THE USE OF MODELS IN URBAN SPACE PATTERN ANALYSIS

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ABSTRACT

This paper focuses on the use of urban space pattern analysis methods. Physical developments once located in space influence a set of social and economic activities. These days urban developments are of large scale and very fast, often involving complex issues. Models are usually used to reduce complexities in problem solving exercises. However, in most developing countries models are seldom used in urban space analyses. Here some models appropriate for the analysis of space patterns are introduced. Documentation on physical developments of settlements is very scarce in Ethiopia. Therefore, this paper is intended to strengthen the scarce literature on urban studies. Finally the case study will inspire practicing professionals to make their planning decisions more rational by using similar analytical methods.

INTRODUCTION

The space pattern of a settlement manifests the social and physical conditions which shaped that settlement. Many professions rely on the built environment for the analysis of societies. Social scientists usually limit themselves to descriptions of social events in a backdrop of a physical space while most architects and urban planners describe the physical space on its own emphasizing the visual character alone. The two approaches should merge to understand societies and their settlements.

There is hardly any systematic record of the physical development of settlements in Ethiopia. The historical records available are simple descriptions of towns, villages or separate buildings therein. Most of these records are by foreign travellers. Even modern planned towns lack a thorough record of system-wide space pattern. It is a common practice in Ethiopia to start studies only when commissioned to plan a city or part of it. Urban development is a continuous process so it requires a continuous search to define goals and objectives. Objectives change so do the means to achieve them. The methods to analyze problems should also develop parallel to the complexity of issues.

Most physical planners in developing countries like Ethiopia do not have the opportunity to keep abreast with developments in planning theories, analysis methods and planning techniques. The purpose of this article is to introduce some analytical models in use elsewhere by architects and planners. The analytical models are introduced first and the applicability of one of the models is illustrated by using Addis Ababa as a case study.

BRIEF SURVEY OF URBAN ANALYSIS MODELS

Modern cities are too complex to be studied without frameworks which lend themselves to deal with parts without losing sense of the overall. Since the 19th century Social Darwinists compared the city with living organisms and drew biological analogies which inclined to view the city as organic totality in which the parts functioned as subordinate cells. Sir Patrick Geddes was one of the pioneer urban theorists who introduced a comprehensive relational theory - the **Activity Matrix**, which consisted of **place**, **work** and **folk** as its basic elements **[1]**. Lewis Mumford's seminal treatise " The Culture of Cities" **[2]** represents the peak of the Chigago School of Sociologists who further developed the concepts of Geddes. Later developments of the relational theory include the C.I.A.M's Grid and Ekistics. The C.I.A.M. Grid which was developed by Le Corbusier consisted of four functions of land use: **recreation, working, living and transport**. **Ekistics** which was developed by Constantine Doxiadis consists of **nature** and **shell, society, man** and **networks [3]**.

These attempts were the precursors of the analytical models developed by Chiristopher Alexander and later generation of analytical models **[4,5]**. However, most of these models are too complex to be illustrated here on a paper of this brief nature.

One of the practical methods to analyse urban spaces of a modest size is the Figure - Ground relationship or the Positive - Negative Print method **[6]**. Here buildings and other urban artifacts are mapped against a background of the unbuilt open urban space or vice versa. Using this method the analyst could determine whether the buildings meaningfully define urban open space or not. As an extension to this method of analysis W.C Ellis [7] designated towns and cities as signifying "Structure of Spaces" or " Structure of Solids" based on the relationship of the solid and void spaces contained in their positive - negative prints (Fig. 1). Urban areas with "Structure of Space" configuration have streets which have progressive spatial relationships; they have a starting point, a linear extension and dialated section (called square) at intervals where there is concentration of activities. In urban areas exhibiting "Structure of Solids" streets or the linear open spaces act as simple links between destinations. These streets some knowledge of the psychological disposition of inhabitants regarding the use of spaces. Analyses methods based on space perception are common in architectural and planning studies, so the introduction to this particular method is meant to enhance its usage.

The following Space Syntax model is a relatively new addition to urban space analysis methods. It is believed it is virtually unknown here in Ethiopia. The model is described in detail and a case study using the model is presented later.

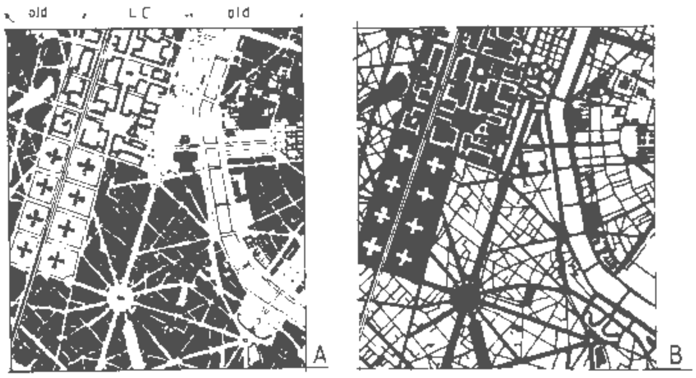


Figure 1 Positive and Negative Prints of Central Paris A. Positive B. Negative
(Note the structure of solids depicted by Le corbusier's proposal in plan voisin)

are different from other open spaces only because of their hard surface. Streets in urban areas with "Structure of Solids' configuration have no sense of enclosedness. Most urban centers which manifest "Structure of spaces" pattern are observed to be those which developed according to social demands. Urban centers, newly established or extensions to existing centers, which are planned on grand- scale ideals lack the spontaneity and intimacy which incremental developments offer. However, planned developments do also produce ambient urban spaces when planning ideal is based on appropriate criteria.

