An application of universal distance using Space Syntax analysis

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Abstract

Space Syntax is a spatial analysis technique that is mainly handled using the Axman software which analyses the axial model of a given spatial system. The Conventional Axial Model (CAM) is constituted of the fewest and longest set of axial lines of visibility and accessibility, and which cover all convex spaces in a spatial system. Despite the huge number of variables that can be produced by the analysis from a single spatial model analysis, the CAM's basic spatial property input is the number of intersections between each line and each other line in the system.

The concept of Universal Distance, defined as the average distance of each segment in a spatial system to every other segment, was first proposed by Hillier (1996) as a future development of the CAM of Space Syntax. A model to measure this Universal Distance has been developed by the Authors (Salheen and Forsyth, 2001). The model that accounts for this concept is constituted of equal segments replacing the axial lines and which are also analysed according to their connectivity to each other.

This paper explains on the way to build the Metric Axial Model (MAM) that counts for distance and which, if applied, represents a measure of universal distance. It includes an application of the proposed model and a comparison between the findings of both the CAM and the MAM analysis on five different districts within Cairo, Egypt. The aspects of comparison are the visual and the numerical analysis of the output of each of the five districts. The paper also links the MAM model to the concept of sustainability of urban form.

Keywords
Space syntax, universal distance,
spatial analysis, Cairo

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1. Introduction

The basic factor that Space Syntax analysis relies on is the accessibility of each space from all other spaces in the system. Accessibility of a space is measured by "calculating shortest journey routes between each link [or a space] and all of the others in the network (defining 'shortest' in terms of fewest changes in direction)" (Hillier, 1998: 36). Configurational model and analysis are used to calculate the measure of accessibility.

The concept of universal distance was first proposed by Hillier (1996) as a future development of the Conventional Axial Model (CAM) of Space Syntax. The universal distance of a node in a spatial system is the sum of all specific distances from that node to all others (Hillier, 1996). More recently Hillier (1999) argues that there is a relationship between universal distance represented by the measure of metric integration, which is defined as the degree that each space is metrically accessible from all others, and the location of urban centres. However, both of the above propositions and arguments were based on a hypothetical model and not a real urban setting.

This paper reports on a comparative application of an axial model that successfully measures metric integration and thus represents the concept of universal distance (Salheen and Forsyth, 2001). The Metric Axial Model (MAM) is constructed using the CAM of Space Syntax. Both of these two models are applied on five districts in Cairo. A third model was suggested by Hillier (1996) that is the result of the superimposition of the two models, CAM and MAM. However, work is still in progress on this third model and the findings will be reported in a future publication.

Although Hillier and Hanson (1984) argue that the Space Syntax model accounts for more than the direct spatial properties, such as inherited social and cultural properties, this paper focuses mainly on the graphical, and thus the mathematical basis of the analysis. The details of the construction of the model have been reported previously (Salheen and Forsyth, 2001), therefore this paper will focus on the application of the new model.

A brief background of the five case studies is offered. The results of the application of the two models in the five case studies are presented both visually and numerically. Visually, the distribution of integration in the maps is described and compared in relation to the topology and some aspects of functionality in each district. Numerically, the measures of integration and other measures are compared between the two models and between the five case studies. Finally the paper discusses the practical implications of the new model and suggests a link between it and sustainability in cities which aims at reducing travel distances. Some functional implications of the new model are discussed but which need further verification.

2. Background of the Case Study Areas

The spatial structures used in the analysis, as case study areas, are five districts in Cairo as seen in Figure 1. The following is a brief background of each one of them ordered according to the date when each district was significantly expanding, in other words when its main urban pattern was laid down.

