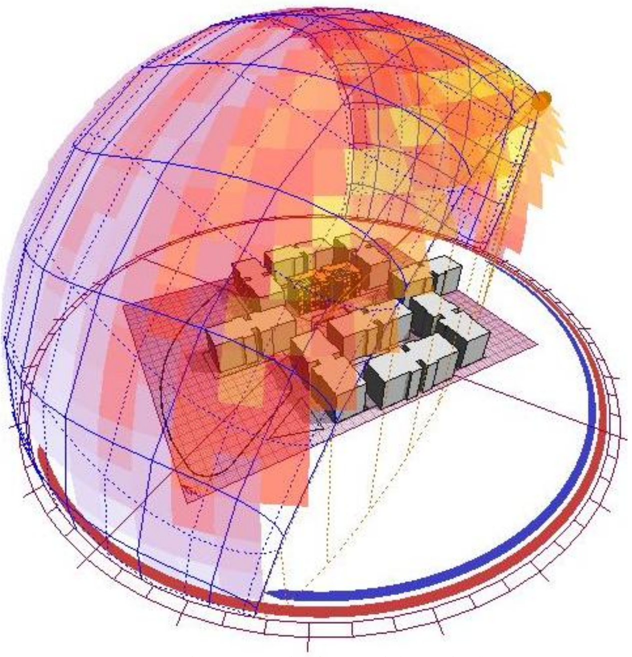


Fig. 6.1 Annual sun path for Addis Ababa

The figure shows the sun path diagram of Addis Ababa relative to the project site. Throughout the year it can be observed that there is a slight difference of inclination angle from month to month. The lowest height of the sun is experienced in November and December which is the winter season. The highest is in April and May. The study is father conceived for daylight intake of a typical housing building from other similar adjacent buildings. Figure …., shows the range of shadow for December whereas fig. shows that of July.

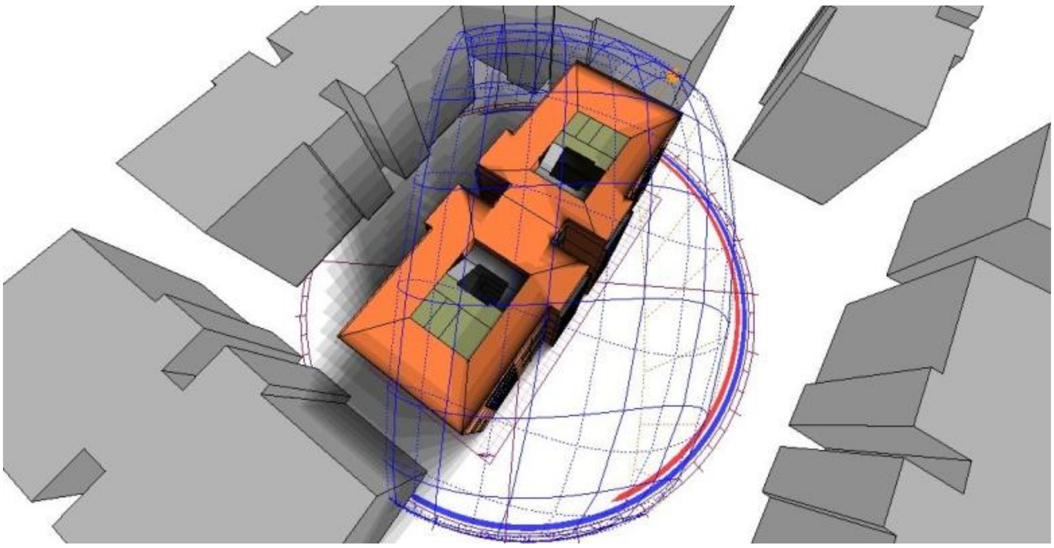


Fig. 6.2 December shadow range for by a typical building on adjacent structures

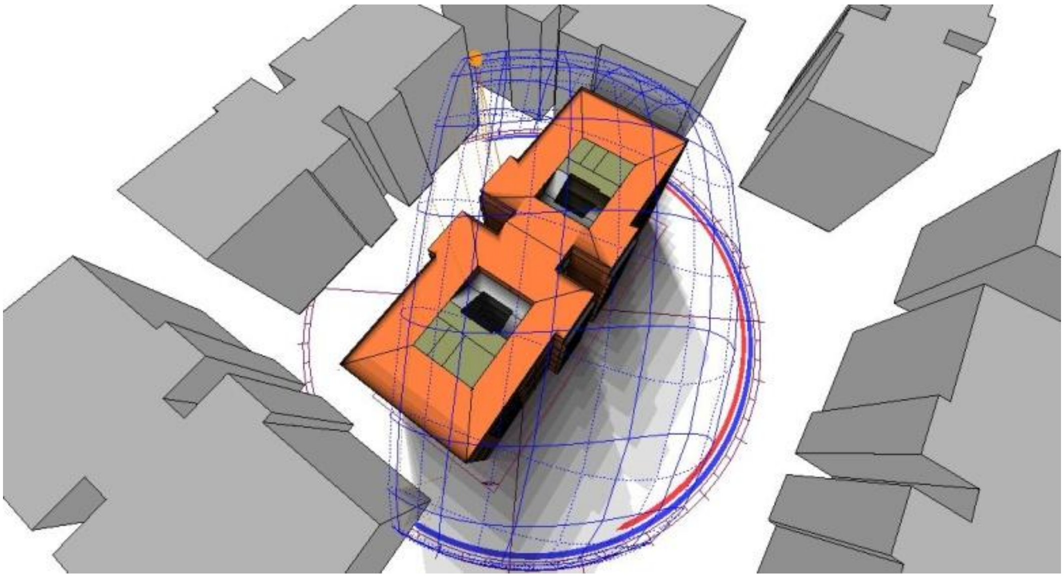


Fig. 6.3 July shadow range for by a typical building on adjacent structures

On the other hand, the shadowing effect of each building with respect to other adjacent is illustrated in fig.. The analysis was made on December 21st- the lowest point of the sun. The study can differentiate between surface of the building which are never, partially and always shadowed. The darker the color of shade, the more obscure of daylight where as the lighter signifies presence of sunlight all throughout the day. In the design decision making, factors of shading, sizing and orientation of windows needs to be considered.

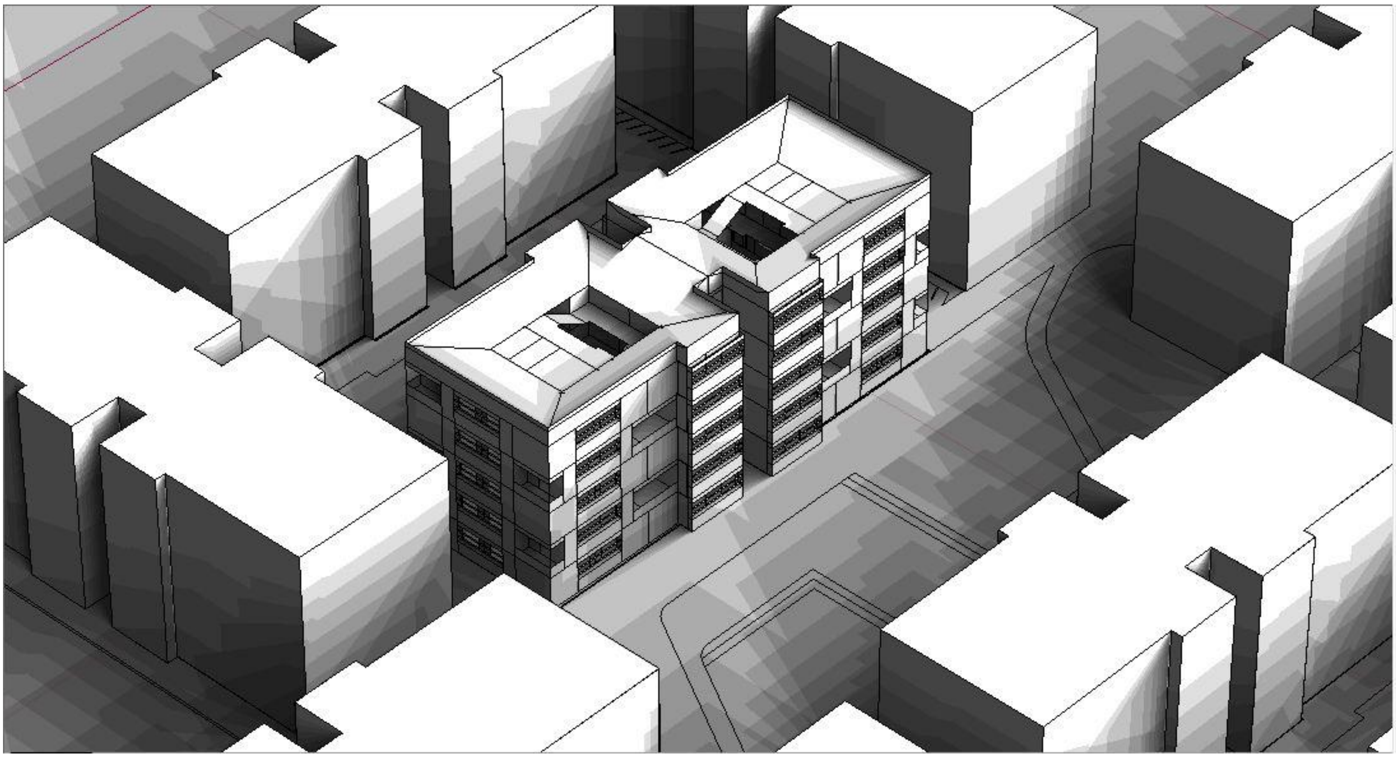


Fig. 6.4 Shadow range of adjacent structures on a typical building on December

6.4. Orientation of Buildings

Building orientation is an actual response of a building to the sun. Well oriented buildings maximize the use of daylight from the sun by reducing the need to use artificial lightings. In addition proper orientation helps to incorporate with it passive solar collection techniques like photovoltaic's, which would increase the chance of using much of the building surfaces. An effective orientation in general assumes that the building receives as much solar radiation in the colder seasons and as well and rejecting in the warmer seasons.

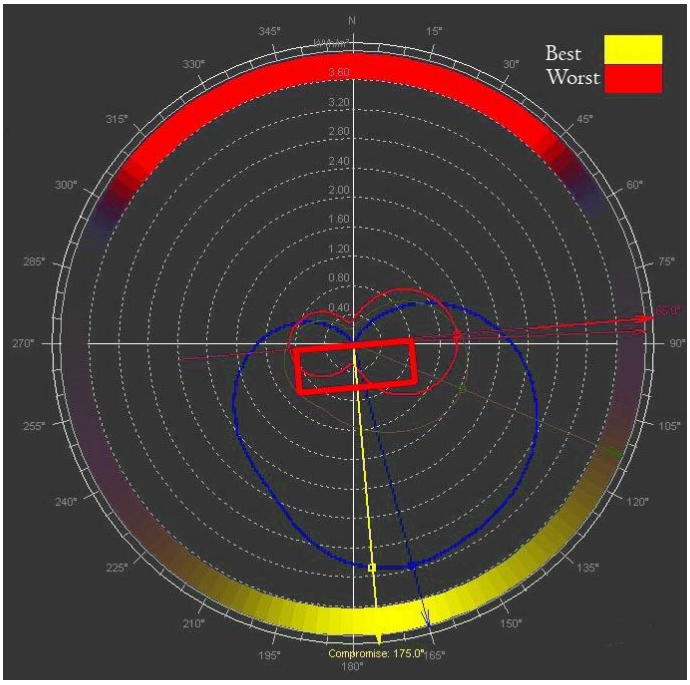


Fig. 6.5 Optimum orientation generated by Ecotect

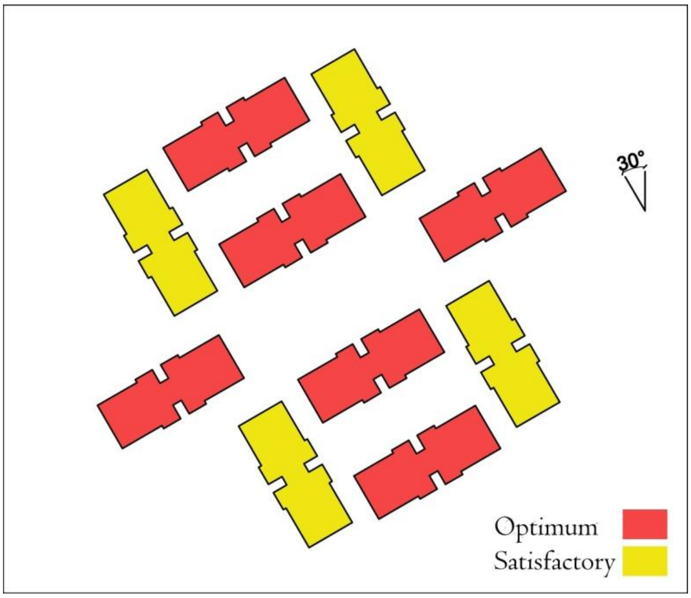


Fig. 6.6 Orientation of residential buildings analyzed based on the result from Ecotect

Ecotect analysis, calculates the amount of solar radiation incident to 1m² vertical surfaces of a point. Three values are recorded for every 5 degree orientation angle. The three values shown in colors red, blue and green as presented in the diagram, describes the three warmest, the three coolest and the average daily solar radiation in kWh/m² respectively. In the case of Addis Ababa the three warmest months are March, April and May with average temperature of 17, 18 and degree Celsius, while the coldest month are November, December and January with average temperatures of 15, 15 and 16 degree Celsius. The three values obtained are plotted in the graph where the radius from the centre describes the incident solar radiation. The most favorable orientation occurs where the radiation of the coldest months exceeds the ones in the warmest month. From the diagram we can deduce that the optimum orientation is when the longitudinal façade of our building is facing south inclined at 5° to the right.

Referring the housing project described as the diagram to the left, it would be noticed that the orientation is shifted 30 degrees to the left form the north. There are two orientation types in the design. This is actually a response to the architectural concept of creating a communal space in between the housing units or among the communities in it.

The design concept is actually much more important in creating an interactive social living. However also, the Ecotect analysis used three warmest and three coldest month's, which the temperatures difference's are not much. As a result we have classified the buildings as optimum and satisfactory.

6.5. Ventilation

Ventilation involves the change or replacement of air in to the interior of space to provide appropriate indoor air quality. It refers to the flow of external air to an indoor space as a result of pressure or temperatures differences. There are two types of ventilation methods, mechanical ventilation /forced/ or natural ventilation. The method of application of ventilation in the project is natural ventilation rather than mechanical. There are two types of natural ventilation occurring in buildings: *wind driven* ventilation and buoyancy-driven ventilation. While wind is the main mechanism of wind driven ventilation, buoyancy-driven ventilation occurs as a result of the directional buoyancy force that results from temperature differences between the interior and exterior. Most often natural ventilation is achieved by means of windows and other intentional openings. The directionality and speed of wind is complicated and hence the concept of prevailing wind is used in the design for natural ventilation for buildings. It is basically a wind direction that blows predominantly in a general path as observed at some point on the earth surface.

The following diagrams illustrate the prevailing winds for four seasons relative to the actual location of the buildings. The buildings are oriented 30° to the right of North.