The structure of solids or spaces method is very simple to use but the revelations which emerge from the analysis are strong indicators of space pattern types contained by settlements [Fig 2]. The limitations on the model are that it requires accurate data on building heights and their relative location. It is also assumed that the analyst has

SPACE SYNTAX MODEL

The spatial structure of settlements signifies social values. This is the tenet on which anthropologists base their study of society. The Space Syntax model which was developed by Hillier and Hanson takes cognizance of social forces in the formation of settlement patterns. The authors argue that spatial relationships should be central to urban and architectural discourses. Some researchers have used territorial theory and others, such theories as semantics of natural languages to understand environmental behaviour and syntax of cities [8; 9; 10]. Hillier and Hanson strongly argue that most of these and other architectural theorists fall short of tackling space as a central theme. The authors claim that when most of these theorists deal with space " --- it is at the level of individual space rather than at the level of the system of spatial relationships that constitute the building or settlement" [11, p.3]. They argue that it is the

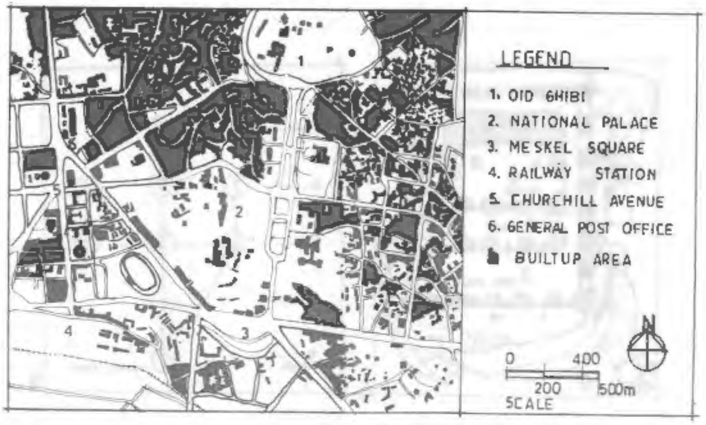


Figure 2 Figure - Ground Map of Central Addis Ababa
(Note the dominance of unstructured open spaces in the City Centre)

ordering of space at various levels which is crucial to the understanding of the morphology of settlements.

The Space Syntax model is built on the basic assumption that order in space originates in social life so the syntax of space is the "relation between generators of settlement forms and social forces" **[11, p.82]**. When people come together they enter into some form of relationship and this relationship forms part of the social force that extends its effect onto the generators of settlement forms. Therefore, the relationship of spaces used by people to reach other spaces in a system (building, village or city) is a useful indicator of the intelligibility and the intensity of use of spaces.

There are three levels of analyses identified by the Space Syntax model.

3.1 The building level using Boundary Graph;
3.2 Small sector of settlements using Convex Space Map; and
3.3 Whole settlements using Axial Map

BOUNDARY GRAPH METHOD

In this method each bounded space is represented by a dot and the link between the spaces is represented by lines (Fig.3). This method is most appropriate to analyse space relationships in buildings. The basic assumption of the model is that buildings transmit social information through their interior space pattern.

To determine the spatial relationship depicted by the organization of rooms proceed as follows.

1. Plan of a building complex is taken
2. Each room is designated with a number or letter,
3. Any space or room is taken and its links are drawn, and
4. Mean Depth and Control Values of the space are calculated (refer Section 3.3 below)

The analyst should interpret the values arrived at in the calculations. In most internal organization of buildings the most central or the least linked space (i.e. high Mean Depth) is the most important room or sacred space while the highly linked space (i.e. having high control value) is the most public space where everyone shonld pass through to reach other spaces.

CONVEX SPACE ANALYSIS

A Convex Space map is a two dimensional representation of open spaces bounded by buildings. It is used to study variations in widths of streets along a linear continuum and location of important public spaces in relation to the buildings which adjoin them. The basic assumption in this method is, if a settlement is planned in response to social needs urban open spaces (i.e. squares and small public spaces not parks) will occur at places where the function of buildings gathers people.
To draw the Convex Space map of an area proceed as follows.