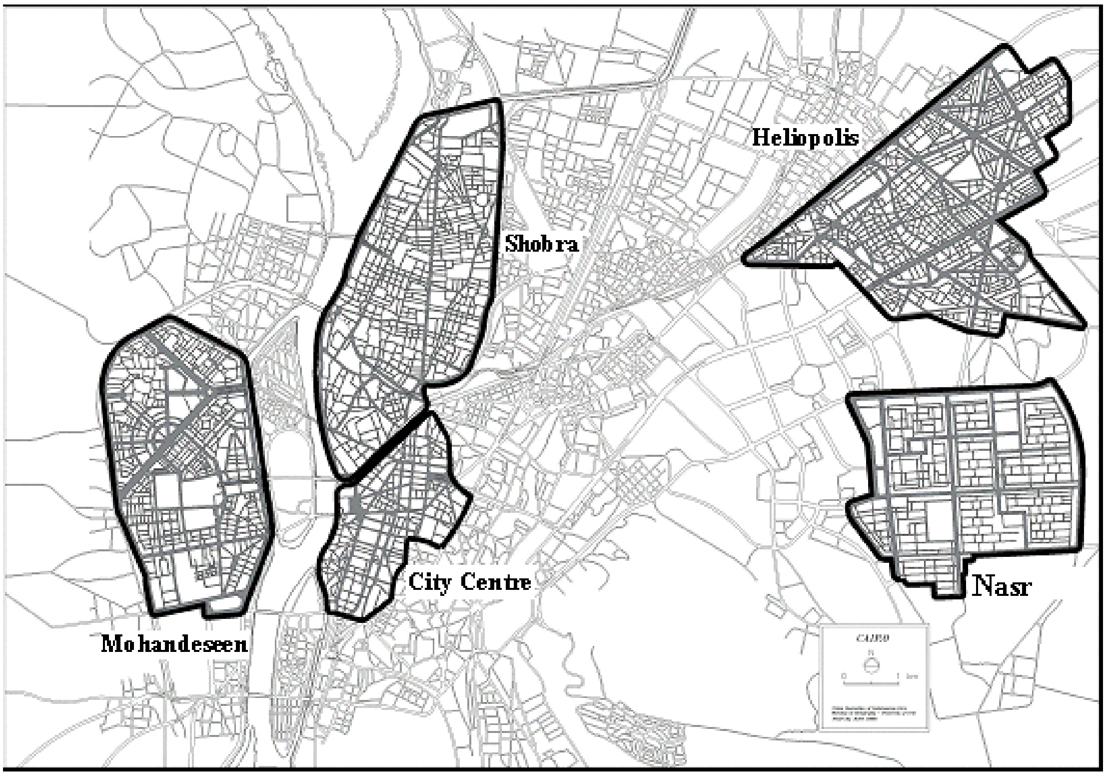


Figure 1: Map of Cairo at the beginning of the 1990s showing the location and street pattern of the five case studies

Cairo City Centre (1860s): It was planned and built in the second half of the nineteenth century. The aim was to imitate Paris, for whose street patterns and architectural styles Khedive Ismael, ruler of Egypt, had a great fondness. This provides a street pattern of mainly radial lines within the principal grid with secondary streets linking them laterally. Significant intersections, with statues at their centre give the character of the city centre. Its borders are very distinct on three sides: the River Nile to the west; Ramsis Street to the north that was originally the El-Ismailia canal; and Fatimid Cairo to the east. Only to the south do its boundaries seem a little loose and this encouraged several activities to expand towards the south.

Shobra (1890s): Shobra street was initially planned to link the Northern palace of Mohamed Ali Pasha – the ruler of Egypt 1805-1848 – to Cairo. Shobra Street at that time was passing through agricultural land which was later divided into individual plots each allocated either to the elite members of the Royal Family or the Nobles. As the demand for residential land increased and as those elite moved to other areas like El-Zamalek Island, Shobra Street served as the main street and many perpendiculars were laid according to the original division between the agricultural basins. However, Shobra district is surrounded by borders, water features to the North and West and railways to the South and East, which stops its urban fabric from extending in all directions apart from various links such as tunnels and bridges. Helioplois (1910s): Although Heliopolis is part of the Eastern Northern extension axis of Cairo, it was developed separated from its surrounding areas and the main urban fabric of Cairo (Moselhy, 1988). It was planned as a garden satellite town and linked to the city centre through a Metro line. As a result of that plan it is designed to be self sufficient in respect to urban services. The urban fabric of Heliopolis could be described as main radial streets with their intersections as main squares or roundabouts. The district is restricted from its Northern and Western sides by the Gesr El-Suez street, which was a canal when it was first planned. To the south it is restricted by military locations and Cairo airport partially restricts it from the Eastern side.

Mohandeseen and Giza (1950s): Unlike the rapid extensions that occurred on the Eastern side of the Nile, the Western side experienced a slower rate of urban expansion. Growth started to accelerate when many bridges were built to link it to the main body of Cairo. However, the location of the railway to the North and West has greatly restricted the district to extending beyond it. Even when an extension to the west of the railway occurs it is in a scattered rural form. The slow expansion rate that this side of the Nile experienced caused it have a mix of urban grids. It has orthogonal, concentric and irregular grid patterns with no one dominant over the others.

Nasr City (1960s): This is the most recently built district of all the five case studies included in this paper. It was planned on a strict orthogonal grid pattern. However, several main streets divided the district into various local communities with designated local centres. The alignment of the internal roads within each community followed a looping system and a hierarchical road order. Nasr City is restricted from the North, West and part of the South by military locations. The extension to the East and the South-eastern direction is available, which has happened over later stage.