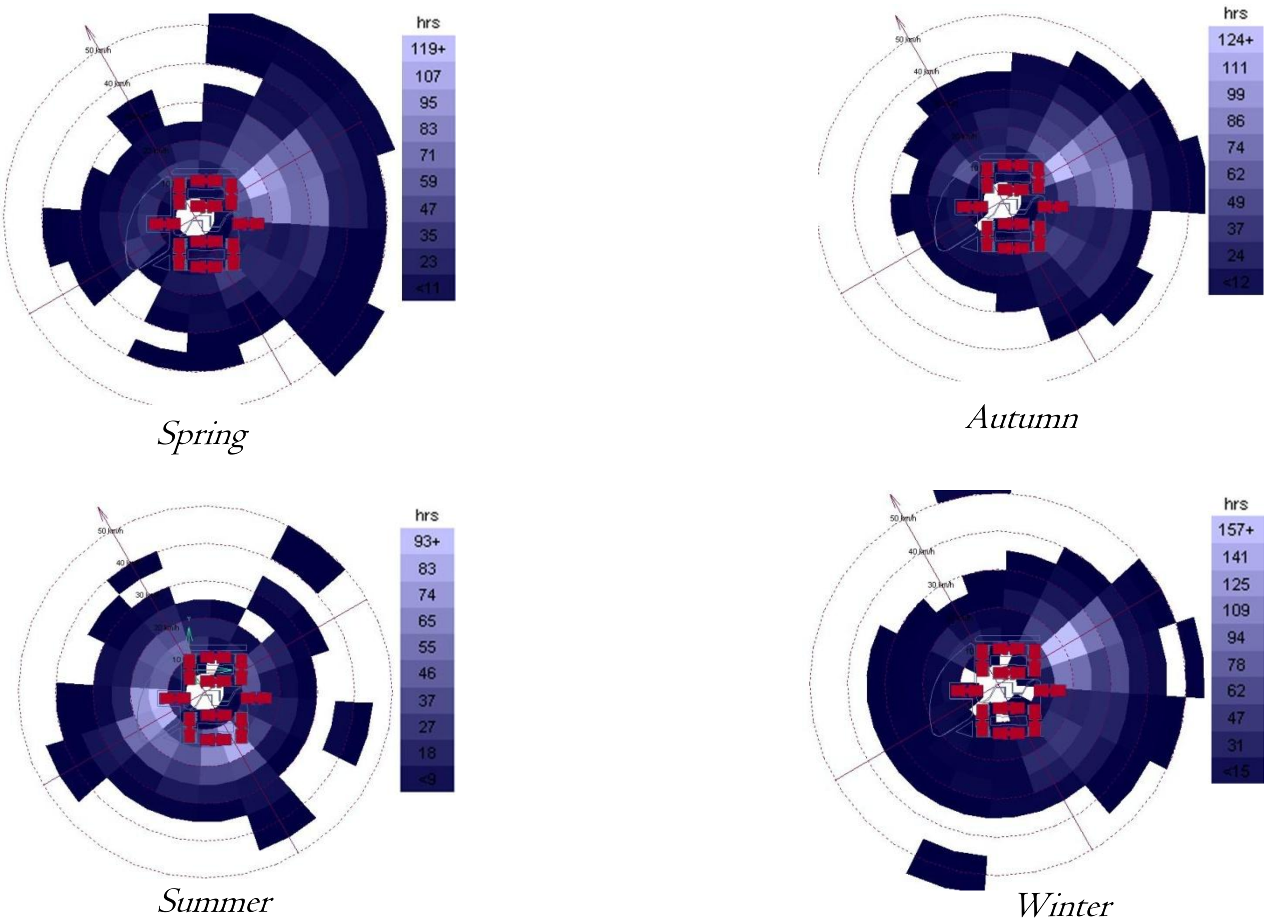


Fig. 6.7 Prevailing wind directions for the four seasons

From the figures above we deduce that in spring, autumn and in winter, the dominant wind direction is from east to west except in summer which is the reverse. Nevertheless, the design of the building considers variant direction of prevailing wind and is adaptable to all circumstances.

The next two diagrams below clearly show the ventilation system of the whole building.

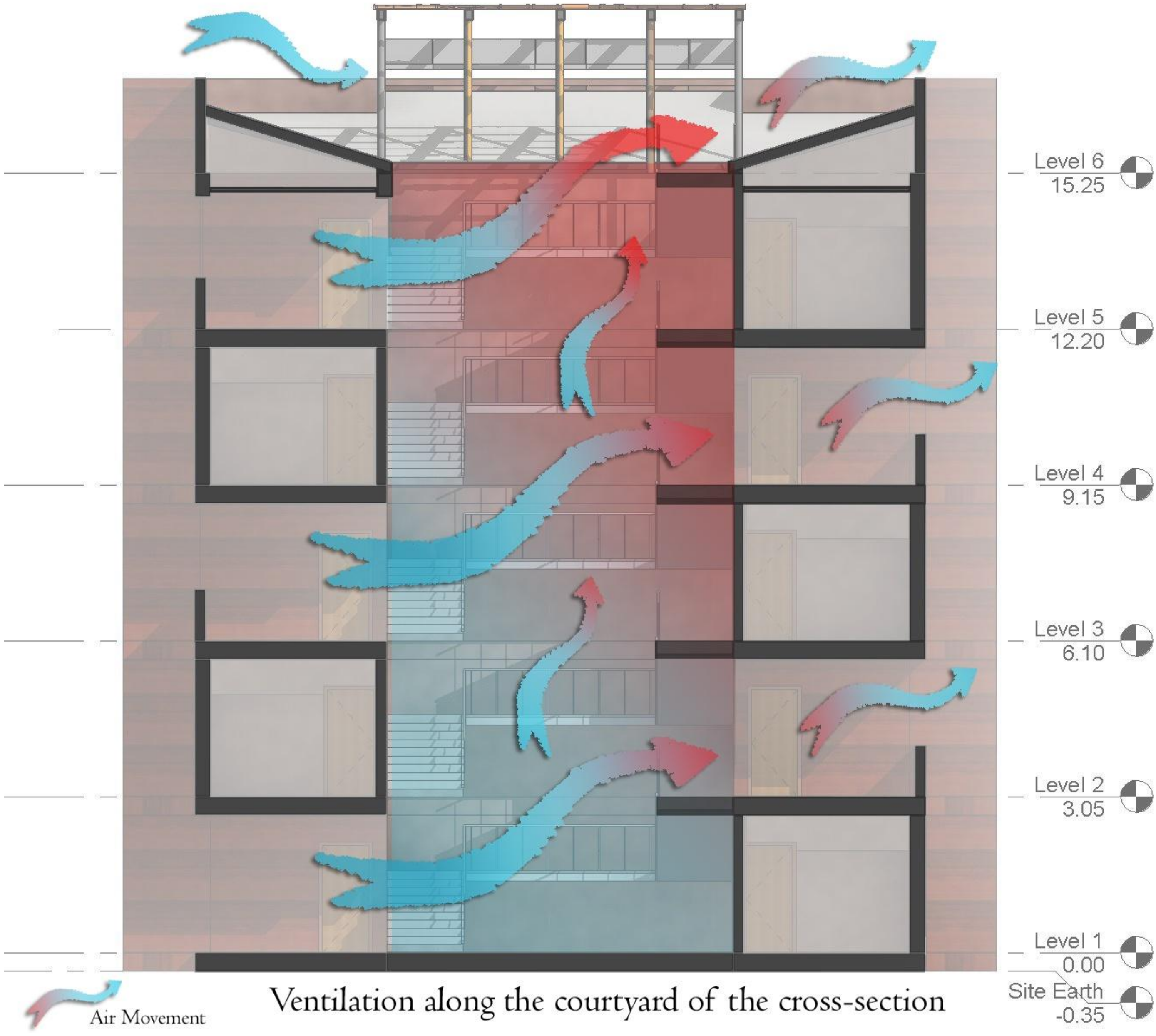


Fig. 6.8 Cross Ventilation along the shorter side of the residential building

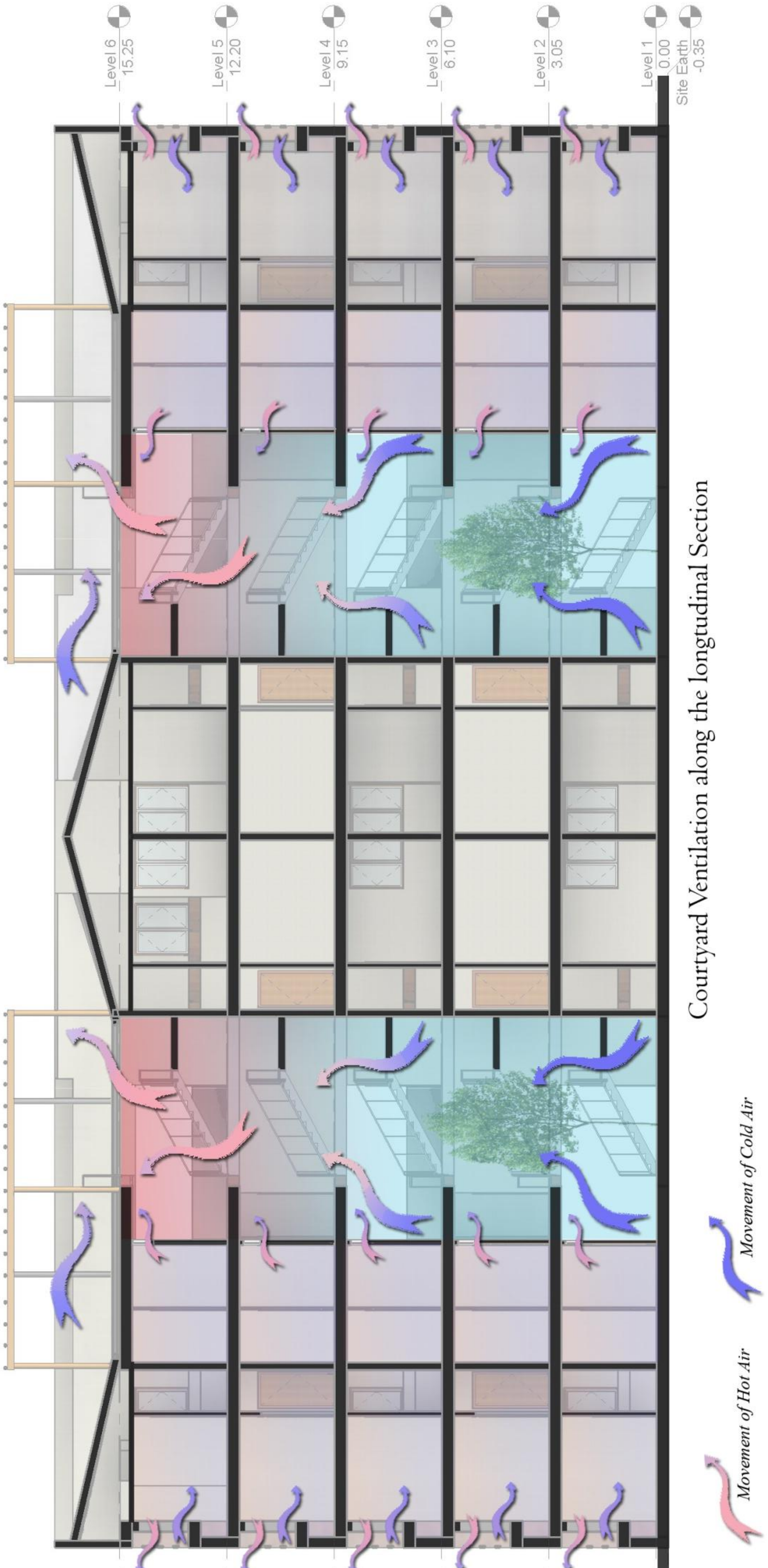


Fig. 6.9 Stack effect along the larger side of the residential building

6.6. Daylight Factor

Definition

Daylight factor is the ratio of natural internal light level to the available external light level at the same time inside a space of a building under a certain sky condition and is expressed in percentages. The space can be termed as a thermal zone. Conditions of the sky greatly affect the analysis of daylight factor. The condition of the sky can be classified as clear sky, partly cloudy and an overcast sky. Daylight factor is very useful in overcast sky conditions i.e. when 90% to 100% of sky is considered to be covered by cloud. Without clearly specifying these conditions the daylight analysis would show inaccurate results. Usually the CIE overcast and clear sky condition is commonly used. It also depends also on the materials that are used in the design of the house. Properties like the reflectivity of each materials and the type of glass used matters in the analysis.

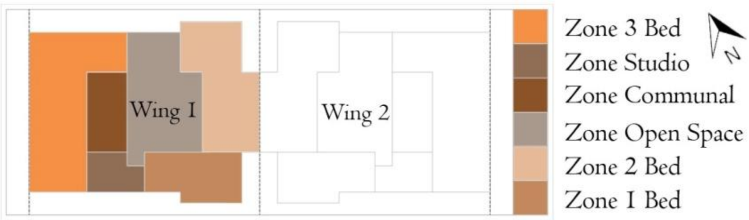


Fig. 6.10 Sub-division of spaces for daylight analysis

Components	Material
External Wall	Rammed Earth
Internal Wall	Straw Board
Window	Single Glazed Wooden Frame
Floor	Concrete Floor

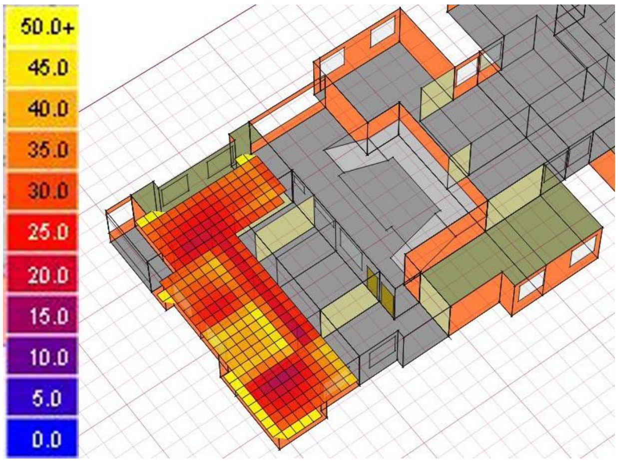
Table 6.1 Materials Used in the residential buildings

Methodology

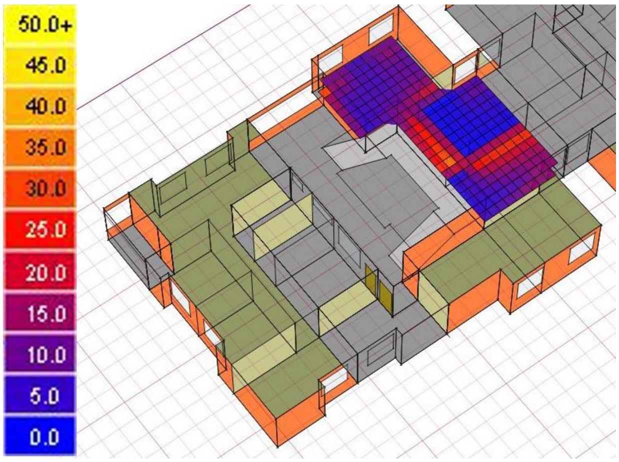
For the purpose of the analysis we divided the floor plan in to two parts, wing 1 and wing 2. The analysis is typically focused on Wing 1. The sky condition that we used is a clear sky, since the location of the project is near the equator with latitude of 9 degree. From the results of Ecotect, we used the design sky luminance calculated by Tregenza formula and found a value of 10046 lux. *According to the British Standards Institute, BS 8206 Part 2 CIBSE a space with a mean daylight factor between 2% and 5% is considered well lit and requires little or no lighting during daytime. A space with a daylight factor of less than 2% appears dimly lit. The daylight factor however doesn't take in to account: direct sunlight, local climate, façade orientation or movable shading.*

Analysis

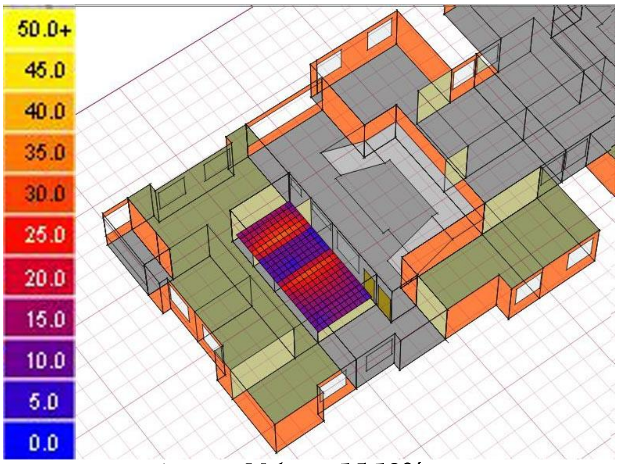
The sequence of daylight calculations has been made for the six zones and has given the following results with average values.