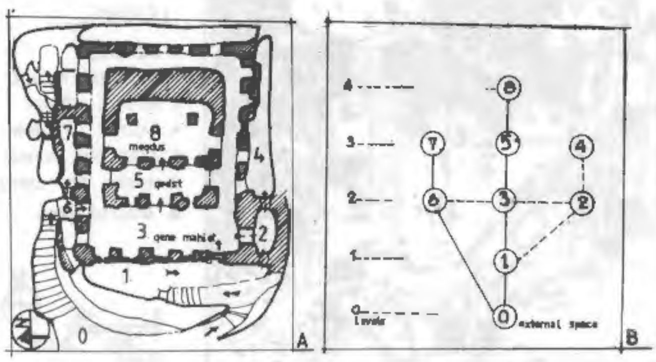


Figure 3 Boundary Graph A. Floor Plan of Adadi Maryam Rock Church B. Space Links of the Church (Note the centremost space (8) is least linked indicating the limitation of accessibility to Meqdus)

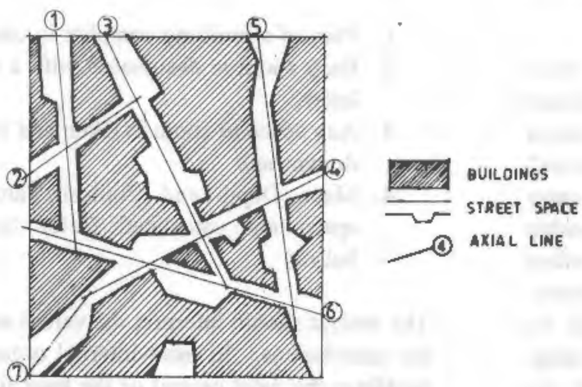


Figure 4 Map of an Area

1. Map of the area to be investi-gated is prepared. The map needs to be large enough to show entrances to buildings; [Fig. 4];
2. The fewest and largest convex spaces to cover the public space system are drwan.
3. A convex space map could be many sided but no straight line from any two points within the convex space should go outside the space (Fig. 5).

The analyst should look for patterns which are most telling from the Convex Space map. Main relationships to be investigated include number of convex spaces per axial line; number of building entrances per convex space, size of convex spaces; the correlation between size of convex spaces and the intensity of their use etc. It is advisable to supplement analysis with actual field survey to arrive at proper interpretation of the results.

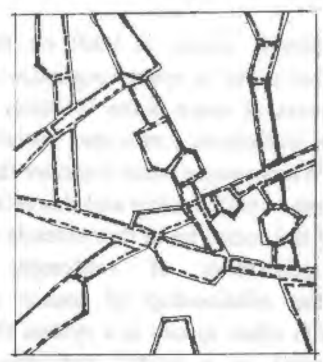


Figure 5 Convex Space Map of the Urban shown in Fig. 4
(Note no line between two points in Convex Space goes outside that space)

AXIAL LINE MAP ANALYSIS

Axial Line map is a one dimension representation of a linear space such as streets. The fewest and the longest straight lines drawn on a map of a settlement along its streets is called its **Axial Map.** From the axial map the **Mean Depth,**(MD)

Control and **Traffic** values of the axial line relative to other axial lines in the system is measured.

MeanDepth, MD, is the ratio of the number of spaces at each level of connection in a system. Low MD indicates a high level of integration (well linkedness) while high values of MD imply segregation. Control refers to the power of a space over movement to reach other spaces. High Control value indicates that higher percentage of people should pass through that particular axial line (a street or part thereof) to reach other spaces. The degree of control needed is a matter for the designer's consideration. Traffic measures the frequency with which axial lines are used in a random collection of trips across a settlement.

Other indicators used in Space Syntax are **integration**, **intelligibility** and **distributedness** or **non-distributedness** of spaces. Integration assesses how well a space is linked with all other spaces; it is inversely proportional to MD. Intelligibility is the relationship between the **Local Property** of a space and the **Global Property** of the same space as a member of the total spatial system. **Distributed** space has more than one route to it while **non-distributed** space has only one access to it. If more spaces in a system are distributed it indicates that there is a tendency towards the diffusion of spatial control while non-distributedness shows the presence of a unitary control.

The dominance of any of the syntactic descriptions does not signify a good settlement structure. An overall correlation of spaces reinforced by a gradation of activities through the street network indicates a good spatial structure.

PRATICAL EXAMPLES TO USE THE MODEL

Given a map of an area (Fig. 4) how to use the Axial line analysis to investigate the spatial properties of the area proceed as follows.

1. The fewest and longest lines are drawn along the street network. (Fig. 4)
2. The axial lines are numbered consecutively.
3. Take any space (i.e. axial line) to check the different properties defined above.

Global Integration

To check how well a space is linked to other spaces take any axial line, say axial line 4. Axial line 4 is linked to 3, 5, 6 and 7. Axial line 3 is linked to 2, 4, and 6; Axial line 5 is linked to space 6; Axial line 6 is linked to space 1, 3 and 5; and Axial line 7 is linked to none except space 4 itself. Starting with the space under consideration draw diagrams that show the levels of links (Fig. 6)

To calculate the **Integration** value of a space list the number of links at each level. Then multiply the number of spaces by the level they are on, add these and divide by the total number of spaces in the system.

E.g. a) Mean Depth (MD) of the system from space 4-

There are 4 links at level 1; and 2 links at level 2. Then MD_4

$$= \frac{(4 \times 1) + (2 \times 2)}{5} = \frac{4+4}{5} = 1.6$$

b) MD of the system from space 5 -

There are 2 links at level 1; 2 link at level 2; 1 link at level 3 and 1 link at level 4.