3. Findings

All axial models were processed and analysed. Main stream Space Syntax analysis presents the findings in two main ways: the visual interpretation of the processed map; and the numerical outputs in the shape of tables of various syntactical variables. The findings from applying the CAM and the MAM in the current study are presented in both ways.

3.1 Visual Analysis

The integration maps, which are the main tools for the visual analysis, are shown in Figures (2-6). In these maps, the more black the segment the more integrated it is and the more grey the segment the more segregated it is. The visual analysis presents the findings of each model and then moves to compare the two models.

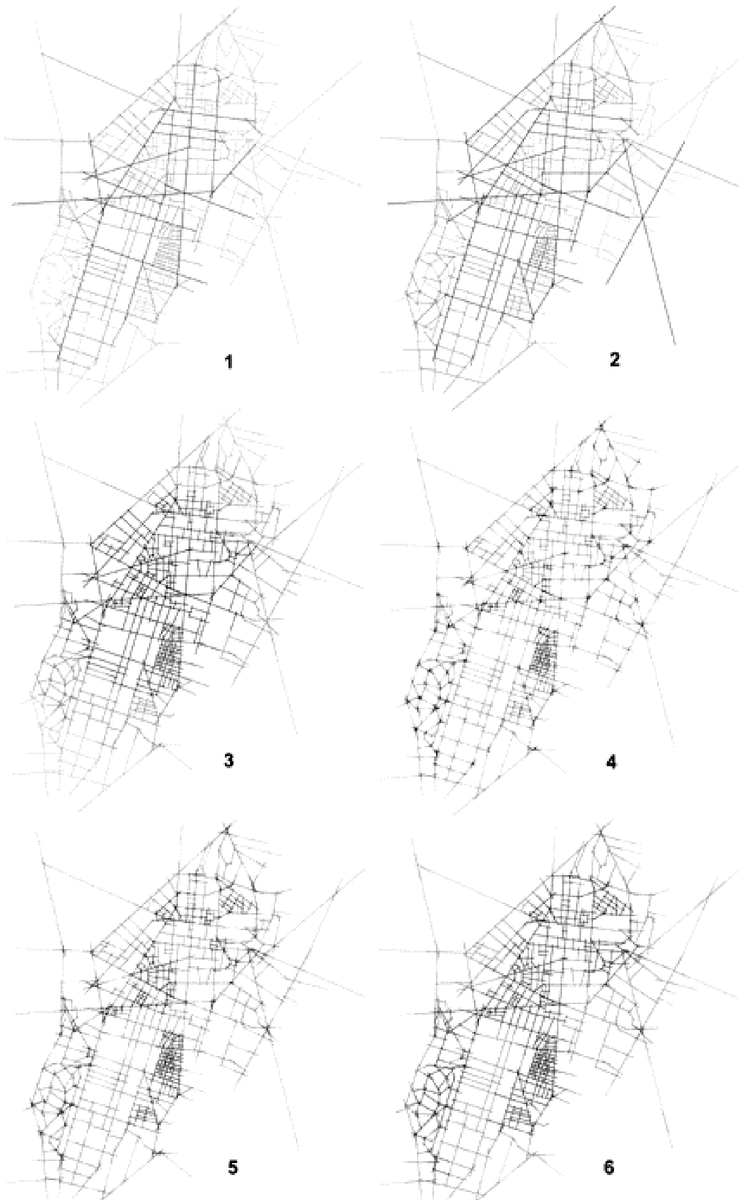


Figure 2: Integration maps of Cairo City Centre

Note: 1) CAM global integration; 2) CAM local integration (r=3); 3) MAM global integration; 4) MAM local integration (r=10); 5) MAM local integration (r=20); 6) MAM local integration (r=50)

Figure 3: Integration maps of Shobra

Note: 1) CAM global integration; 2) CAM local integration (r=3); 3) MAM global integration; 4) MAM local integration (r=10); 5) MAM local integration (r=20); 6) MAM loca integration (r=50)