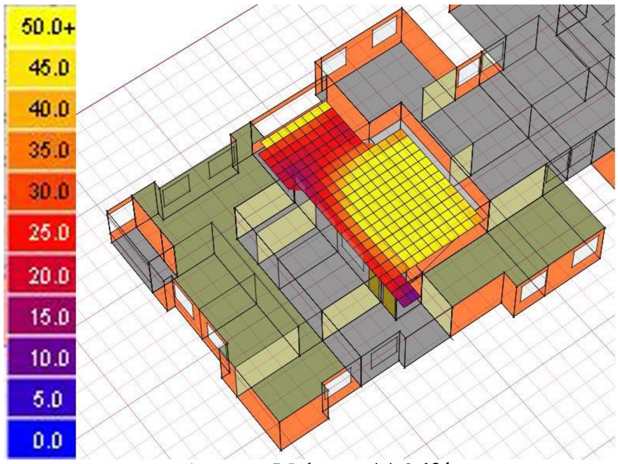
Average value: - **35.12%**



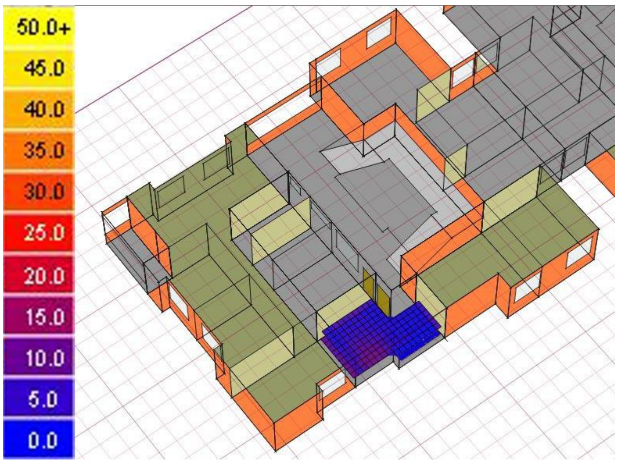
Average Value: - **14.48%**



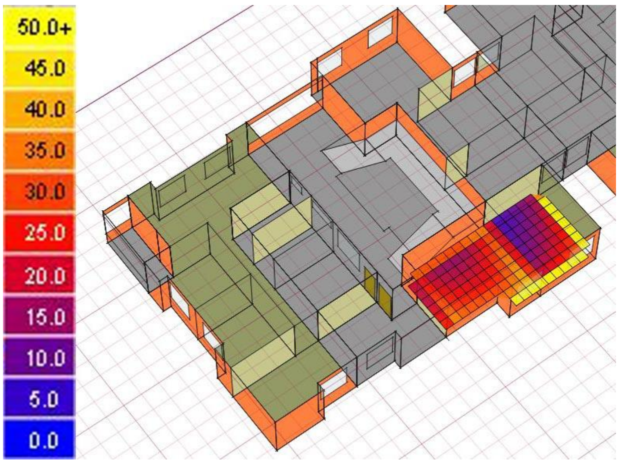
Average Value: - **15.18%**



Average Value: - **44.36%**



Average Value: - **9.29%**



Average Value: - **31.16 %**

Fig. 6.11 Daylight factor analysis results with average values for every zone

The values obtained from daylight factors are quite high. This high result may be due to the use of clear sky condition for the calculation. Nevertheless, what we can deduce from the result is that there won't be any necessity to provide artificial lighting throughout the day while the sun is around. This could reduce the energy demand of the housing units on day time. However glare and solar gain could cause overheating in the warm seasons and heat lose in the cold seasons.

6.7. Shading

The concept of shading in refers to the blocking of unwanted solar heat resulting from the daylight of the sun. If the daylight is allowed much more than the required it could cause overheating. The aim of shading generally is to exclude in the summer and to maximize the exposure in winter of direct sunlight. Nevertheless, the position of the sun varies throughout the day and as well as the year. The rotation is also dependent on the location of the place- referring to its latitude and longitude. To incorporate appropriate shading design, a reference to the cyclic nature of the sun is needed which indicates four important dates of the year.

Name	Southern Hemisphere	Northern Hemisphere	Description
Summer Solstice	Dec 21/22	Jun 20/21	Sun at its highest noon altitude
Autumn Solstice	Mar 20	Sep 22/23	Sun rises due east, sets due west
Winter Solstice	Jun 20/21	Dec 21/22	Sun at its lowest noon altitude
Spring Equinox	Sep 21/22	Mar 20	Sun rises due east, sets due west

Table 6.2 The four important dates for the seasonal cycle

Addis Ababa's location as indicated earlier is in the northern hemisphere, at latitude 9°. This indicates that the sun is at the lowest point in December 21st in the winter solstice with an average maximum temperature of 22°C. Compared with Milan which is also located in the northern hemisphere, but at latitude 45.4°, has an average maximum temperature of 7°C. Annual sun path comparison is made with Milan below. From the figure, we can see that the daylight hours in Addis Ababa is more than that of Milan in December at 14:00.

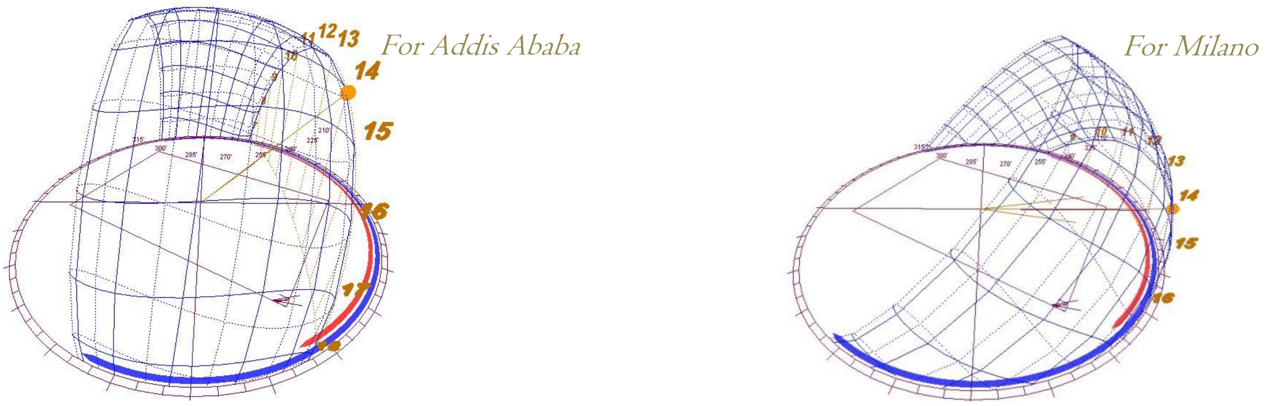


Fig. 6.12 Comparative sun path diagrams for Addis Ababa and Milan, respectively, on December

Methodology

Our approach to provide a suitable shading design is accompanied by a series of steps. For the design of shading in general the altitude angle of the summer solstice and the winter solstice are critical. The aim is to minimize the amount of sun light received during the summer while maximizing during the winter. This is due to avoid the overheating periods of the summer season and to receive heat gain during the winter where the temperature is at its lowest point.

However in the case of Addis Ababa, the temperature difference is only 10°C depending on the elevation and prevailing wind patterns. The high elevation moderates temperatures year-round, and the city's position near the equator means that temperatures are very constant from month to month. Mid-November to January is the winter season in Addis Ababa. The Highland Climate regions are characterized by dry winters; therefore that is the dry season in Addis Ababa. During these seasons the daily highs will not be more than 23°C, the night time lows can get to freezing and range of temperatures can be felt between the highs and the lows in one day.

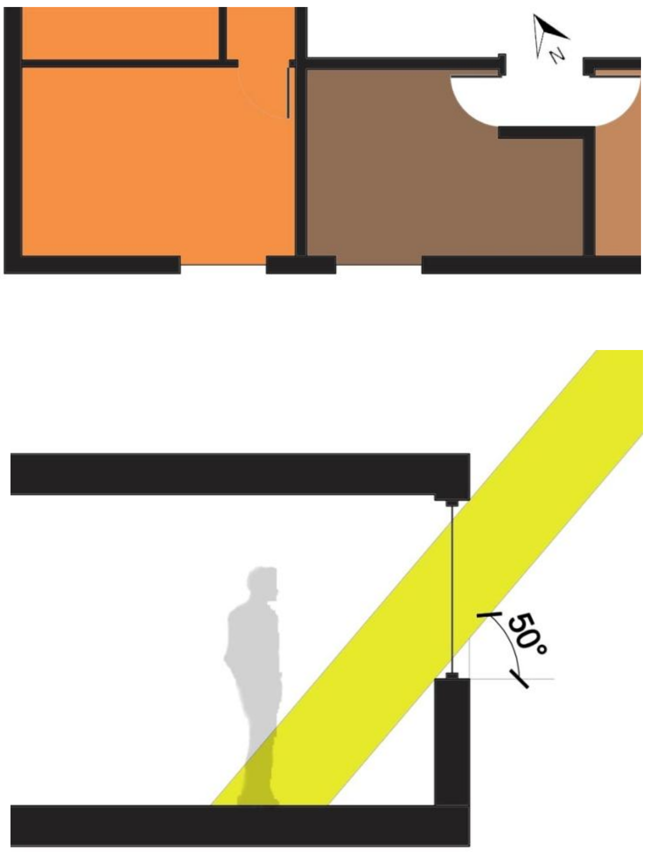


Fig. 6.13 Daylight penetration at the initial stage of the design

This leads to the fact that there is no need to receive heat gain in the winter season, or to design a shading element considering heat gain. Rather what's to be considered is to avoid over heating at the time of the year where the sun is at its lowest height – the time of which is in the winter solstice, December 21st.

For the purpose of our analysis we choose the time 1400 where the sun could be at its peak in overheating. From results from Ecotect, we found that the altitude angle on December 21st at 14:00 is 49.7° ˜50°. The analysis is made typically on the most south facing window façade as shown in the upper part of Figure 6.13, indicating the initial stage of the design.

At the stage of the architectural design development we had a floor plan which is not depressed to the interior, and there was a possibility of overheating as a result of being not shaded.

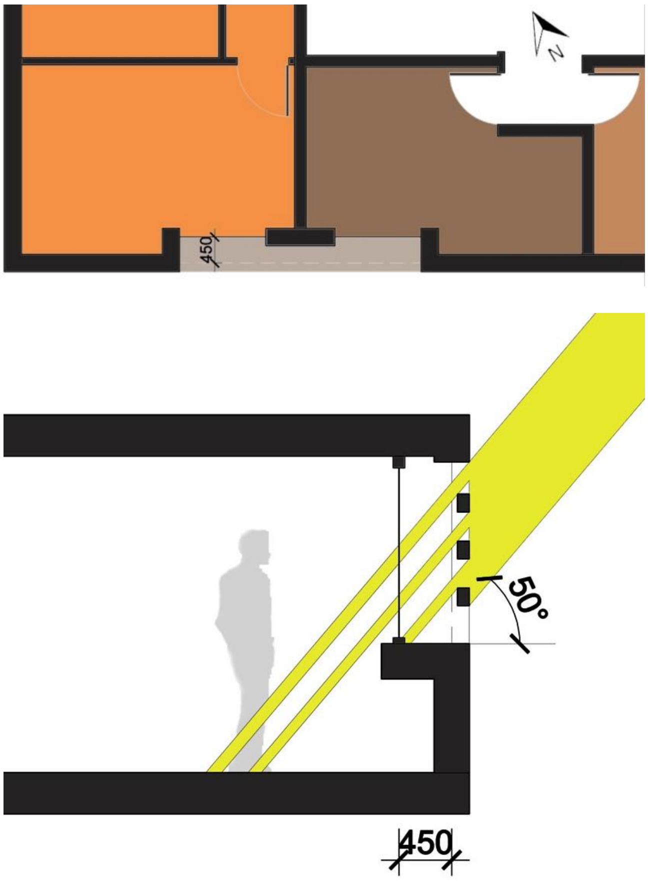
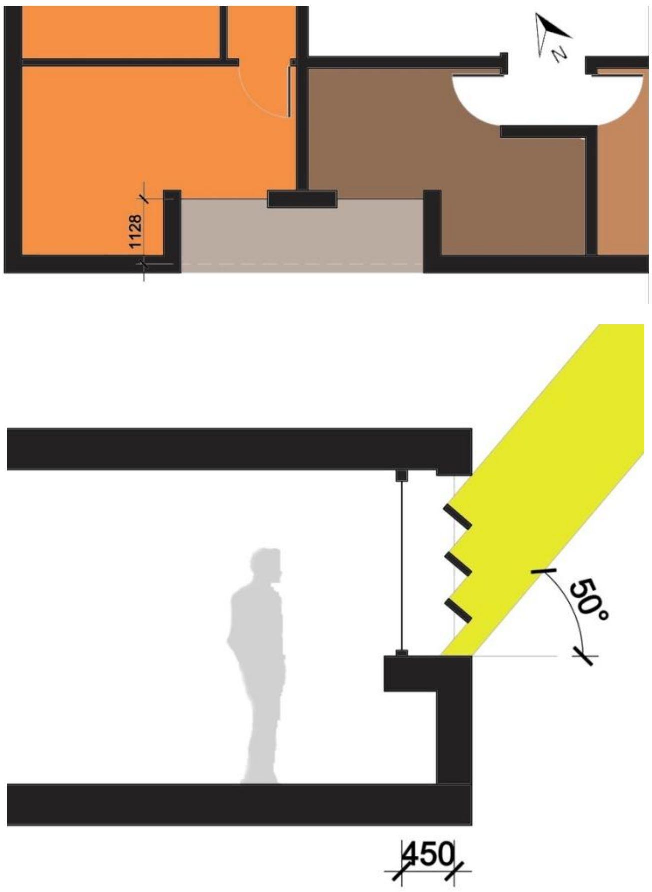


Fig. 6.14 Daylight penetration at the final stage of the design

The immediate solution was to depress part of the wall by 450mm to the interior space and allowing the same walls to act as a fixed vertical and overhang shading. In addition louver type horizontal shading elements were added with a dimension of (0.15, 0.1, 5.05) m in height, depth and length. As can be seen from the section a certain amount of direct sunlight is obstructed.

However we proceeded in providing some other options since the analysis was made on a typical window façade. The best option among which was to rotate the louver 140° anticlockwise as a supplement of the incoming ray angle. The result was fully blocking the ray but had some insufficiency of blocking the view of person by a total of 17.6cm.



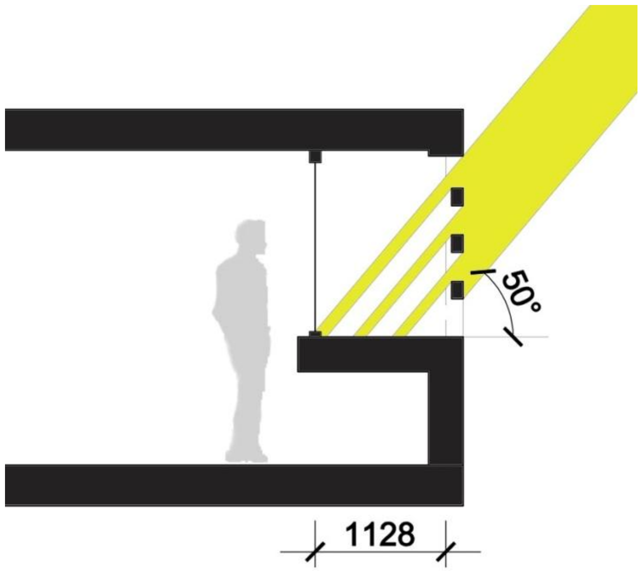


Fig. 6.15 Optional shading mechanisms which will completely block the direct incoming sun light.

The other option was to completely depress part of the walls by 1.2m until the direct sunlight was obstructed. This of course was not a good solution since it disturbs the functionality of the interior space.