Then MD_5

$$= \frac{(2 \times 1) + (2 \times 2) + (1 \times 3) + (1x4)}{6}$$

$$= \frac{2 + 2 + 3 + 4}{6} = 1.83$$

Space 4 is more integrated than space 5 in the example.

Global Integration is inversly related to Mean Depth, thus if a system is stretched out it will have higher Mean Depth but lower integration while a more compact system shows a low Mean Depth and a high integration. There are two theoretical limits of integration. The lowest possible integration is when all axial lines are stretched out, one axial line leading to only one axial line, i.e one street leads to only one street, [Fig. 7A]. The highest possible integration occurs when all the spaces are connected to only one space (Fig. 7B); i.e. all streets lead to just one central place; thus all movement should pass through it. By drawing axial lines, then consecutively seleeting spaces and connecting all other spaces in the system to it integration values can be calculated for each space. Integration values of the different space could be

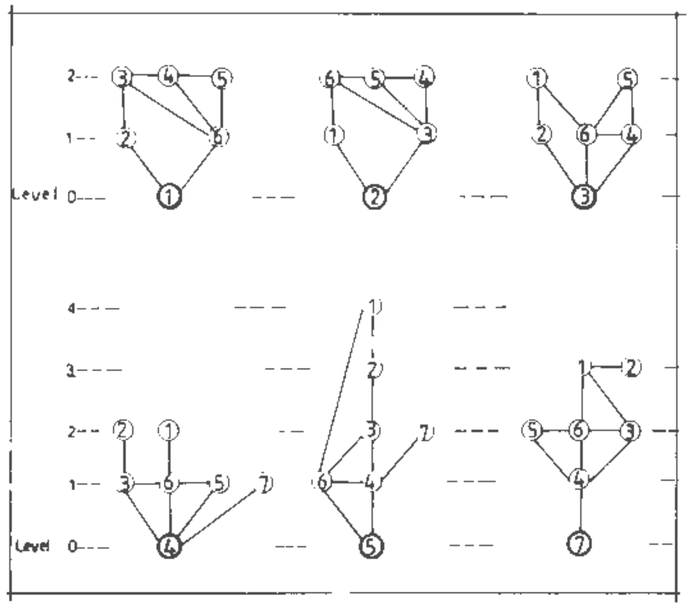


Figure 6 Axial Lines and Levels of Urban Area shown in Fig. 4
5 Starting space 6 - 5 Link between axial spaces 2 Axial space in the system

arranged in decreasing or increasing order thereby indicating where in a settlement the most integrated or the least integrated spaces are located.

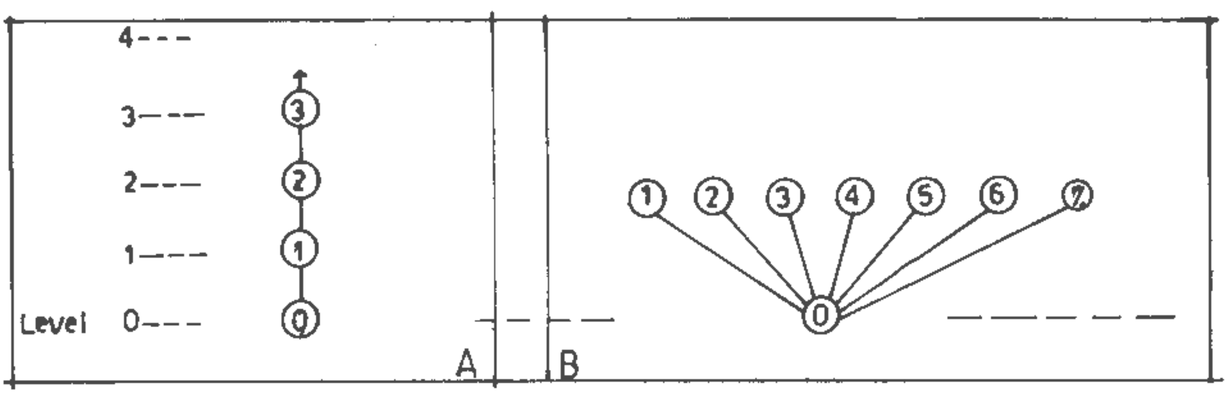


Figure 7 Theoretical Limits of Integration
A. Lowest limit = ∞ B. Highest limit = 1

Local Control

Control assesses the capacity of a space to influence movement through the spatial network. Control measures the number of choices that a space provides to neighbouring spaces. If a space has more neighbour spaces but it constitutes to be the only neighbour for the other spaces then that space has a high Control value. However, if the neighbour spaces have that space as a member of neighbour spaces in the system then that space has low Control.

Control is defined by the equation

$$C = \sum \frac{1}{C_n}$$

Where C_n — the number of connections
C — the control

Eg. a) Consider space 3 in Fig 6. Axial line 3 has 3 neighbour spaces 2, 4 and 6.
- Space 2 has 2 neighbour spaces 1 and 3; Space 4 has 3 neighbour spaces 3, 6, and 5; and Space 6 has 4 neighbour spaces 3, 4, 5 and 1.