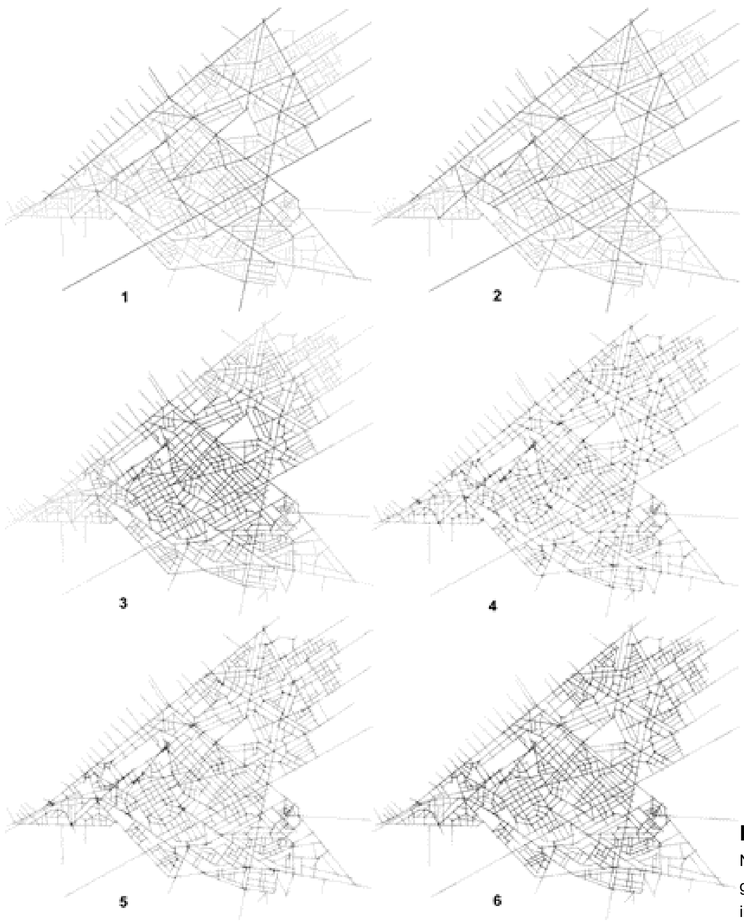


Figure 4: Integration maps of Heliopolis

Note: 1) CAM global integration; 2) CAM local integration (r=3); 3) MAM global integration; 4) MAM local integration (r=10); 5) MAM local integration (r=20); 6) MAM local integration (r=50).

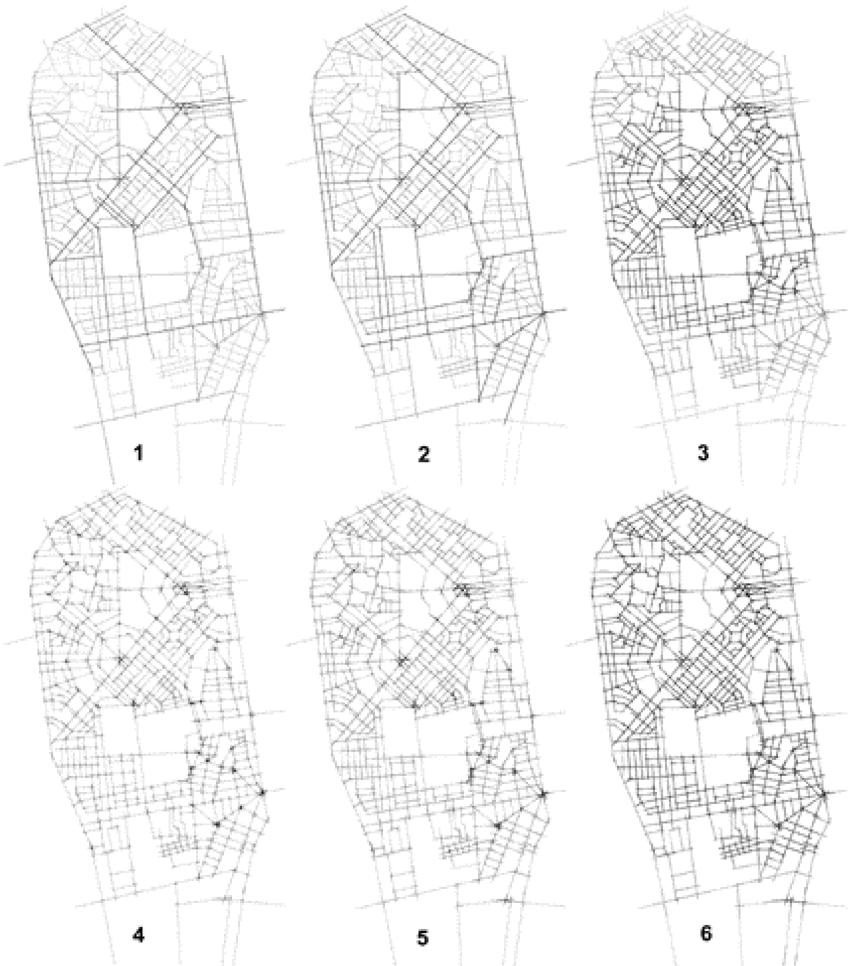


Figure 5: Integration maps of Mohandeseen

Note: 1) CAM global integration; 2) CAM local integration (r=3); 3) MAM global integration; 4) MAM local integration (r=10); 5) MAM local integration (r=20); 6) MAM local integration (r=50).