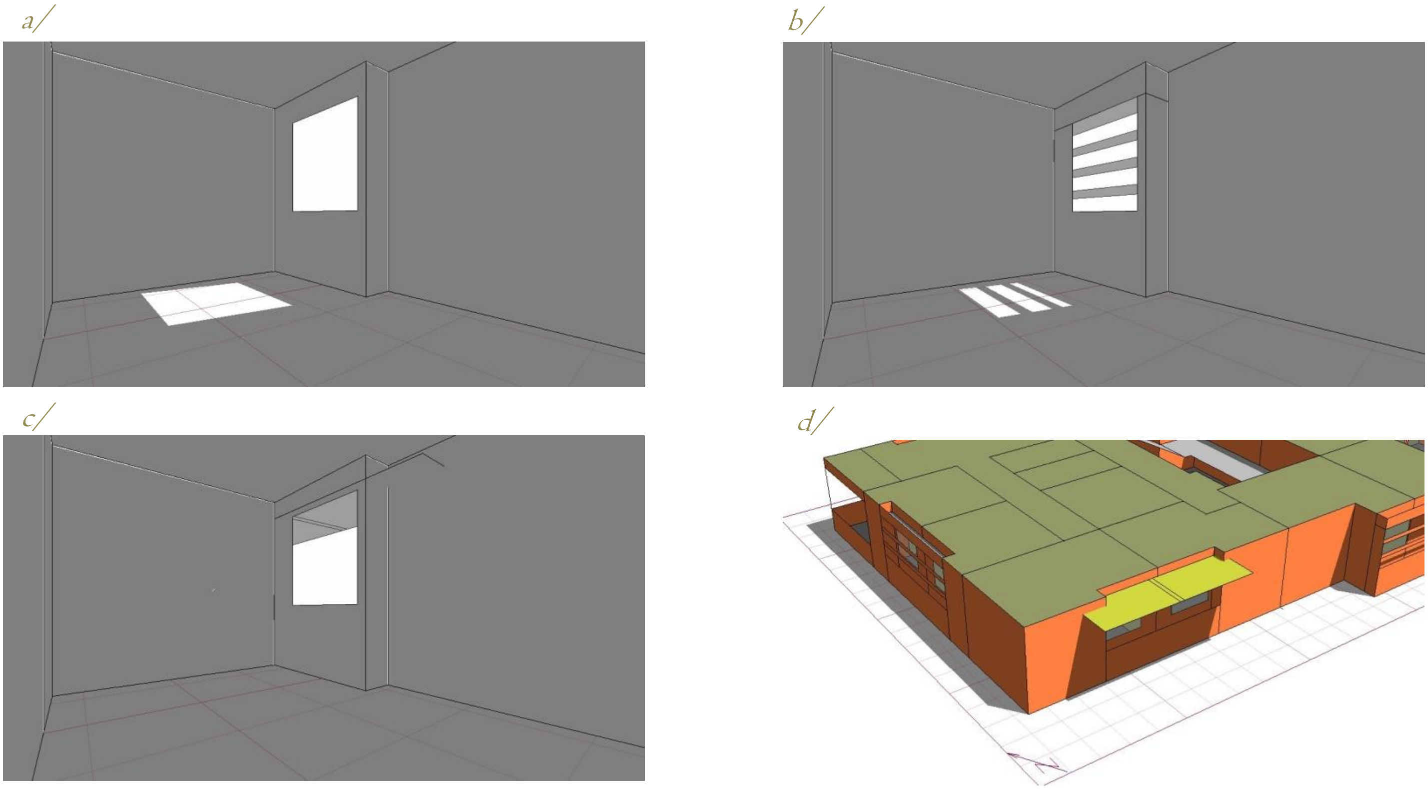


Fig. 6.16 Comparison of Shading Mechanisms

a/ Window without shading.

b/ Shading proposed in the building

c/ & d/ Shading results from Ecotect

6.8. Thermal Comfort

Description

Thermal comfort is the condition of the minds that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Thermal comfort is affected by heat conduction, convection, radiation and evaporative heat loss. It is maintained when the heat generated by human metabolism is allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Since thermal comfort is being defined as the condition of the mind, large variations could be obtained from person to person in terms of physiological and psychological satisfaction. It is thus difficult to obtain an optimal thermal environment for many in a given interior space. However, experiments and data's are available to define certain conditions that are found to be comfortable for a specified percentage of occupants.

Parameters

Accordingly there are six factors that directly affect thermal comfort that can be grouped in two categories: personal factors - because they are characteristics of the occupants – and environmental factors - which are conditions of the thermal environment. Even if all these factors may vary with time, standards usually refer to a steady state to study thermal comfort, just allowing limited temperature variations. According to ASHARE thermal balance is achieved when overall Heat gains = Heat losses.

Thermal comfort Parameters	
Environmental Parameters	**Personal Parameters**
Air Temperature (dry bulb Temperature)	Activity level of occupant
Relative Humidity	Insulative capability of persons clothing.
Velocity of air movement around person	
Radiant exchange between person and environment	

Table 6.3 Thermal Comfort Parameters

Thermal Comfort Models

When discussing thermal comfort, there are two main different models that can be used: the static model (PMV/PPD) and the adaptive model. For naturally ventilated buildings like in our case the ASHARE standard 55 -1992, recommends to use the adaptive comfort temperature boundaries, using the 90% acceptability limits as defined in the California High Performance schools (CHPS) Best Practice Manual, Appendix C – A Field Based Thermal Comfort Standard for Naturally Ventilated Buildings, Figure 2."

Adaptive Comfort Model

We have recognized that comfort depends on context. People living year round in air-conditioning spaces are quite likely to develop high expectation of homogeneity and cool temperatures, and may become quite critical if thermal conditions deviate from the centre of the comfort zone they have come to expect. In contrast people who live or work in naturally ventilated buildings, where they are able to open windows, become used to experiencing inherently more variable indoor thermal conditions that reflect local patterns of daily and seasonal climate changes. Their thermal perceptions – both their preferences' as well as their tolerance are likely to extend over a wider range of temperatures' than are currently reflected in the ASHARE standard. 55 comfort zone.

For this reason of adaptivity ASHARE proposed for a new adaptive comfort standard to compliment the traditional PMV based comfort zone. The adaptive model is based on the concept that there is a strong relationship between indoor comfort and outdoor climate, taking into account that humans can adapt and tolerate different temperatures during different times of the year. The adaptive hypothesis predicts that contextual factors and past thermal history modify building occupants' thermal expectations and preferences. The model states that factors beyond fundamental physics and physiology play an important role in impacting people's expectations and thermal preferences. Thermal sensations, satisfaction and acceptability are all influenced by the match between one's expectations about the indoor climate in a particular context, and actually exist.

The result led to a proposal for an Adaptive Comfort Standard (ACS) that would serve as an alternative to the PMV – based method in ASHARE Standard 55. The outdoor climate environment for each building was characterized in terms of mean outdoor dry bulb temperature $T_{a,out}$, instead of ET*. Optimum comfort temperature, T_{comf}, was then re-calculated based on the mean $T_{a,out}$:

$$T_{comf} = 0.31 \times T_{a,out} + 17.8 \quad (°C)$$

Based on this calculation we tried to define the optimum comfort temperature of the project area Addis Ababa. The mean dry bulb temperature of Addis Ababa is 15.9°C, which according to the formula the comfort temperature is 22.7°C.

Fig. 6.17 Sub-division of spaces for Thermal comfort analysis

After obtaining this result we proceeded with Ecotect analysis for comparison of the comfort value. The analysis is carried out on one typical floor. The courtyard space and the 3 bed balconies are excluded from the analysis just to only consider the internal space comfort.

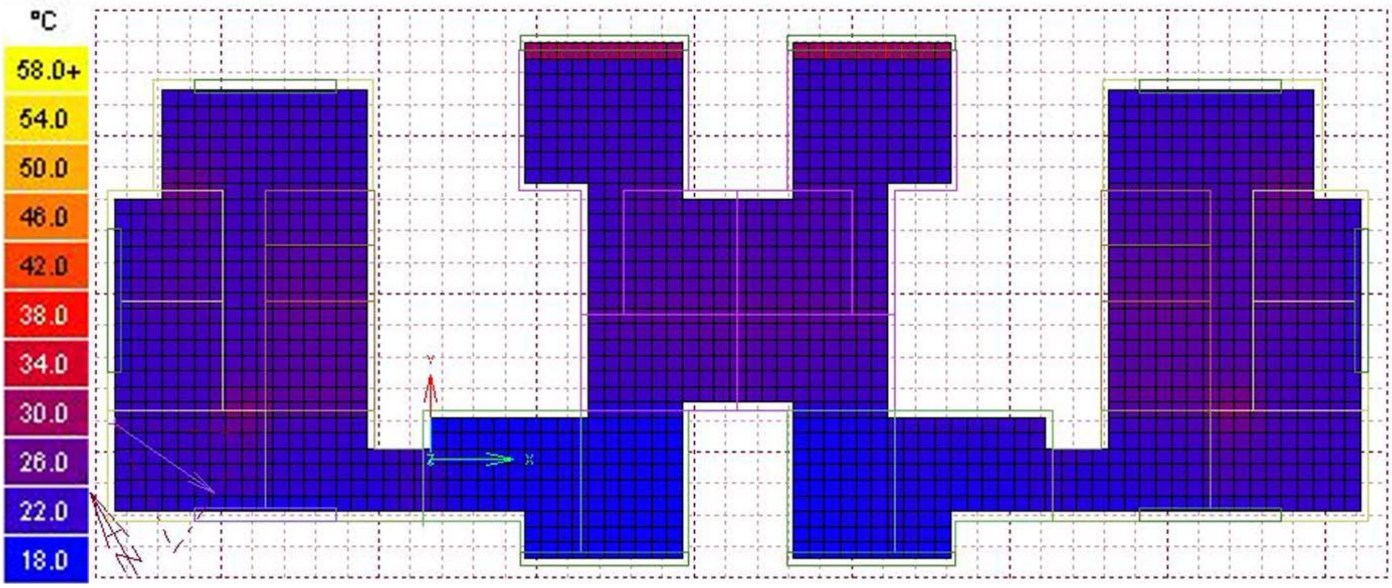


Fig. 6.18 Analysis of Comfort level expressed in terms of mean radiant temperature

An average value of 22.8°C is obtained using Ecotect. In comparing the result with Adaptive Comfort Standard (ACS), we can identify that the values are almost the same. As it can be seen from the figure thermal comfort is maintained except in places showing purple colour signifying a temperature of

26°C. This is due to the reason windows being a means of natural ventilation as well as means of overheating.

In addition also we tried to calculate the monthly load for the whole housing building. The type of system used is natural ventilation and the comfort optimum temperature is assumed to in the range of 18°C to 26°C. This off course is an assumption and thus considers wide range of values for the perception of comfort level.

Design Consideration									
Internal Design Conditions		**Occupancy and operation**							
		Occupancy		**Internal Gains(W/m²)**		**Infiltration rate (ACH)**			
Clothing (clo)	1	Number of people	130	Sensible Gain	5	Air Change Rate (ach)	1		
Humidity (%)	60	Activity (W)	70	Latent Gain	2	Wind Sensitivity (ach)	0.25		
Air Speed (m/s)	0.3								
Lighting Level (lux)	300								

Table 6.4 Design Considerations for thermal comfort

For the values assumed in the design:

Clothing Value (clo):- 1 for a light normal day clothing in Addis Ababa.

Humidity (%):- 60 which is the maximum acceptable humidity level in interior space, above which can encourage the growth of mold and mildew. At lower relative humidity below 30%, the occupants might experience eye irritation.

Air Speed (m/s):- Since this is a parameter that a designer assigns, 0.3 is assigned which signifies a pleasant breeze.

Lighting Level (lux):- Different activities require different lighting level. However 300 lux is appropriate for a room with a reading desk.

Number of people:- assuming the number of people living in each typology in wing 1, we calculated the total to be 130 people for 5 floors.

Typology Type	Number of people
3 Bed	6
2 Bed	4
1 Bed	2
Studio	1
Total	**13**

Table 6.5 Number of people in a typical designed flats

Activity (W):- the biological heat output assumed is 70 W assuming a sedentary or clerical activity. If any other activities involved the output might increase but could be compensated with the natural ventilation.

Sensible & Latent gains (W/m²):- an average of 5 and 2 respectively is taken in account. The values include both lighting and small power loads.

Air Change Rate (ach):- an average of 1.

Wind Sensitivity (ach):- 0.25 which represents a reasonably protected condition.

Accordingly, the final result is as shown below. It's based on degree hours on a flat comfort band. Degree hour is defined as the number of degrees by which the hourly average is below or above the set standard temperature. It weights each hour of discomfort by the number of degrees outside the comfort range. Flat comfort band uses also the upper and lower temperature bands configured for a space.

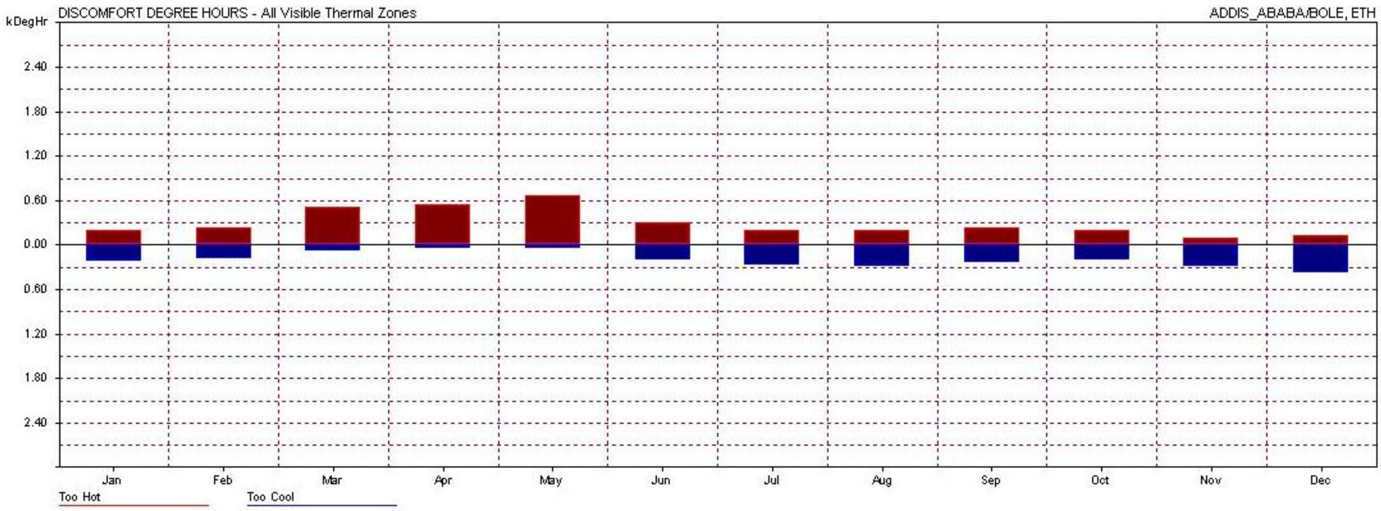


Fig. 6.19 Discomfort degree Hours

The *monthly loads/discomfort* graph displays the relative level of thermal discomfort likely to be experienced in a space over an entire year. The red bars represent the proportion of time considered to be too hot, while the blue bars represent when it is too cool.

In the month of March, April and May, Addis Ababa experiences the highest position of the sun and thus one could experience warmer indoor condition, whereas in November, December and January, which is the winter season, is colder. The too cold hours are because almost all throughout the year the night time temperature decreases. The rainy seasons, July and August experience both colder and warmer temperatures. However, since the temperature difference is less, people use adaptive techniques as a response to the perception of discomfort. Changing clothing's and use of natural ventilation are some of the response.

6.9. Solar Energy

Solar energy is the energy derived from the sun through the form of solar radiation. Solar powered electrical generation relies on photovoltaic's and heat engines. A partial list of other solar applications includes space heating and cooling through solar architecture, day lighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. The passive solar technologies has been implemented in our project by optimizing the orientation of the buildings accordingly to receive the necessary amount of daylight in the interior spaces. The use of Rammed earth as a main building material, with the ability to store heat up to 10 hrs with a thermal storage capacity of 1830J/m³°C and in addition providing a naturally ventilated spaces are also other design approach that are used in the housing design.

The earth in total receives 174pW(*10^{15} watt*) of incoming solar radiation -Insolation at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. Solar energy can be harnessed at different levels around the world, mostly depending on distance from the equator. And since Addis Ababa is located very near to the equator at latitude of 9°, the possibility of using solar energy is immense.