Therefore,

$$C_3 = (\frac{1}{2} \text{ for line 2}) + (\frac{1}{3} \text{ for line 4}) + (\frac{1}{4} \text{ for line 6})$$

$$\frac{1}{2} + \frac{1}{3} + \frac{1}{4} = \frac{13}{12} = 1.09$$

b) Take space 6 which has axial lines 1, 3, 4 and 5 as its neighbours (Fig.4)
Space 1 has 2 neighbours; space 3 has 3 neighbours; space 4 has 3 neighbours and space 5 has 2 neighbours.

Therefore

$$C_6 = \left[\frac{1}{2} + \frac{1}{3} + \frac{1}{3} + \frac{1}{2}\right] = \frac{10}{6} = 1.66$$

Space 6 has higher control value than space 3 in the spatial system of the given example.

The control value of all axial lines in a system could be computed and compared with each other manually or by using computer model. It could be deduced from the comparison of control values which space or area of a settlement is acting as an important stepping space before passing to other areas.

DESIGN APPLICATION

The Space Syntax model deals only with physical aspects of spatial connectedness. Interpretation of social forces which bring about the manifested spatial structure rests on the researcher. Spatial organization affects pattern of movement and the use of spaces. The probability of encountering others is raised in spaces which have high control and high integration. The model could be complemented with local surveys to check the correlation of global integration and density of use. If a designer can predict where in a spatial system people were likely to be, facilities could be provided to promote social activities. This type of prediction is readily tackled using Space Syntax model.

The Space Syntax model could be used to investigate sets of urban issues. Where are zones of unused spaces located? Are some areas too strong/or too distributed? If the integration values of a system are high there is no need to readjust the space system; the problem lies somewhere else. But, if urban areas are highly segregated and at the same time less active it is an indication that the street system does not encourage people to go there or to pass through it. It rests on the analyst what to check in a system. The Space Syntax model offers a verifiable method of analysis.

ANALYSIS OF SPACE PATTERNS USING SPACE SYNTAX -- CASE STUDY: ADDIS ABABA

Introduction

The city of Addis Ababa is a little older than a century. The development of the quarters of the City is mainly based on the sefer system (12). The sefer system is an order of settlement where a chieftain and his followers establish a cantonment. The chief's quarter is usually located on a high ground and his followers settle nearby according to their rank. This settlement typology is the formative model of most towns founded by emperors and provincial chieftains in pre-20th century Ethiopia. Addis Ababa shares this legacy as its initial settlement pattern.

Starting from the time of its establishment Addis Ababa was a Capital City, so there were several chiefs residing in it. The Emperor's Ghibi being the centre several chiefs with their retinue settled at different locations far apart from each other. The passage of time and the stability of the empire brought more people to the City. More dwellings were built in each sefer and the gap between the sefers was reduced. However, there were left-over vacant lands between the sefers. The paths which link the different sefers were of a meandering type to adapt to the terrain and the haphazardly developing quarters. These patterns are still visible in the central areas. The present street network of Addis Ababa epitomizes the pattern of streets which developed through a natural path selection method and those which developed through conscious planning (13).

In the following sections the development of the street network and its relation to the societal factors which shaped the City will be examined using Space Syntax model.

ANALYSIS OF SPACE RELATIONSHIP DEVELOPMENTS IN ADDIS ABABA

Three maps representing three periods in the development of Addis Ababa were chosen to illustrate the use of the Space Syntax model in the analysis of space pattern developments in the City. The early stage is represented by the 1912 map, the intermediate period by the 1937 map and the current situation by the 1986 map. This analysis focuses on the street network on a city level; thus the axial line analysis is used for the purpose.

Description of the Method

The longest and fewest straight lines were drawn along the street network of the three maps [maps 1; 2; 3]. Due to the immensity of the area to be dealt with and the large number of streets, the axial lines drawn do not cover all areas and all streets but most areas and most streets in all three maps were represented by axial lines [Fig. 8; 9; 10]. The axial line analysis is scale-free so the length of the axial lines on the different maps have no comparative value.

The different axial lines were taken separately and their Mean Depth and Control value was calculated. The computation could be manual as illustrated earlier or a computer programme specially developed for this purpose could be used. The values of the different measures for the different axial lines are then compared. It is advisable to take either, say, the top most integrated spaces or the least integrated spaces to check which parts of a city are well interconnected and which areas are not. It depends on the analyst where the main emphasis lies in the investigation.

Space Syntax Values for Addis Ababa

In Fig. 8A the lowest 10% Mean Depth (i.e the most integrated axial lines) are concentrated around Arada and the Imperial Ghibi. The area between the Imperial Ghibi and north of it is seen to be more interconnected than any other area of the City by then. The top 25% axial lines which have higher control of movement in the street system are scattered over a large area (Fig.8B). Exception is observed around Arada the-then market area, which is presented here as an area with a relatively higher concentration of high control axial lines.