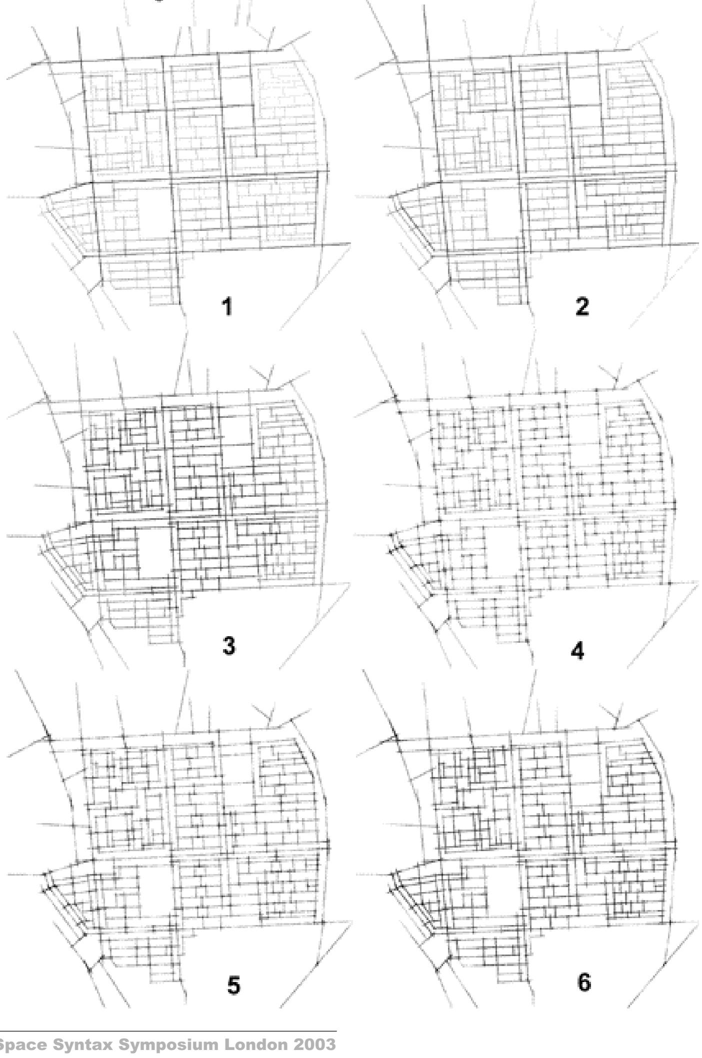


Figure 6: Integration maps of Nasr City

Note: 1) CAM global integration; **2)** CAM local integration (r=3); **3)** MAM global integration; **4)** MAM local integration (r=10); **5)** MAM local integration (r=20); **6)** MAM local integration (r=50)

CAM: In all five districts the global integration of the CAM picked out the most important street but in identifying its following streets some differences appeared between three types of grids. In the cases of clear grid patterns with clear boundaries from surrounding districts, which are the cases of Heliopolis and Nasr City, the analysis almost completely picked out the same hierarchy of roads defined by the traffic and transportation map used in the analysis. In the case where a mixed road pattern is used, in Mohandessen and City Centre, the analysis picked some of the important lines but their order was influenced by the density of lines in some parts of the system over the others, with that clearly demonstrated more in City Centre than Mohandessen. Finally Shobra Street dominated the spatial analysis of the district which is named after it, to the degree that it is difficult to point any other important street.

In Heliopolis and Nasr City, the globally segregated areas appear where the permeability of the original grid is interrupted, where in the other three districts the globally segregated areas appear where the grid pattern changes from the strict geometrical to the deformed grid.

The local integration maps of the CAM of the five districts did not reveal any new observations from what the global integration has revealed already. The local integration has picked out almost the same streets already identified by the global integration. An explanation of that might be in the existence of long streets through most of the five districts. These streets raise the average local integration of each district to be close to the global. The longer these lines in crossing each district the more they raise the local integration. For example, see the difference between the variation between the global and local in Shobra, Nasr City and Heliopolis where long streets cross the whole district and that variation in the other three districts where shorter streets exist. Another observation is that segregated areas at the global level continue to be segregated on the local level.