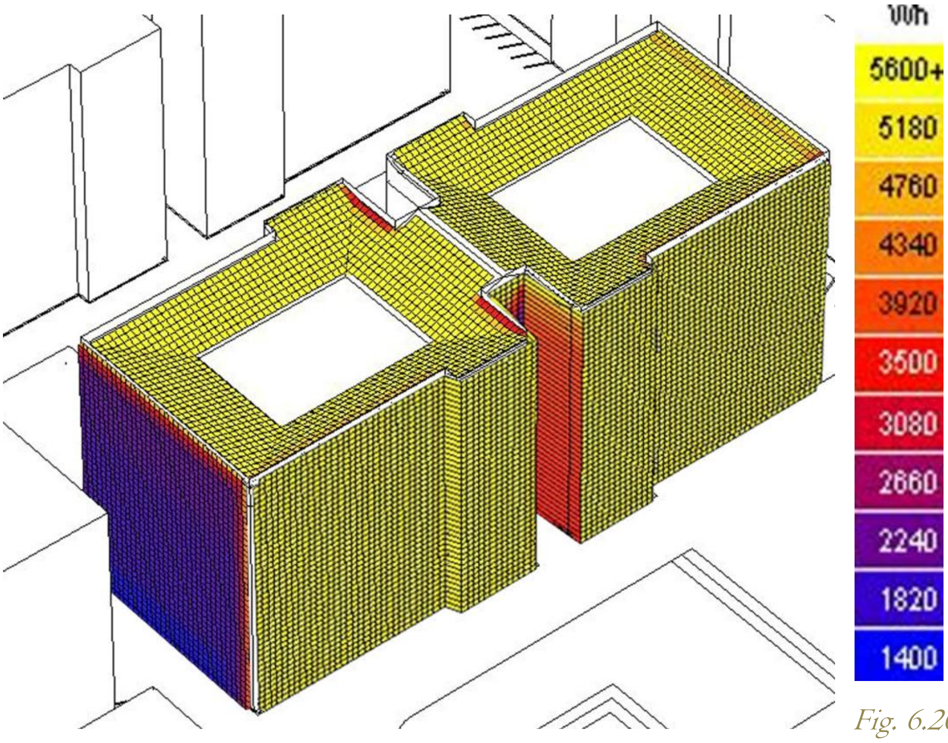


Fig. 6.20 Total Insolation in Watt Hour

For our project we propose to use photovoltaic panels which convert light in to electric current with photoelectric effect. The proposal is to use the pitched roof to provide a means of placing PV's. This would enable to cover the electricity consumption for the daily usage of the housing as well it could provide a sustainable energy source for the whole power grid of the city. This off course needs a system and an implementation plan which is beyond the scope of this thesis.

6.10. Appropriate Technology

What is Appropriate Technology?

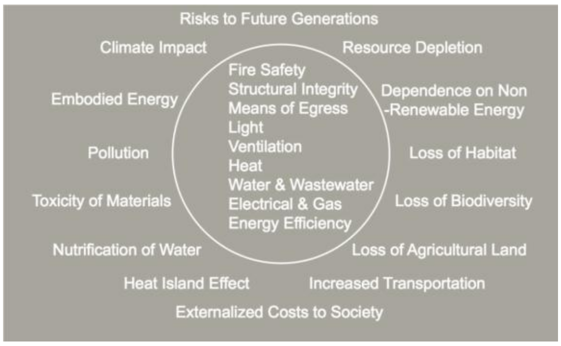
How does it help the society?

How can it Shape the future?

Appropriate technology isn't necessarily low tech. It's the right level of technology for what must be done, based on the specific use and real needs, circumstances, and to the degree that they are knowable, the consequences flowing from its use. It can be high-tech or no-tech or anything in between.
The best definition of truly appropriate technology is that it is technology that doesn't make us or our communities dependent on systems over which we have no control. If we think about this seriously, it means technologies that enhance the local capacity to meet local needs - which is the true foundation for sustainability and for real security.

In the carbon, energy and economically constrained era we're entering, all aspects of energy dependency of our building practices must be considered. I*n terms of technology transfer, we have much to learn from vernacular building as we seek ways to build smaller-footprint, more appropriate, affordable, and beautiful structures.* We've always been doing the best we could with what we had and knew.
What is needed is a more complete and balanced regulatory response to address and balance all these risks together. One of the important things to realize about traditional and non-industrial materials and building systems is that they have mostly been rejected not because they are inherently inferior but because they're labor-intensive. It's worth pointing out that many people think of "labor intensity" as jobs. Most of the traditional building materials and systems were being abandoned at the time modern codes and standards were developed so they aren't included. Here are some of the larger risks which are also attributable to the built environment and therefore part of the responsibility for safeguarding the public, most of which are currently unregulated.

a/



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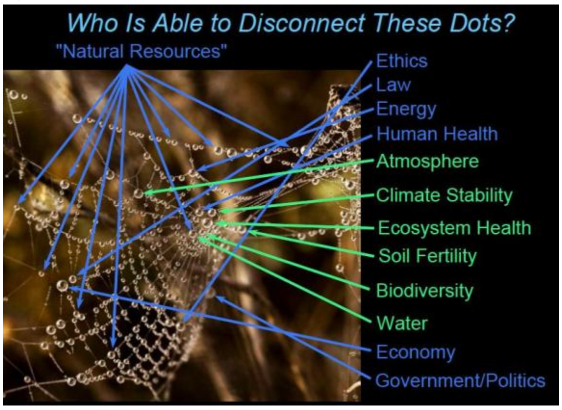


c/

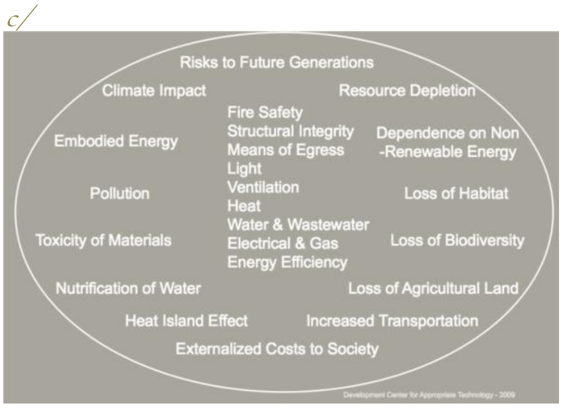


Fig. 6.21 Relationship between various issues concerning our built environment

a/ Design Issues exclusive of Risks

b/ Spider web relationship of Natural Resources with various elements

c/ Inclusive thought of design solutions with their impacts on the environment

Fig. 6.22 Buildings in Yemen which are made of earth materials

The buildings in Figure 6.22 are in Yemen. They are 8 to 9 story tall buildings made of earth and in some cases stone, many of which are hundreds of years old and in continuous use. Yet we imagine that such materials can't be used for larger structures.

Being aware of unintended consequences can shift preferences towards *local, simple, less*. A crucial benefit of doing things locally is that the feedback loops are shorter and higher quality: it's harder to miss or ignore the unintended consequences of what you're doing. By minimizing unintended consequences leads to a natural preference for doing things as simply and locally as possible. Our awareness of the great changes taking place and of these emerging global realities requires us to act in new and different ways than we have in the past.

What sort of solutions did we provide?

Since the main aim of our project was to come up with a sustainable solution that is based on the cultural realities and common values of the society, we had to really look in to different aspects that could define their living styles and the reasons behind them. As discussed in the previous parts, we have tried to integrate the input from the society in a participatory way and make them feel that they are part of the process. And according to our design they could be part of the construction in some of the processes that will not require skilled labor. But we can say that we have successfully dealt with the appropriateness of our technology from the choice of local materials that has a really low impact on the environment and its surrounding, the simplicity of the volume of buildings proposed and provision of renewable energy resources. We have also tried to figure out a way in providing new, for the context, and simple ways of an *in-situ* construction methods that will suit the knowledge level of the builders, i.e. the society.

In the following parts we will be going through the different reasons behind our choice of each locally accessible materials and other environmental solutions that have been incorporated in the design.

6.10.1. Rammed earth *(pisé)*

Rammed earth walls are constructed by ramming a mixture of selected aggregates, including gravel, sand, silt and a small amount of clay, into place between flat panels called formwork. Traditional technology involved repeatedly ramming the end of a wooden pole into the earth mixture to compress it. Modern technology replaces the pole with a mechanical ram (Pneumatic tempers). Stabilized rammed earth is a variant of traditional rammed earth that adds a small amount of cement (typically between 5 and 15 per cent) to add strength and durability. Stabilized rammed earth walls need little added protection but are usually coated with a permeable sealer to increase the life of the material – this varies with circumstance and there are thousands of unstabilized rammed earth buildings around the world that have given good service over many centuries. Most of the energy used in the construction of rammed earth is in quarrying the raw material and transporting it to the site. Use of on-site materials can lessen energy consumed in construction. Rammed earth provides some insulation and excellent thermal mass.

> *The term pisé is of Latin origin from pisé de terre. First used in Lyons, France in 1562, the term applied to the principle of constructing walls at least 50cm thick by ramming earth between two parallel frames that are then removed, revealing a completed section of hard earth wall. While 50cm thick walls can still be constructed if desired, with or without cement, most modern rammed earth walls in different places are built using cement at 30cm thick for external walls and 30cm or 20cm for internal walls.*

6.10.1.1. Performance Summary

Appearance

The colour of finished earth buildings will depend upon the colour of the earth used and also according to whether grey or white cement is added. White cement will brighten and lighten the wall colour and is generally preferred for pale colored earths, whereas grey cement will give a softer and more discrete final colour. The ramming process proceeds layer by layer and this can introduce horizontal stratification to the appearance of the walls. The stratification due to ramming can enhance the overall appearance and can be controlled as a feature or eliminated.

Fig. 6.23 Stabilized Rammed Earth samples made from different colored earths

The texture of the finished walls of the earth building can be determined by varying the maximum gravel size and the compaction technique. Smooth walls with a fine granular finish are possible with a fine screened mix, or, by using a coarser mix, the wall finish of the earth building can be made rougher and more rustic in appearance.

Fig. 6.24 Stabilized Rammed Earth wall with layers of stratification clearly visible

Fig. 6.25 Fine textured wall in crushed

Fig. 6.26 House with rustic finish

Brushed finishes help reduce formwork marks that can create a concrete-like appearance, but this is only necessary with fine grain size ingredients. Unusual finishes can be achieved by including shapes in the formwork that can be released after the wall has been rammed. Other possibilities include embedding rocks and other objects in walls for aesthetic effect.

Layers of ramming are visible as are the chamfered corners that are required to allow the walls to be easily released from the formwork. It is possible to form vertical curves, made by carefully ramming along a drawn guideline on the interior of the formwork. Horizontal curves are also possible but require specialized, and therefore expensive, formwork.

Thermal Properties

The thermal performance of rammed earth is measured in a number of different ways. The most commonly used properties are:

- *Thermal Resistance (R-value)*- This is a measure of the opposition to heat transfer offered by a building element of specified thickness and is measured in m^2K/W. According to Standards Australia (2002), a 300mm thick rammed earth wall has an R-value between 0.35-0.70 m^2K/W.
- *Thermal Transmittance (U-values)*- This is a measure of the overall rate of heat transfer, by all mechanisms under standard conditions, through a particular section of construction and is measured in W/m^2K. Minke (2000) claims that the U-values for a 300mm thick rammed earth can be as much as 1.9-2.0 W/m^2K. Rammed earth, as a dense material, has poor insulating properties.
- *Thermal Storage*- This is a measure of the specific heat capacity expressed in volume terms and has units of J/m^3 °C. Houben & Guillaud (1994)[4] claims that for rammed earth the thermal storage is around 1830 J/m^3 °C.

  Thermal mass Effect: Rammed earth's relatively low thermal resistance is countered by its large thermal mass. Thermal mass allows a material to absorb heat during warm periods and then release this absorbed heat over cooler periods that follow. when applied to a building

[4] *Houben, H. and Guillaud H., 1994, Earth Construction, A comprehensive Guide. Intermediate Technology Publications, London, UK.*

envelope, thermal mass simply mitigates internal temperature fluctuations, as shown in the figure below.

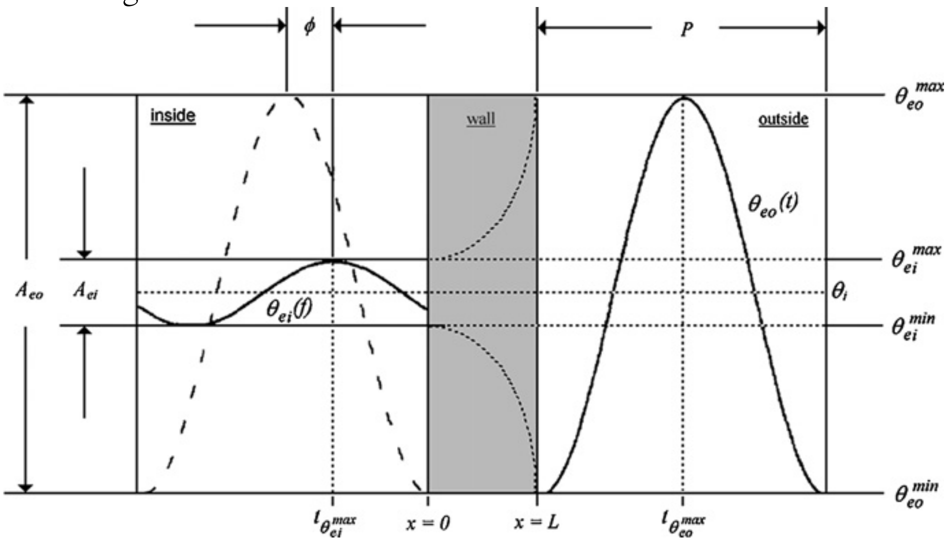


Fig. 6.27 Visual explanation of thermal mass transmission effect. Large external temperature fluctuations on the right are moderated to lesser internal fluctuations on the left side (Hall M.A., Assessing the moisture-content dependent parameters of stabilized earth materials using the cyclic-response admittance method, 2008)

Overall, this increases the effective winter design temperature and decreases the effective summer design temperature, which reduces the energy required to condition the internal building space. But in a moderate climate such as ours where the day's average temperature is comfortable, heating may not be required even though night time temperatures are cool.

Sound Insulation

One of the best ways to insulate against sound is have monolithic mass – rammed earth provides this very well. It has excellent sound reverberation characteristics and does not generate the harsh echoes characteristic of many conventional wall materials. A stabilized rammed earth wall with thickness of 300mm have a typical R_w (weighted sound reduction index) of the wall = 58.3 dB.[5]

Fire resistance

There are no flammable components in a rammed earth wall and its fire resistance is thus very good. Stabilized rammed earth is classified as 'non combustible material'. In tests by the *CSIRO(Commonwealth Scientific Industrial Research Organization) Report No. 1839,* a 150mm thick rammed earth block wall achieved a near four hour fire resistance rating.

Durability and moisture resistance

The basic technology has been around for thousands of years and there are many rammed earth buildings still standing that are centuries old. Rammed earth possesses a generally high durability but all types of rammed earth walls are porous by nature and need protection from driving rain and long term exposure to moisture. It is essential to maintain water protection to the tops and bottoms of walls. Continued exposure to moisture may degrade the internal structure of the earth by reversing the cement stabilization and allowing the clays to expand, however, in general, rammed earth has moderate to good moisture resistance and most modern rammed earth walls do not require additional waterproofing. New water

[5] *Stabilised Rammed Earth - Physical Properties and Compliance with UK Building Regulations*

repellent additives that waterproof the walls right through may make rammed earth suitable for very exposed conditions, including retaining walls, but may inhibit the breathability of the material.
Durability of Stabilized Rammed Earth materials is determined using the *'accelerated erosion test' (AET)* in accordance with:

- Standards New Zealand, 1998, *NZS 4298: 1998 Materials and Workmanship for Earth Buildings*, Wellington, New Zealand
- AET value for Stabilized Rammed Earth = 0.0 mm/min

Tests performed by Materials Consultants Aust. Pty. Ltd. Report No. 202/87

Test results

Bricks characteristics	Different walls treatment							
	Cement (%)		lime (%)		Cement (%) + Lime (%)		Cement (%) + Resin (%)	
	5	8	8	12	5 + 3	8 + 4	5 + 50	8 + 50
Compressive strength in dry state, MPa	15.4	18.4	15.9	17.8	17.5	21.5	17.2	19.5
Compressive strength in wet state, MPa	9	12.7	10.1	11.7	12.3	15.6	11.5	14
Water strength coefficient	0.58	0.69	0.64	0.66	0.63	0.7	0.67	0.72
Capillary absorption, %	2.35	2.2	3.7	2.9	2.3	2	2.3	2.1
Total absorption, %	8.27	7.35	9.8	9.02	8.1	7.9	5.9	5.3
Weight loss (wet–dry), %	1.4	1.25	2.3	2.1	1.2	1.0	0.9	0.9
Weight loss (freezing and thawing), %	2.35	2.23	3.7	2.9	2.3	2.0	2.3	1.8
Hole depth, mm – After spray test	1.0	0.5	2.2	1.0	1.0	0.5	0.25	0.2
Hole depth,[a] mm – Real life exposure	–	–	1.0	0.5	–	–	–	–

[a] Values obtained using a comparator.