The 1937 axial map of Addis Ababa (Fig.9A) shows the top 25% most integrated spaces in the City. Well linked streets are located west of the Imperial Ghibi. Unlike the 1912 axial map more integrated streets are observed south of Arada. At that period according to the space pattern manifested by the streets more integrated streets were found around Arada and the Railway Station. The 25% High control axial map of 1937 shows a fair distribution of controling spaces over the entire urban area. A higher concentration of high control axial lines is observed around the Railway Station (Fig.9B).

In the 1986 axial map the 10% top most integrated streets are located mainly south of Arada and westward from the Arada-Railway Station axis (Fig. 10A). In comparison to the newer areas the street network of the older part of the City is less integrated. The control values of the 1986 street network shows the 25% high control axial lines are scattered over the entire urban area with a few exception of concentration around Mexico Square, the Railway Station and Megenagna (Fig.10B).

The correlation of Space Syntax values for the three periods in the development of Addis Ababa using Pearson Correlation Matrix was workedout. The correlation values indicate a minor decrease from 0.56 in 1912 to 0.54 in 1937 and 0.45 in 1986 [14]. This range represents a medium intelligibility in a street system.

Interpretation of Space Syntax Values.

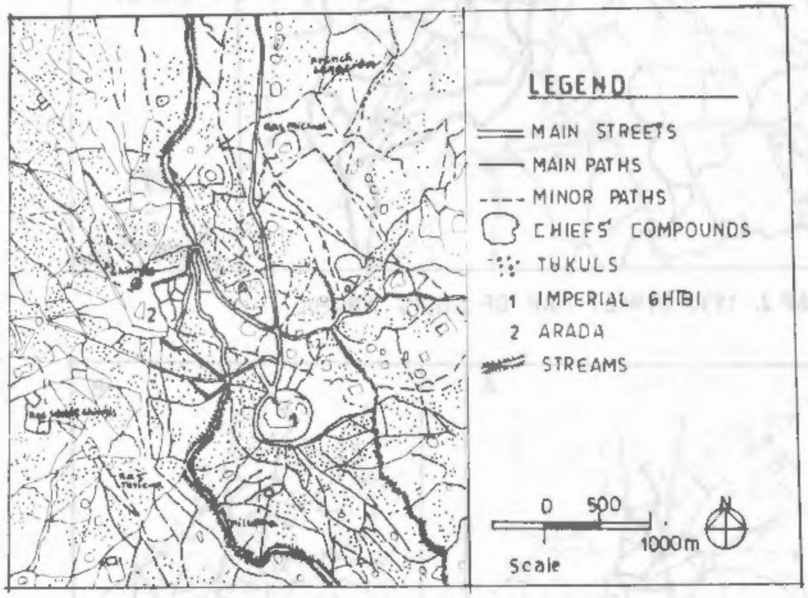
The Space Syntax values of the space pattern of Addis Ababa at three periods were seen in section 4.2.2 above. As stated earlier the Space Syntax model shows only relationships of spaces. It is left to the informed analyst to interpret these relationships. In this section the Space Syntax values for Addis Ababa will be interpreted.

The 1912 axial map showed integrated streets concentrated around Arada and the Imperial Ghibi.

From social and urban history of the City of Addis Ababa, It is known that by 1912 and prior to that the imperial seat and the market at Arada were the hub of the Capital City . The area north of the Imperial Ghibi was developed much earlier than the southern part. What the Space Syntax value revealed was the positive correlation of social activities and the manifested street network.

sefer has higher control over movement between sefers. Even then, the street spaces that head towards the market area and Ghibi are observed to have higher control over random movement through the City.

By 1937 Addis Ababa has grown in terms of space and population. The market area at Arada was the



Map 1. 1912 STREET MAP OF ADDIS ABABA

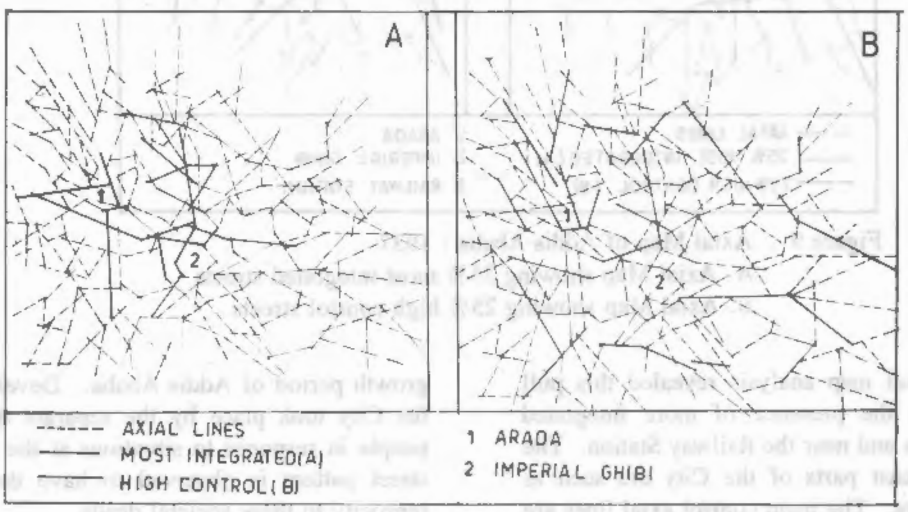
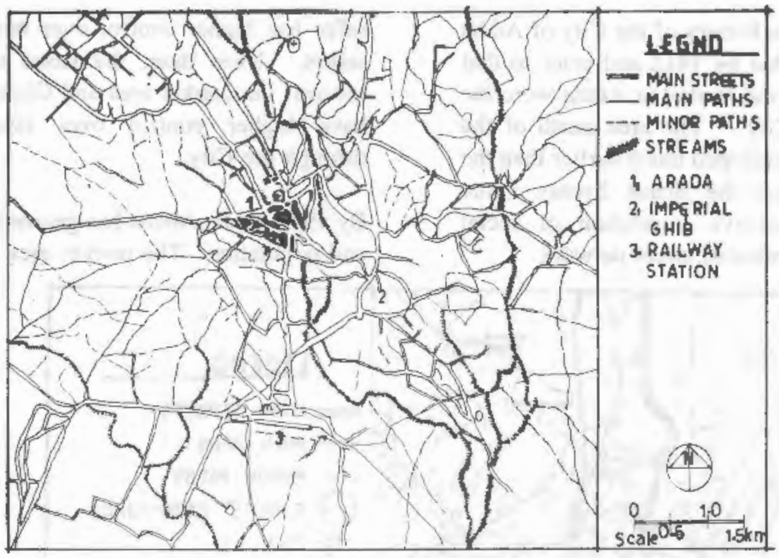