MAM: The global integration of the MAM, turned up as a hotspot in the metric centre of each district and which decreases in importance as it moves away from that centre. A closer look at this hotspot in each district reveals the same grouping of districts as in the CAM but in an opposite way. These hotspots tend to match the centre of activity in mature districts, City Centre and Shobra, and others with mixed grid pattern like El-Mohandeseen. In the districts with a strict grid pattern, although the global integration of MAM shows their main activity centres, because they are developed mainly on a corridor-like centre with private setbacks between the buildings and the public space their centres are not yet in the shape of clustering areas. However, the MAM global integration maps have all lacked a clear definition of any second order centres as they presented one spectrum of integration from the most integrated segments at the metric centre and the most segregated segments towards the edges of the spatial system.

The local Integration of the MAM reveals a new way of looking at integration. Instead of integrated streets, it shows local metric integration poles represented in the shape of hotspots or centres of activity. At lower integration radii (up to radius 20), these hotspots are mainly individual intersections. At integration at radii higher than 20, nearby active intersections cluster to create areas or nodes of metric centrality. The location of these nodes is quite remarkable, as in all the five cases these nodes do not coincide with the global integration of the MAM. Their location is not also governed by the global integration in respect to globally segregated areas which tend to have their own local centres which sometimes compete with centres located in globally integrated areas such as in the City Centre. A bias is also spotted in the local integration analysis towards areas with shorter block length such as that seen in the case of the City Centre. The short block length into Al-Gizira Al-Gidida area attracts the local integration of the whole district (mathematically speaking) and just at radius 75 when other areas start to show some significance.

The comparison between the findings of CAM and MAM is better presented in the shape of a table and according to the four main aspects of the integration maps which are integrated and segregated areas both globally and locally. Table 1 summarises the main points of difference between the two models according to the five case studies involved in this paper.

Table 1: Differences between MAM and CAM based on visual analysis of integration

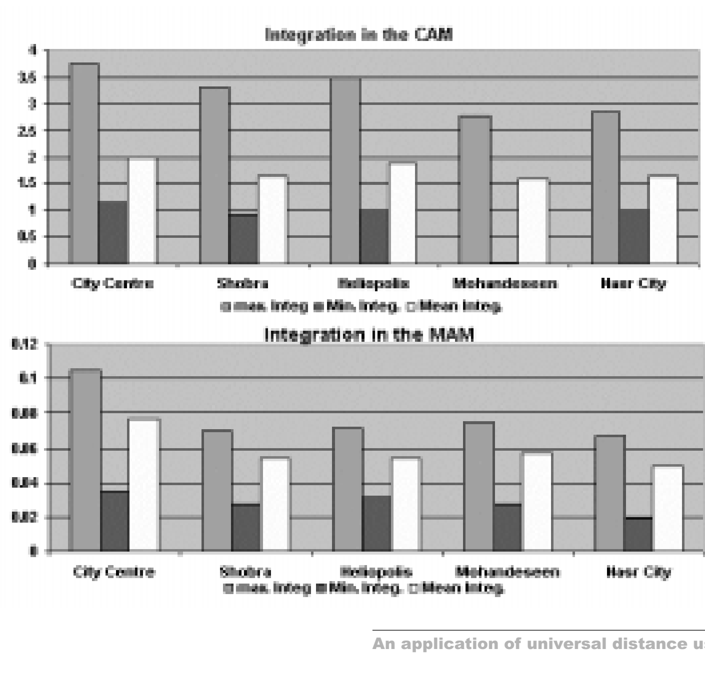
	CAM	MAM
Most globally integrated lines	Major *street network* in the area, clearer in rigid geometrical districts than in districts with irregular grids.	Central *area*, which might develop into centre of activity if other urban features like setbacks and building density support that notion
Most globally segregated lines	Where the permeability of the rigid grid is interrupted or where the grid pattern changes from rigid to irregular grids and usually at the edges.	Strictly at the far edges from the metric centre.
Most locally integrated lines	The same lines highlighted in the global integration with different order.	Nodes at intersections at lower radii. Various hotspots where short block length exists at higher radii. They are different from the globally integrated centre. Globally segregated areas develop their own local nodes and hotspots.
Most locally segregated lines	The same as those lines globally segregated.	Where the length of blocks is longer than elsewhere.

However, there was an observation which might need further research to explore its significance. This observation is mainly sparked by the difference in the local integration maps. In MAM, the map picked out a local market area in the case study of the City Centre with its high-density grid pattern as being the most integrated even more than the heart of the city centre. That points to the origin of movement in each area. For example, whereas most of the movement in this local market area is locally originated, most of the movement in the city centre core is globally originated.