Table 6.6 Comparative Performance of some common rammed earth stabilizing agents (Guettala, 2006)

Breathability and toxicity

Provided it is not sealed with material that is impervious, rammed earth maintains its breathability. Finished walls are inert, but care should be taken in choice of waterproofing or anti-dust finishes to avoid adding toxicity to the surfaces.

Environmental impacts

Rammed earth has potentially low manufacturing impacts, depending on cement content and degree of local material sourcing. On-site materials can often be used but materials should be tested for their suitability.
The embodied energy of rammed earth is low to moderate but compared to other building materials, as will be seen on the table below, we can say it has a really low embodied energy. Composed of selected aggregates bound with cementitious material, rammed earth can be thought of as a kind of 'weak concrete'. It may help to understand cement and earth products as being at different points on an energy continuum with earth at the low, and high strength concrete at the high end. Its cement and aggregate content can be varied to suit engineering and strength requirements.

Although it is a low greenhouse emission product in principle, transport and cement manufacture can add significantly to the overall emissions associated with typical modern rammed earth construction. The

most basic kind of traditional rammed earth has very low greenhouse gas emissions but the more highly engineered and processed variant of rammed earth has the potential for significant emissions.
The calculation of embodied energy is based on the following four components:
1) Energy in transportation/extraction of sand and soil
2) Energy in mixing
3) Energy in compaction
4) Energy in cement

Material	Embodied Energy MJ/Kg
PVC	80.0
Cement	5.6
Galvanized steel	38.0
Aluminum	170.0
Hardboard	24.2
In situ concrete	1.9
Glue-Laminated timber	11.0

Material	Embodied Energy MJ/Kg
Copper	100.0
Glass	12.7
Concrete Blocks	1.5
Stabilized Earth	*0.7*
Acrylic Paint	61.5
Synthetic rubber	110.0
Plywood	10.4

Table 6.7 Embodied energy of different Materials

Buildability, availability and cost

Rammed earth is an *in-situ* construction method. Although its buildability is good, formwork for rammed earth demands good site and logistics planning to ensure that other trades are not adversely effected in the building program. Services should be well planned in advance to minimize difficulties. After walls have been rammed in place, conduits for pipes and wires can be provided much as in other masonry construction, but may impact on surface finishes.
Cement and formwork may have to be transported long distances, increasing environmental and economic costs. Testing of local aggregates and potential mixes is advisable. Traditional rammed earth using human power for ramming and simple wooden formwork can be low cost (and low energy).

6.10.1.2. Construction process

Selection of the earth to be used for Stabilized rammed earth walls is critical to their strength, durability and appearance. Once a sub-soil or crushed material has been found that appears to have suitable physical characteristics and is in a colour according to the design, it should be sent to a soil laboratory for testing. A laboratory can determine the particle sizes by sieve tests, whether it is likely to shrink during drying and most importantly what strength the final compacted material will achieve. The architect or engineer will usually specify the technical properties required according to the building structure, the weather conditions, etc. The mix of particles and stabilizer can be tailored to meet the requirements of the particular job. Sample cores are usually taken during the construction process to confirm that the correct mix and physical qualities are being maintained.

The earth is thoroughly blended with (normally) between 5 and 15% stabilizer, a water-repellent admix and just enough water to form a damp mix. Stabilized rammed earth is made by compacting a gravel, sand, silt, clay mixture and cement between formwork in a series of layers approximately 100mm thick.

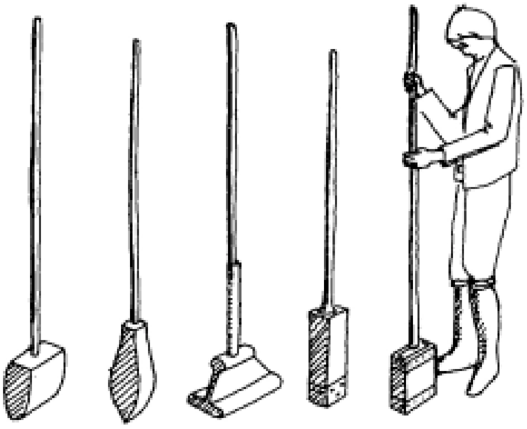


Fig. 6.28 Manual Tamping Equipments

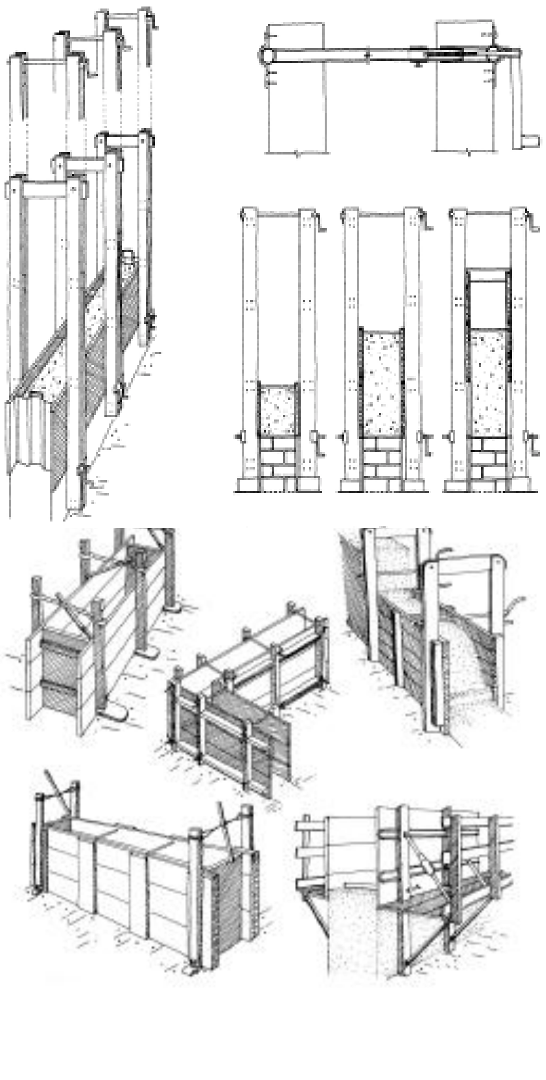


Fig. 6.29 Formworks in the construction process of rammed earth walls

Traditional techniques use manual tampers with conical or flat heads, see Fig. 6-28. Conical tampers give a better bond between the different earth layers, but need more time. It is preferable to use a tamper with two heads, one with a round surface and the other with a square surface. The square tamper has to be used at the borders of the formwork.

Formwork

Plywood or steel sheets are both used in making formwork, which is superficially similar to the formwork used for in-situ concrete, but with its own specific requirements. Propping and temporary stays are required in the construction process and these may impact on other site work operations if the primary structure is more than just rammed earth. Walls are built in sections and the rise of each level of formwork is often visible in the final finish. Walls are built up in layers of approximately 100mm. As the wall rises it is possible to take out the lower portions of formwork provided the wall has set strong enough. When making a choice of formwork the following general criteria should be kept in mind:

- *Strength*- the formwork should be able to withstand the outward pressure of the earth during compaction. Typically pressures during rammed earth compaction are considered to be much higher than general concrete works, though the area and period of time over which the pressure acts is typically much less (Norton, 1997);
- *Stiffness*- formwork should be sufficiently stiff to maintain the form without excessive distortion during compaction. Typically, forms should not deflect more than 3mm over the length between the ties under full pressure (standards Australia, 2002) or when applying a 150kg load at the mid-span between two supports (Norton, 1997; SAZS 724:2001, 2001) ;

- *Durability*- forms must be able to meet the expected number of uses under normal site handling conditions and appropriate maintenance, without performance deterioration;
- *Adaptability*- the formwork should be capable of accommodating variations in the width and layout of the wall to meet structural and architectural requirements;
- *Ease of handling*- formwork must not be too heavy or bulky in order to avoid making assembly difficult and time-consuming;
- *Ease of alignment*- formwork parts should include smooth horizontal and vertical slots, comfortable holes for bolts and smooth running ties to allow easy and consistent horizontal and vertical alignment; and
- *Ease of compaction*- the shuttering system should not obstruct the compaction process.

The basic elements of any formwork system, traditional or modern, are:

- *Shutters*- the two sides of the form;
- *End stops*- the boards which close-off the open ends of the formwork;
- *Ties and bolts*- these can be either direct through-bolts, cantilever bolts, threaded ties or ties with wedges (keable, 1996);
- *Props or stays*- the (fixed or movable) vertical posts used to brace the form;
- *Spacers*- bolting often requires spacers in order to set the width of the wall. Spacers should be softer than the formwork in order to prevent damage to the form faces (keable, 1996); and
- *Wedges*- for adjustment of the formwork.

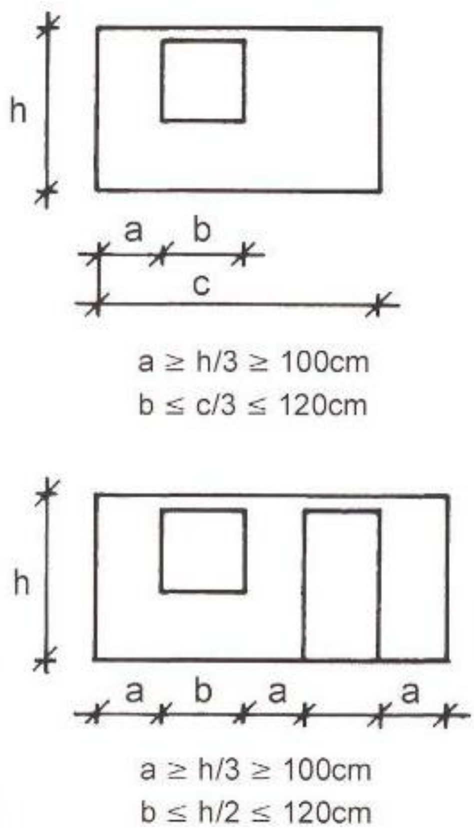


Fig. 6.30 Opening Regulations in rammed earth wall constructions (without lintels)

Openings

Openings may be formed either by creating full-height or partial-height sections when building individual freestanding panels of solid earth, by using block-out forms or using structural lintels. Without lintels we can have spans of up to 1 meter in stabilized walls (subject to strength and engineering requirements). Specialized formwork can be made to make features like pointed arch or circular windows and the formwork can often be re-used. Detailing window and door openings up to full height of the wall avoids the need for structural support within the rammed earth. Arched and flat openings formed by block-outs inserted inside the wall formwork are an effective means of providing openings over modest spans up to 1.5 m (Keable, 1994; Easton, 1996). Lintels may be formed from solid timber, concrete, stone or other suitable materials or formed by incorporating steel rebars or rolled sections (Tee or Angle section) inside the rammed earth directly over the opening. Lintels require adequate bedding length to avoid bearing problems, and are capable of spanning over 3 meters in both natural or cement stabilised rammed earth.

Finishes

The off-form finish of stabilized rammed earth generally requires no additional finish. A clear water repellent coating may be needed in some instances and unstabilized rammed earth should be protected by eaves, overhangs or render, as they are more prone to erosion. Walls can be wire brushed shortly after being released from the formwork to eliminate the visual impact of the joins between the formwork and achieve an appearance closer to monolithic sandstone. Selection of the ingredients for rammed earth also affects this.

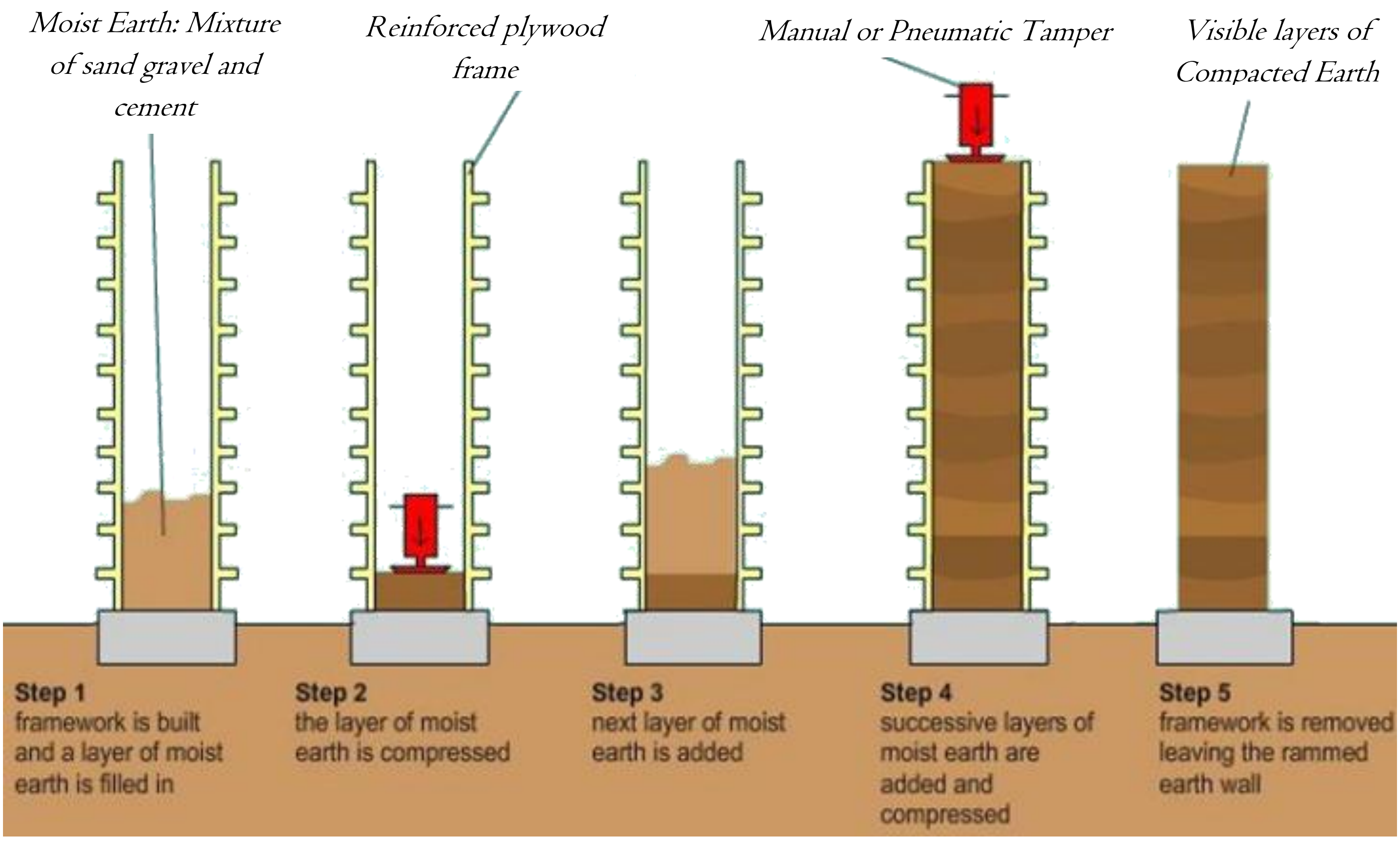


Fig. 6.31 Steps of Construction for a Stabilized rammed earth wall and formwork assembly detail

6.10.2. Pressed Straw Panels - Internal Partitions

The search for solutions for appropriate housing methods has existed since the construction of the first primitive shelters. Proposals and experimental approaches for housing are almost always strongly dependent on cultural context: on traditions, social circumstances and the available resources. The situation in the rural areas of Ethiopia is in this respect is very specific.

The rural population in Ethiopia has a strong traditional way of living oriented around models handed down from the past. The country consists of a number of different cultures and ethnic groups with marked contrasts in the landscape and locations that often lie far apart and in isolated areas. Nonetheless to this difference the traditional construction material almost all over the country is the same, it is composed of earth material as a wall with straw in it and full straw as a roofing material. The pictures below are from two different traditional type of housing.