Figure 8 Axial Map of Addis Ababa - 1912
A. Axial Map showing 10% most integrated streets
B. Axial Map showing 25% high control streets

The control values of the streets during the same period show dispersion over a large area. This is in keeping with the scattered sefers where no single

hub of the City. Another important development in the City was the arrival of the railway which pulled development southwards to the relatively plain



MAP 2. 1937 STREET MAP OF ADDIS ABABA

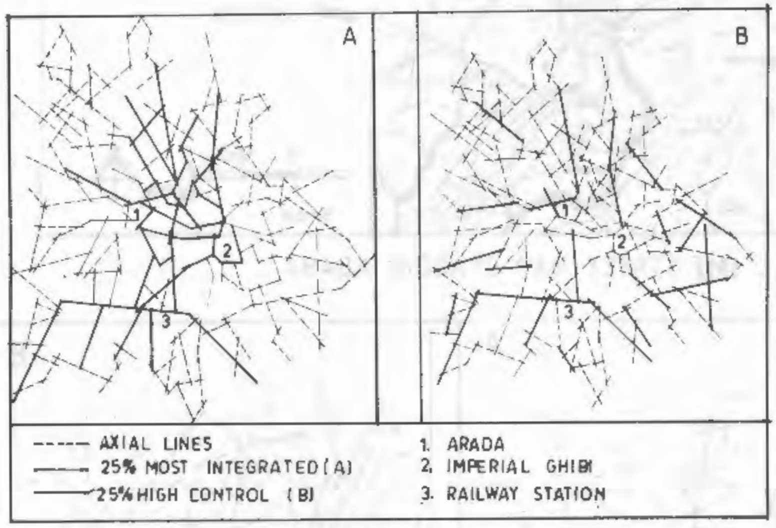
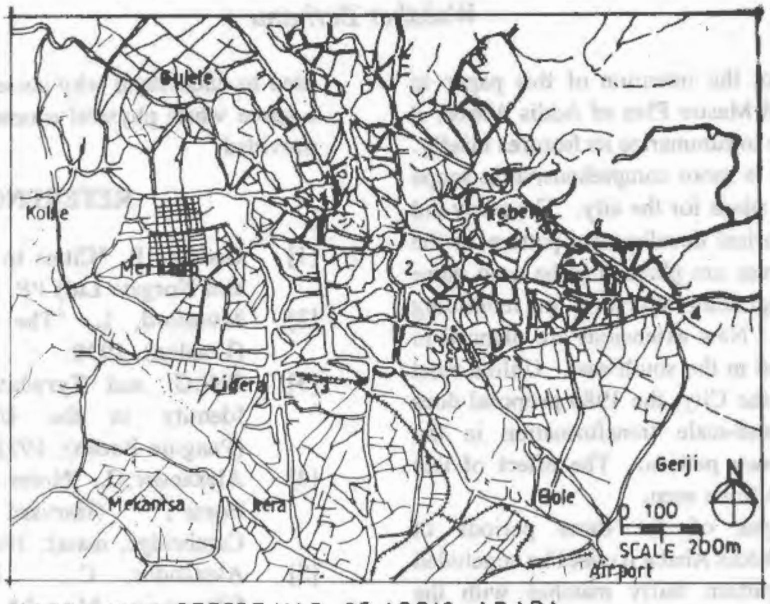


Figure 9 Axial Map of Addis Ababa - 1937
A. Axial Map showing 25% most integrated streets
B. Axial Map showing 25% high control streets

area. The axial map analysis revealed this pull factor through the presence of more integrated streets in Arada and near the Railway Station. The far west and east parts of the City are seen as isolated quarters. The main control axial lines are scattered all over the City as in the 1912 map. This indicates the relative stability in importance of different parts of the City. Once again, although not master-minded by any specific group, the street pattern grew in response to social activity developments in the different parts of Addis Ababa.