3.2 Numerical Analysis

The usual tradition of Space Syntax in the numerical analysis is to compare the syntactical measures with field observations to establish a link with real behavioural/social data. This helps in finding out if the model can successfully predict social behaviour or not. In this study, collecting field observation data for the case study areas was not possible due to limited research funds. Thus the numerical analysis is focused on comparing the measures of the two models in all five case study areas and aims quantitatively at seeing how the two models differ from each other and how each one gives different results for different grid patterns. This is expected to be interesting in obtaining an insight into the mathematical/graphical behaviour of each model and each urban grid involved in the analysis.

Besides the known measures of space syntax, the Average Length (AL) of all the axial lines in the system was found to be an important measure which links the CAM to the MAM. It is defined as 'the length unit used in MAM multiplied by the ratio between the number of lines in MAM to that in CAM'. Assuming that all buildings in the urban system have an average facade length, the AL is the reverse of the measure of the "axial articulation" (Hillier and Hanson, 1984: 99), which is the ratio of the number of axial lines to that of buildings.



In Table 2 several variables are included for each case study area (see also Figure 7). The measures presented in the table are a selection of wider set of measures which has been tested between the two models and the five case studies. For example, the area ratio is included to test if the size of the case study has a clear influence on the results of any one of the two models. Because of that it was presented relative to the area of the smaller district that is the City Centre.

Figure 7: Numerical measures in relation to the five districts and the two axial models

Table 2: Numerical meatures in relation to the five districts and the two axial models

District	model	# lines	Area ratio	Max. Integ.	Min.Integ.	Mean integ.	Mean Depth	Mean Connec.	AL
City centre	CAM	396	1.00	3.7489	1.1535	1.9772	3.5842	5.2609	267.8
	MAM	10604		0.1044	0.0356	0.0764	105.3556	2.2527	
Shobra	CAM	540	2.34	3.3116	0.9292	1.6314	3.9591	4.5539	322.5
	MAM	17416		0.0699	0.0272	0.0534	166.5087	2.2581	
Heliopolis	CAM	658	2.62	3.4815	1.0082	1.8923	3.9468	4.9362	343.5
	MAM	22604		0.0717	0.0306	0.0541	166.7633	2.1952	
Mohandessen	CAM	463	2.16	2.7791	0.0160	1.5918	4.2570	4.8553	333.7
	MAM	15448		0.0742	0.0275	0.0565	154.7273	2.2169	
Nasr City	CAM	249	2.10	2.8620	1.0002	1.6378	3.8795	4.2731	530.2
	MAM	13202		0.0672	0.0194	0.0491	167.2094	2.1368	

A close look at the measures shows the following observations:

1) City Centre area enjoys the shortest AL of axial lines with 267.8 m/seg. It has the highest mean integration in both CAM and MAM. It is significantly the shallowest, or least in depth, spatial system of them all.

2) Nasr City with its orthogonal grid, which is not completely permeable, has the highest AL with 530.m/seg, that is much more than all other spatial systems. Although it is second to the smallest (area wise) district it was the deepest metrically (MAM) and the least metrically integrated (MAM) which might signify its vehicle oriented planning.

3) The other three districts have close AL to each other and are not extremists in any respect apart from Mohandeseen that came out as the deepest spatial system syntactically (CAM) which might have resulted from its unconnected mixture of grids.

4. Usefulness of Universal Distance (MAM): a Link to Sustainability

So what implications this might have in practice? The study links the analytical results of MAM to the international growing need for a more sustainable development. One of the main categories of sustainability indictors in cities is transportation (Newman and Kenworthy, 1999). The most important sustainability indicators within transportation is the reduction of car use and minimising travel distances in general. This reduction could be achieved by offering alternative transit modes and can also be reached by minimising travel distances in general. This also has positive impacts on the social and economic environment in general such as saving travel time for other activities thus enhancing the social and economic environments.

In order to understand the implications of the metric integration, a differentiation between young and mature cities is needed. Newman and Kenworthy (1999: 15-16) cite some differences between these two types of cities based on an analogy with an ecosystem. The major differences between the two cities are that the mature city has main five features that are not yet developed in the young city, which are:

1) High-energy efficiency and waste materials are recycled.
2) Enhanced form of functions, quantity and quality, with complex established links between them and users.
3) Compact spatial system with complex spatial relationships.
4) Diverse community constitution, complex and multiple interrelationships.
5) System can withstand many forces and is generally stable and resources are better facilitated and managed.