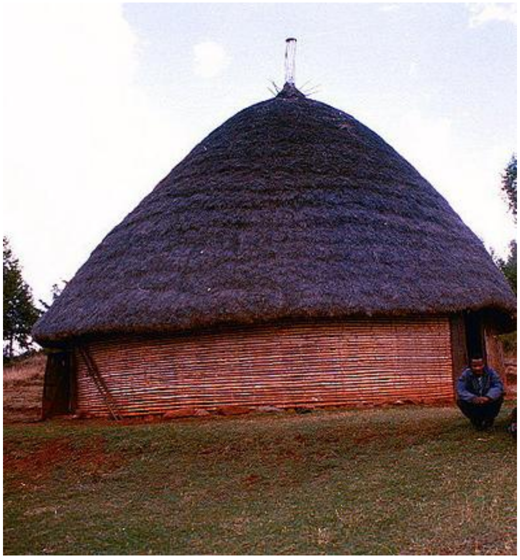


Fig. 6.32 Southern region (Gurage and Chencha society) traditional housing

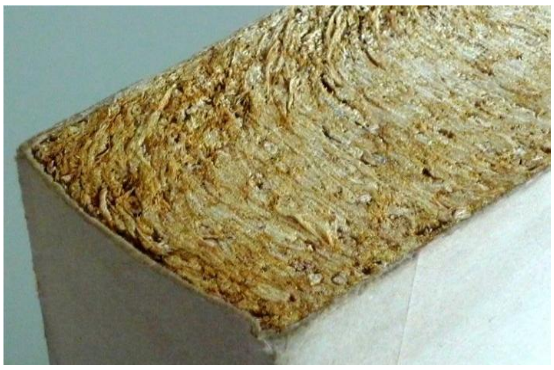
From tradition to modern

Straw is mainly seen as a 'waste' product of agricultural production. In Ethiopia, it is usually burned on after harvesting season .Straw is a renewable material offering good thermal insulation properties and a much lower environmental impact than many current mainstream construction materials. As an organic, renewable material, it is inherently environmental friendly and recyclable. However straw alone is not well suited for contemporary housing construction. Modern production technologies such as oriented strawboard offer a possible alternative.

Straw bale is very suitable as infill insulation for timber frame buildings with either an external render or timber rain-screen finish. Straw provides a vapor-permeable wall construction using a locally sourced, low-impact material, although it does need careful detailing and construction to avoid the ingress and retention of moisture.

Straw boards may be used in both infill (non-load bearing) and modest load bearing wall applications. Non -load bearing straw bale walls are mainly used for external infill above the damp-proof course level in moderate or sheltered environments. They can be constructed either on site or as prefabricated panels delivered to site already enclosed in a protective outer finish, such as lime render. Detailing requirements for both approaches are similar, although construction sequences are different.


a/


b/

Due to this Ethiopian institute of architecture building construction research group started a project called Sustainable *Emerging Cities Unit* (SECU), which we have mentioned in the knowledge part of this paper, focused on researching and testing this innovative and low-weight construction material. In the recent past, the company STRAWTEC in Berlin implemented a production system for pressed straw panels which were used for the SECU experiment. The straw panels for experiment came from abroad, Berlin but production will start in Ethiopia in 2012.

Fig. 6.33 Transition from traditional to modern mechanisms

a/ Straw for making thatched roofs in traditional construction

b/ Straw Panel for the SECU experimental units

Why Straw Panels?

Advantages

- The design is based on principles and criteria for cultural and social identification
- Constructed from affordable and recyclable materials to reduce dependency on imported materials,
- It can have standardized connections and construction details,
- Affordable and achievable on-site realization.
- Avoids thermal bridging and provides good air tightness with simple detailing
- Good insulation qualities
- Lightweight material with simple construction details and processes
- Light weight reduces load on foundations, reducing the need for materials with high embodied energy (e.g. concrete)
- Low-cost renewable material, widely available from local sources, that stores carbon throughout its life,
- Simple building skills suited to self-build and community projects

- Suitable for in situ and prefabricated approaches
- Vapor-permeable construction envelope

Limitations

- As an agricultural co-product, inconsistent properties (e.g. dimensions, density and moisture content) can be problematic during construction,
- Details restricted by need to protect the straw from water ingress; careful detailing needed for exposed areas,
- Limited to relatively lightweight fixings,
- Limited water resilience (giving rise to concerns over flood damage) and problems for repair if water damaged (especially load bearing walls),
- Requires shelter before finishes can be applied,
- Suitability of rendered external finishes limits application in some areas,
- Use limited to above damp-proof course or equivalent level.

Typical Properties of Straw panels

- Minimum recommended compacted straw dry density: 110–130 kg/m^3
- Thermal conductivity: 0.055–0.065 W/mK (density 110–130 kg/m^3)
- Recommended initial moisture content: 10–16%
- Recommended maximum in-service moisture content: normally not to exceed 20–25%.

Carbon Storage

The embodied carbon of straw bale products is very low relative to many other construction materials. As with all plant-based material, carbon is stored during plant growth and continues to be stored through its use as a building material. At the end of its life, it might either be used as animal bedding (if cleaned of any other materials such as lime render), be ploughed back into the ground as soil conditioner or possibly used as biomass fuel.

Production

The straw is minimally processed and compacted into a board, in the process reducing the environmental impact of burning, e.g. on air quality and combustion fuel. The straw is reduced in a chopping mill for 25 minutes, highly compressed (250 bars) and heated up to 300 °C. Wheat or bale straw can be used, as can any other plant such as banana leaves. The production does not use any glue or bonding agent. Through heating, the natural starch (lignum) in the straw is activated and functions as natural glue without any other chemical additions. In a linear industrial process, straw is compressed into flat boards, each approximately six centimeters (6cm) thick, clad with cardboard on each side, similar to gypsum boards, which also achieves a high fire resistance. Given their regular sizes of 120 cm by 250 cm, the boards are easy to handle and work with. . The standard dimensions are 120 cm wide and 6 cm thickness, while the length is flexible. In the context of rural houses it can be used as non-load bearing and load bearing elements.

Connections

Using natural as well as artificial types of adhesive, casein-based glue presented the best results. This natural glue has been used for centuries in Ethiopia and is extremely long lasting. It has the advantage that no heat is required in its preparation or application. It also allows for a convenient working time before hardening. Casein is a powder byproduct found in the making of milk products such as cottage cheese. The casein, when mixed with hydrated lime, forms a creamy paste, bonding firmly during application and enables waterproof connections. Mixing proportions of casein and lime had to be tested intensively to find the best adhesive quality with the straw boards. It also showed the possibility to be used as filling paste to close gaps between components and finish and create a waterproof edge for all of the straw panels. They can be drilled and screwed.

Fig. 6.34 Straw panel Connection Process

6.10.3. Waste Management

Ethiopia is one of the countries with the lowest sanitation coverage. Problems with current sanitation systems include:

- Collapsing of pit latrines,
- Wastewater leakage from pits and septic tanks resulting in groundwater pollution,
- Lack of faecal sludge management and treatment facilities,
- Irregular water supply restricting the use of water flushed toilets,
- Need for inexpensive and hygienic fertilizer.

The fact that Ethiopia is one of the heavily agricultural products dependent countries of the world with almost 80% of the population making a living by cultivating crops , led us to come up with waste management solutions that could help the society in general. Generally, farmers in Ethiopia use imported fertilizers such as DAP (Diammonium Phosphate), which has a huge impact in deteriorating the soil fertility thereby affecting the environment.

Based on the points mentioned on the previous parts we came up with some sustainable solutions for the management of wastes including good usage of rainwater. Next we will be going through the different aspects of the solutions that are incorporated in the design of the residential blocks.

Urine Separating Compost Toilets

Composting toilets are dry toilets which operate without the need for flushing water or sometimes as flush toilet together with a separator that separates the flushed water from the excreta, so the solid parts could be led into the composting container. We chose this systems to improve the current improper usage of toilets by the society and upgrade the sanitation management of the city to a more sustainable one. They can be used independently of connections to sewers and provide a safe and hygienic sanitation alternative for a range of possible applications. Composting toilets can considerably reduce household water consumption and the costs for wastewater treatment and also they retain substances, which may be harmful to the environment.

Benefits of Compost Toilets

The use of compost toilets means that cities and peri-urban areas do not need to extend capital intensive sewerage networks and sewage treatment plants. The recurring cost of maintaining additional infrastructure is also avoided. Both these factors represent a huge saving. Also, in areas where toilets would be flushed with municipal water there is an enormous saving in water requirements. Cross contamination between water mains and sewers is eradicated where compost toilets are well established as the standard sanitation technology. Soils are steadily improved by the regular addition of good quality compost. Conventional sewage treatment invariably leaves a dangerous sludge that still needs further treatment or incineration whereas compost toilet systems produce a useful product. In water logged areas where there was previously no satisfactory sanitation system operating, the benefits that compost toilets provide are clear. They can prevent ground and surface water contamination and protect people’s health in areas where open defecation on the ground or directly into water bodies has been the norm. The production of safe compost and effective use of the urine and wash water are also a significant benefit. The technology also lends itself extremely well to areas with hard rocky soils where excavation of pits is difficult, expensive or inappropriate. Again the compost is valuable and can help to provide a better chance of establishing plant cover on thin and fragile soils.

Summary - advantages of urine Separating compost toilet

- No need to dig pits.
- No need for sewers and treatment plants.
- No need for external infrastructure.
- Safe and affordable for anywhere but especially high water table and or water scarce areas.
- Does not pollute the ground or surface water or the soil.
- Does not produce flies or smell.

- Uses less water than any other toilet.
- Totally self-contained sewage treatment on site. There are no sewage pipes, no septic tanks, and no dangerous emptying of hazardous sludge.
- No mosquitoes. Septic tanks and pit latrines often have poorly fitting covers or the covers are not carefully replaced after emptying. These places then become prime breeding sites for mosquitoes. In a compost toilet there is no place for mosquitoes to breed.
- Produces safe, useful, non-odorous compost.
- The evaporative plant bed can support growth of attractive flowers, fuel wood, vegetable or plantain.
- Urine has a good soil conditioning property.
- The final products of composting are very much useful for fertilizing crops.

Awareness Raising

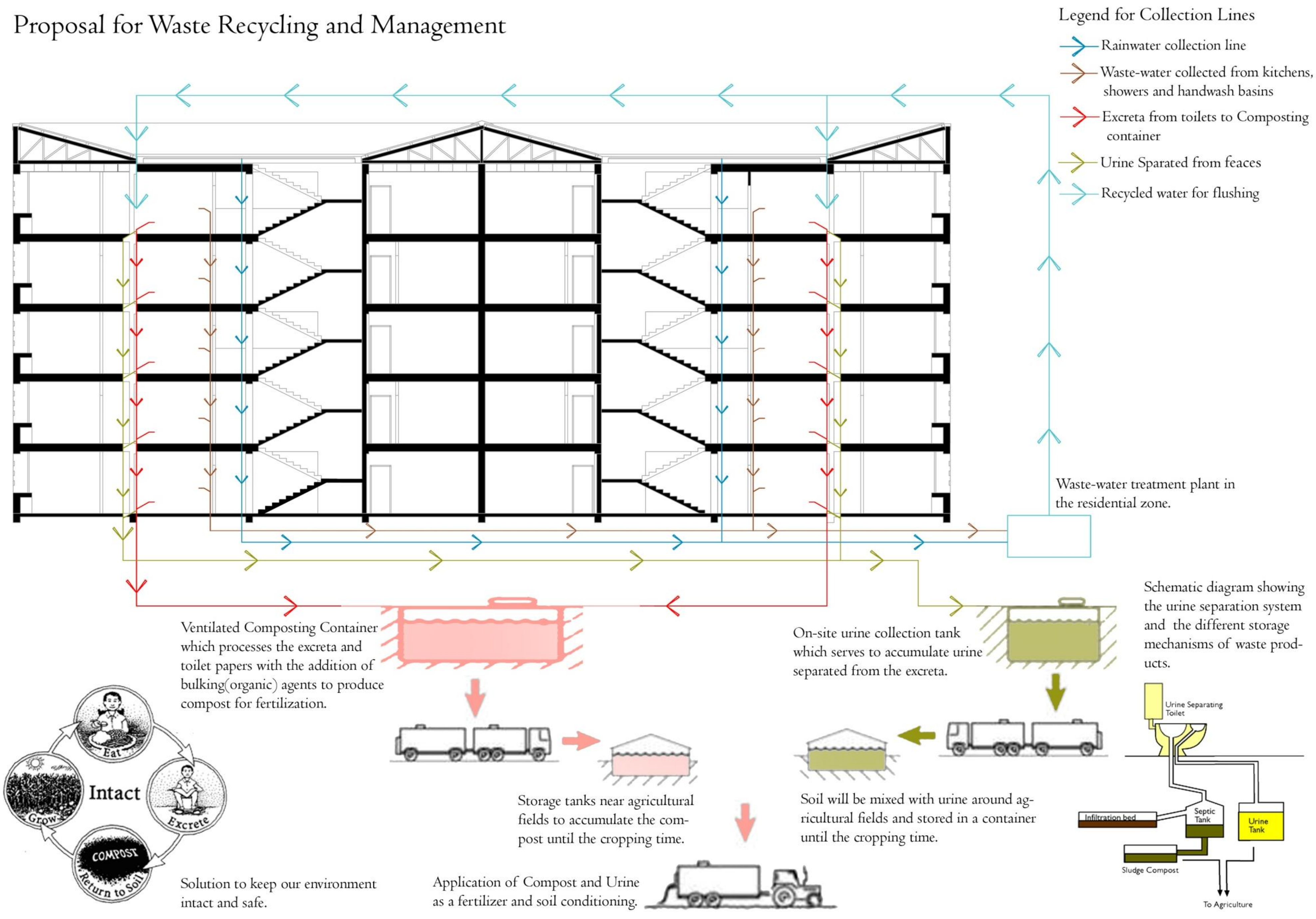
Adequate awareness raising and training needs to be given to the users in the early stages of establishing the compost toilet. It is essential that the toilet is correctly designed and built and that there has been a very interactive and participative approach to its introduction. If these steps are taken, there is a far greater chance of the compost toilet being "owned, understood and accepted" by the community which is essential if it is to be successful. The need for interactive training and awareness raising is to unravel and dispel the misunderstandings and confusion that often surrounds sanitation, health, hygiene, water and the environment.

Operation & maintenance

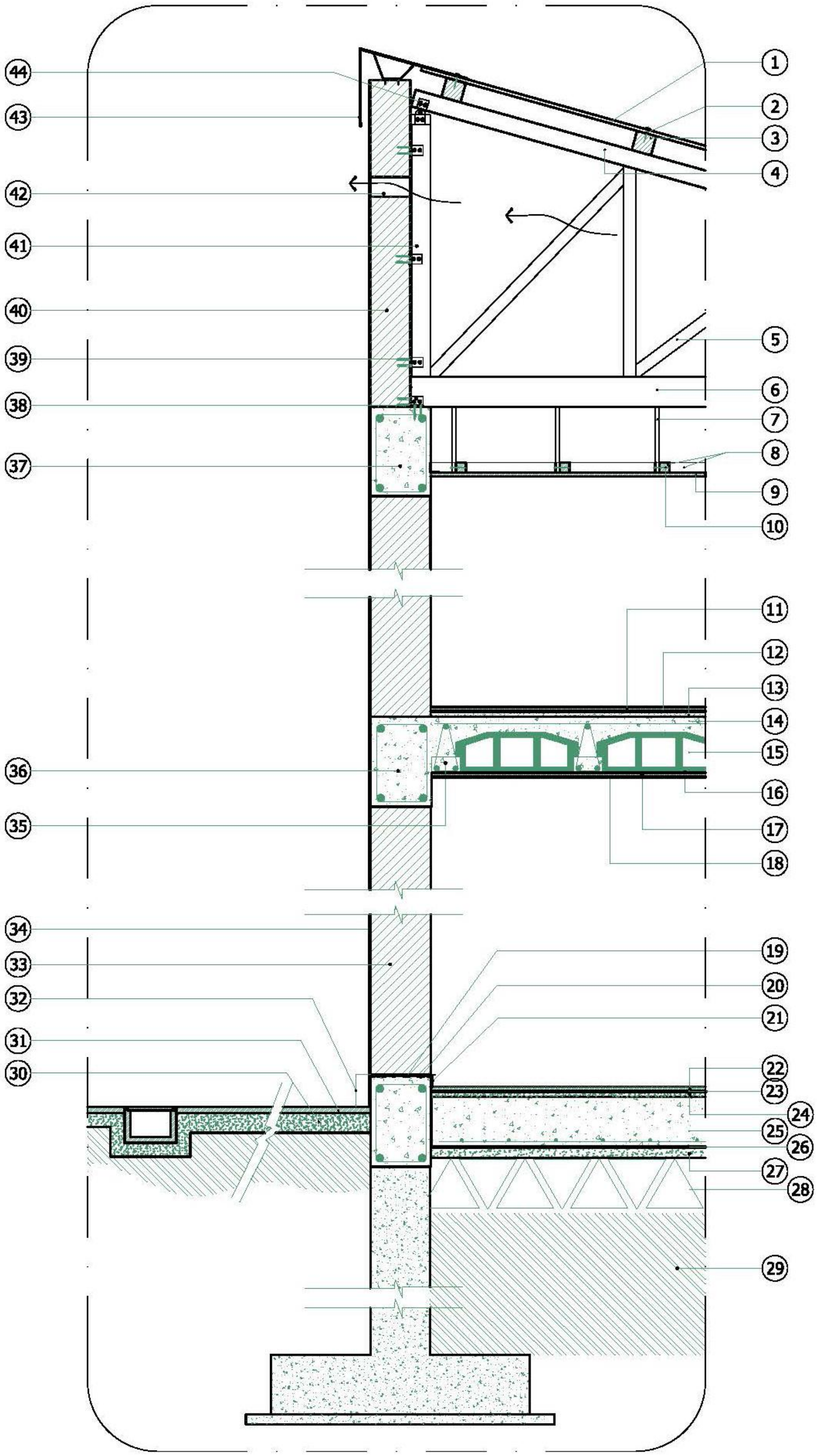
A cost analysis showed that investment costs are comparable to the implementation of septic tank systems. Operation and maintenance can be done in an adapted and cost-efficient way. Replacing mineral fertilizer by urine can result in additional monetary benefits particularly in the light of rising fertilizer prices.[6] The projected implementation of urine-separating toilets is an alternative approach for resource-efficient and nonpolluting sanitation even in multi-storey buildings. This strategy creates a strong link between sanitation and agriculture and contributes to employment generation with regard to micro and small enterprises taking over the operations and management the sanitation system. The diagram in the next page shows the different sustainable solutions provide in the design concerning waste management.