The period up to 1937 constitutes the traditional growth period of Addis Ababa. Developments in the City took place by the separate decisions of people in response to situations at the time. The street pattern is observed to have developed in reprocity to these societal deeds.

The 1986 axial map of Addis Ababa represents the epitome of the street network that has evolved over the whole period of the City's existence. In the 50 years period between 1937 and 1986 there were five planning commissions; each plan has left its mark on the development of Addis Ababa. Integration values from the Space Syntax analysis



MAP3. 1986 STREET MAP OF ADDIS ABABA

1. ARADA
2. OLD GHIBI
3. RAILWAY STATION
4. MEGENAGNA

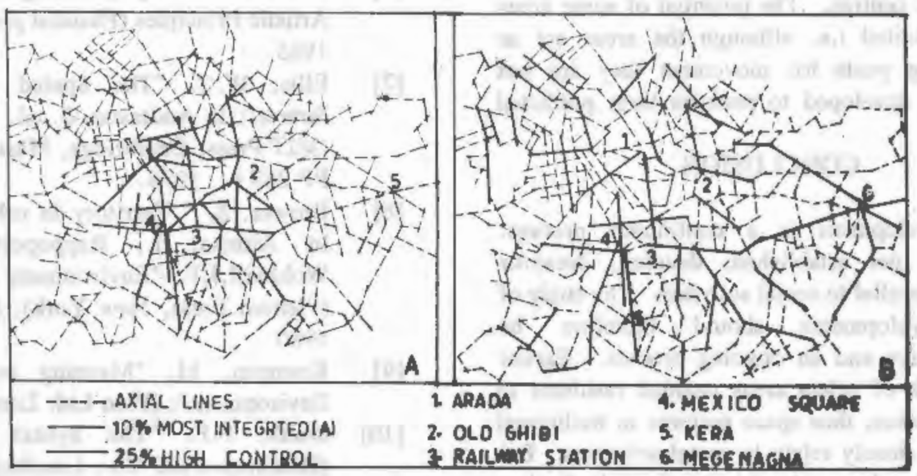


Figure 10 Axial Map of Addis Ababa - 1986
A. Axial Map 10% most integrated streets
B. Axial Map showing 25% high control streets

show inspite of the tremendous growth of the City, highly interconnected areas lie in the near south-west direction from the former city center (Ghibi and Arada). No vivid reason is available for this situation. For example, the shift to the Railway Station in the 1937 map was a logical outcome due to the development of the area around the station. The reason for this situation must be the incoherent growth of the new areas. The control values of the 1986 map further signify this statement. The growth of Addis Ababa in area has not been parallel with the development of activity centres as it used to be before. For example, from the control values the area around Mexico Square and Meganagna are expected to be high activity centres. But the street pattern prediction is not supplemented with actual development to make the areas high activity nodes. Nefas Silk and Bole area are also seen to be well linked to the City street structure. However, only major integrating streets have meaningful urban activities while areas further from the main streets lack services. Merkato is the hub of the City but this area is not highly integrated in the street network. Thus some disparities are observed in the space pattern of Addis Ababa.

Although it is not the intention of this paper to dwell on the 1986 Master Plan of Addis Ababa, it seems appropriate to summarize its features briefly. This Master Plan is more comprehensive in scope than most former plans for the city. The study did consider the historical development pattern of the City. Central Areas are planned to be used more efficiently by upgrading structures or rebuilding dilapidated areas. New extensions are planned in the south-west and in the south-east. Unlike most former plans for the City, the 1986 proposal does not envisage grand-scale transformation in the existing urban space pattern. The effect of this master plan is yet to be seen.

From the analysis of the three periods of developments of Addis Ababa it could be concluded that the street pattern fairly matches with the societal forces which arose at the times. However, a diffusion of spatial control is observed where areas have become undifferentiated and with no strong focal centres. The potential of some areas is not exploited i.e. although the areas act as commanding posts for movement they are not sufficiently developed to perform their predicted centerness.

CONCLUSION

Urban development is a continuous process. Settlements get established, develop, decay/or transform parallel to social activities. The study of urban developments should therefore be comprehensive and an ongoing process. Earlier slow growth of urban areas enabled residents to rectify mistakes; thus space patterns in traditional settlements closely relate to social activities. But where fast development exists it is the task of urban planners to have a foresight about the result of current planning decisions. Thus the use of appropriate models to analyse urban space patterns and later on to synthesise results is of paramount importance.

The Space Syntax model introduced here greatly facilitates the understanding of space relationships. Physical accessibility is one of the conditions which enables people to be in a place. The level of spatial inter-connectedness of a system indicates where people would be in the space system. Since this aspect is readily dealt with by Space Syntax, the model could be used to test development proposals prior to implementation; or, it could be used to identify urban areas of high potential for redevelopment; or conversely the method could be used to understand why society decides not to use a space while physical accessibility is sufficiently provided.

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