[6] *Urine-Diverting Dry Toilets in Multi-Storey Buildings in Ethiopia, by Franziska Meinzinger, Martin Oldenburg, Ralf Otterpohl*

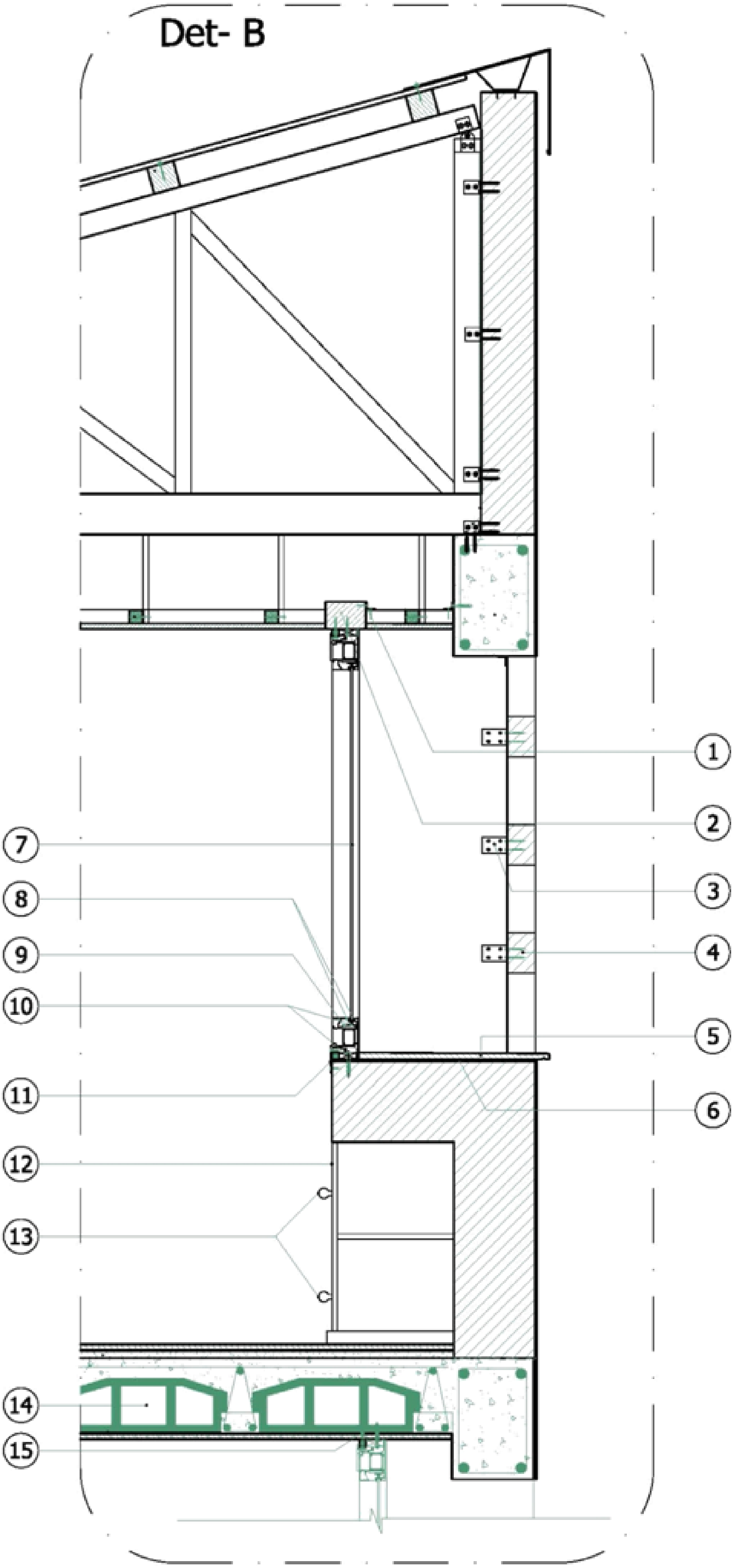
Proposal for Waste Recycling and Management



Det- A

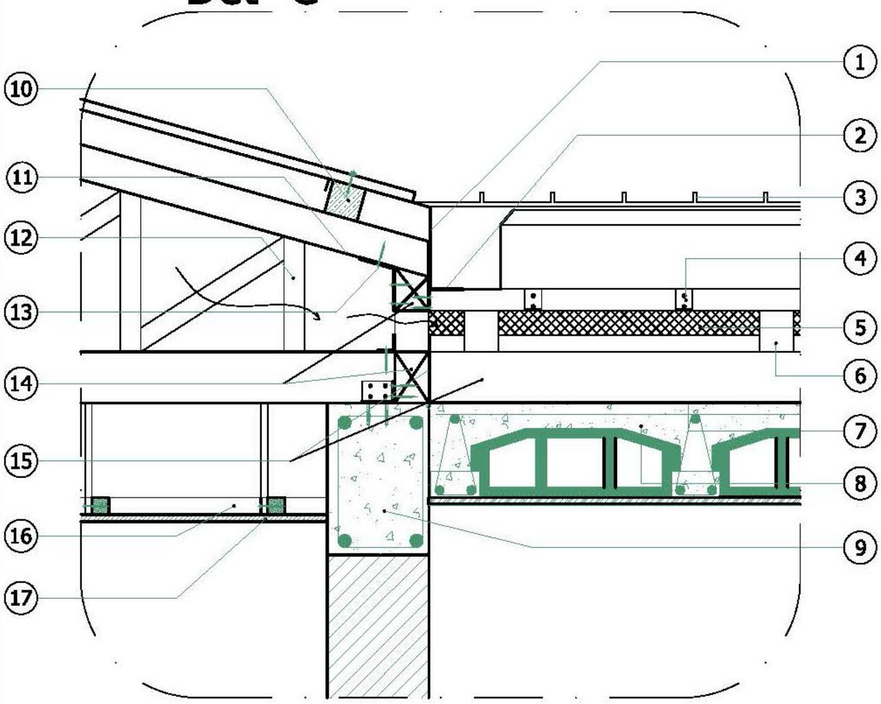


1. 0.7mm corrugated steel EGA sheet
2. Ø6mm screw with rubber for preventing water percolation
3. 5cmx5cm wooden perlin
4. 5cmx5cm minor wooden girder
5. Ø8cm Eucaliptus wooden truss meneber with nail connection
6. 15cm thick wooden main girder
7. 3cmx3cm wooden vertical member to support the grid
8. 5cmx5cm wooden sturcuitural grid to support the ceiling
9. 2cm thick chip wood ceiling
10. Ø8mm screw connection of the grid for ceiling with vertical member
11. 2cm Ceramic floor finish
12. 0.5cm water proofing
13. 3cm cement screed for leveling for ceramic
14. 10cm reinforced conserete
15. 20cm hollow conceret ribbed slab block
16. 2cm cement plastering
17. 0.5cm gypsum plastering as finish
18. Air gap
19. Two coats of bituminous paint on top of gread beam
20. 0.5cm Ampitude roughen grade beam top
21. 5cm nib above floor level required during construction and wet floor
22. 2cm ceramic floor finish
23. 0.5cm ceramic glue
24. 3cm cement screed
25. 25cm C-25 reinforced concrete
26. 0.5cm Damp proofing membrane
27. 5cm C-5 lean concrete below slab
28. 25cm hard rock
29. Foundation soil
30. 10cm scoria(red ash) to level for pavement
31. 3cm terazzo tile
32. Min 150cm from paved surface to top of grade beam
33. 30cm cement stabilized rammed earth load bearing wall
34. 0.25cm water repellant
35. 12cm wide secondary beam
36. 30cmx40cm Periferial beam
37. Reinforced concrete Top tile Beam
38. 1cm thick steel plate connecting wooden structure with Parapet and concrete
39. screw connection with rammed earth providing horizontal stability
40. 20cm thick rammed earth parapet
41. 10cm thick wooden vertical truss member
42. 15cm opening to ventilate the roof
43. 2mm thick Metal Sheet coping
44. Bolt connection b/n inclined member and vertical truss member



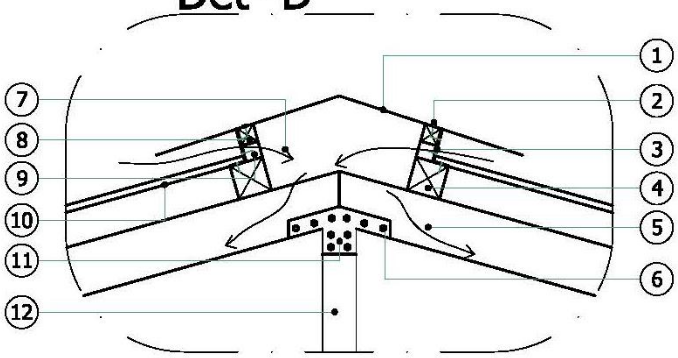
1. 3mm thick steel plate connecting ceiling with embaded wood
2. 15cmx10cm wood embaded in rammed earth to support the window
3. 5mm thick steel plate supporting sunbreaker
4. 10cmx15cm wooden sun breaker
5. 2cm thick white wolega marbel window sill
6. Poly fix ceramic glue
7. 5mm thick single glazed window
8. window seal
9. Bridge setting block
10. setting block to support the window by screw connection with rammed earth
11. 1cm Painted Steel cup
12. 2cmx2cm rectangular steel to support the rammed earth
13. wooden cabinate handel
14. 30cm thick Ribbed slab
15. screw connection of window with floor slab

Det- C



1. 0.7mm thick metal sheet for gutter
2. 5mm thick metal plate supporting gutter
3. 0.7mm corrugated steel EGA sheet
4. 5mm thick metal c/c 50cm plate supporting gutter screwed on horizontal wood
5. insect screen steel wire mesh to protect from animal and insect
6. 10cmx10cm wooden vertical support c/c 100cm
7. 3mm thick waterproofing membrane on top of roof slab
8. 30cm thick ribebed slab
9. 30cmx40cm reinforced concrete structural beam
10. 5cmx5cm wooden perlin
11. 5cmx10cm wooden rafter for roof support
12. Ø6cm eucaliptus tree wooden truss member
13. 5mm thick metal plate conncting wooden truss members
14. horizontal wooden supports to allow opening
15. 3mm thick water proofing membrane to protect wooden member
16. 5cmx5cm wooden sturcuttural grid to support the ceiling
17. 2cm thick chip wood ceiling

Det- D



1. 1mm thick steel sheet copping cover
2. Ø6mm screw and Ø2cm rubber on top for preventing water penetration conneceted with wooden member
3. 5mm thick steel plate to connect wooden members with main purlin
4. 10cmx10cm wooden purlin
5. 15cmx10cm structural wooden truss member
6. Bolt conncection of truss members
7. Air circulation through openning
8. 5cmx5cm wooden member minor purlin to carry steel copping
9. 5cmx5cm wooden member c/c 100cm for ventilation purpose
10. 0.6mm steel EGA sheet for roof covering
11. 5mm thick steel plate connecting truss members
12. 10cm thick wooden vertical truss member

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- Architect's Data, *by Ernst and Peter Neufert*
- Lecture series - Thermal Comfort, *by Gabriele Masera, Politecnico Di Milano, Milan, Italy, 2008.*
- Thermal comfort: Compliance with ASHRAE 55 55-1992, *Credit 7.1 of the LEED Environmental Quality section (1 point)*
- A Design Sequence for Diffuse Day-lighting: 'DAYLIGHTING RULES OF THUMB', by Tiffany Otis Christoph Reinhart, Harvard Graduate School of Design
- Eurocode 8

Useful Internet Links

http://www.earthbuilding.com
http://www.earthbuilding.org.nz
http://www.earthconstruction.com/earth.htm
http://www.rammed-earth.info
http://www.eartharchitecture.org
http://wiki.naturalfrequency.com/
http://www. xploringgreentechnology.com
http://www.eiabc.edu.et

Appendix

List of Symbols and Abbreviations

[A] Area	[m^2]
[As] Area of Steel Section	[mm^2]
[AH] Absolute Humidity	[g/Kg]
[ALT] Solar Altitude Angle	[°]
[AZI] Solar Azimuth Angle	[°]
[b] Breadth	[m]
[be] Effective Section	[mm^2]
[bf] Flange Width	[mm]
[C] Index	[-]
[clo] Unit of clothing insulation	[-]
[DBT] Dry Bulb Temperature	[C°]
[DF] Daylight Factor	[%]
[DPT] Dew Point Temperature	[C°]
[E] Modulus of Elasticity, Steel	[Gpa]
[e] Eccentricity	[mm]
[Ec] Modulus of Elasticity, Concrete	[Gpa]
[Fc] Compressive Strength, Concrete	[Mpa]
[Fct] Tensile Strength, Concrete	[Mpa]
[Fu] Maximum Stress, Steel	[Mpa]
[Fy] Yield Stress, Steel	[Mpa]
[G] Irradiation	[W/m^2]
[Itr] Moment of Inertia about X-axis	[mm^4]
[IL] Illuminance	[Lux]
[Ix] Moment of Inertia about X-axis	[mm^4]
[l] Length	[m]
[RH] Relative Humidity	[%]
[l_{bd}] Longitudinal Reinforcement Length	[mm]
[LAT] Latitude	[°]
[LON] Longitude	[°]
[q_d] Distributed Dead Load	[KN/m^2]
[q_l] Distributed Live Load	[KN/m^2]
[R_S] Surface Resistance	[$m^2.K/W$]
[R_{Si}] Internal Surface Resistance	[$m^2.K/W$]
[R_{So}] Outside Surface Resistance	[$m^2.K/W$]
[r_t] Radius of Gyration about X-axis	[mm]
[S] Distance	[mm]
[S_{trb}] Section Modulus -Bottom	[mm^3]
[S_{trt}] Section Modulus -Top	[mm^3]
[s_x] Section Modulus about X-axis	[mm^3]
[t_c] Thickness of Concrete	[mm]
[T_i] Indoor Temperature	[C°]
[T_o] Outdoor Temperature	[C°]
[T_s] Surface Temperature	[C°]
[U] Heat Transfer Coefficient	[$W/m^2.K$]
[V_n] Shear Stress in Section	[KN]
[WBT] Wet Bulb Temperature	[C°]
[δ] Displacement	[mm]
[λ] Thermal Conductivity	[W/m.K]
[ρ] Concrete to Steel Area Ratio	[-]
[Σ] Summation of	[-]