Newman and Kenworthy (1999) have shown that the most recent attitudes towards re-centralisation in cities are towards the concentration in the central business district and other inner locations in the form of a series of nodes which Willoughby (1994) calls the development of “local millieux”. There is an opposite argument which says that once commuters get into their cars, driving for one mile will not be that different from driving for a mile an half. However, urban planning and design should always target reducing the preliminary expected travel distances to correspond to the generally accepted recommendation of sustainability. In that respect, MAM presents an efficient, rapid and cheap method to identify potential locations for metrically central nodes (Salheen and Forsyth, 2001).

Because there are few applications of the MAM, it will require more work to confirm its usefulness. However, several practical applications of this model lie in its simple metric basis and in linking it to the concept of sustainability in cities which always aim at minimising travel distance. Among these applications are:

First, the segment which is the most metrically integrated is reached by the shortest trip distance from all other segments in the system, therefore it is suitable for a destination which is targeted by all parts of the system. However, a compromise should be calculated for various alternatives having similar targeted destinations, thus seeking the same location, and should consider the time frequency of being targeted.

Second, segments or areas globally segregated should be accommodated by the more private functions such as housing, so that they become the target only of their tenants and receive fewer visitors.

Third, local integration at a certain radius, which represent a certain metric distance equal to the radius multiplied by the segment length, could be seen as an indication of the total number of segments that could be reached from each segment in the system with that metric distance. In other words it is a measure of the potentiality of each segment to be a destination at certain distance thresholds.

Fourth, in young cities local Integration at various radii refers to nodes which are reached by more segments in catchment areas of various distances. Thus locating community services can be done according to accurate walking distances. It can be used to test designed location or the opposite in identifying best locations.

Fifth, in mature cities local integration picks out nodes which are suitable for future development as local service centres and in diagnosing problems such as the emergence of unplanned commercial and other types of activities to compensate for under-serviced locations.

Beside the above implications of applying the MAM using the usual Space Syntax analysis and which reflects on issues of minimising travel distance and sustainability, reversing the application could also be useful. The effective distance of an existing service is currently represented by a circle on a plan with its radius equal to the acceptable travel distance of the service. This does not represent the real travel distance because of the geometric complexity of urban structures. The MAM can be employed using specific functions in Axman like 'point depth', which calculates how far, syntactically, all other lines in the system are from a single line. That would help in determining the metric distance from a service centre or other destinations (Salheen and Forsyth, 2001).

5. Conclusion

Recent publications and developments in the field of Space Syntax (Hillier, 1996) point to the importance of modelling the urban form in a standardised way which recognises distance. Also metric integration is gaining more significance in some particular aspects, like centres allocation (Hillier, 1999b). In this paper the metric axial model (MAM) was applied together with the Conventional Axial Model (CAM) on five districts in Cairo. It was found that each model provides a useful analysis technique in a way that they complement and do not replace each other.

The most important result in the MAM is that it highlights the difference in space use according to its location on a single street, solving the 'length problem' that currently exists in the CAM. So a segment of a line which falls on an intersection was shown to be more integrated than the other segments on the same line but in an intermediate location. This shows the relevance of metric integration to location of centres of activity in the urban environment as it moved from picking out streets to areas or nodes.

The use of both models in five different cases helped to pin down some key features of the geometry of the urban grid, such as the properties of the orthogonal grid, or the way it develops over time, such as the dominance of Shobra Street. In some cases, as in the City Centre, a relationship between the function and numerical variables such as the AL was found. Linking the findings of the new model to one indicator of sustainability gave fruitful results in the practical implications of the new model especially considering it's low cost and fast processing time.

As this is the first comparative application of this technique in Space Syntax, some points for further investigation and development have arisen including the importance of investigating the statistical correlation between real environment and outcome values from both CAM and MAM. Space Syntax research used to test the statistical correlation between pedestrian movement and the analysis output; however few have considered studying the origin of this movement whether locally or globally generated and which was raised in one case study in the application of the MAM in this paper. Another way of doing this correlation with a real environment might be by using a comprehensive field observation of urban centres and comparing their locations on the map with various local integration maps of MAM.

References

Brotchie, J., Batty, M., Blakely, E. and Hall, P., 1995, *Cities in Competition: Productive and Sustainable Cities for the 21st Century*, Cheshire, Melbourne

Hillier, B., 1999, "Centrality as a Process: accounting for attraction inequalities in deformed grids", *Urban Design International*, 4, 3&4, pp. 107-127

Hillier, B., 1998, "From Research to Design: Re-engineering the space of Trafalgar square", *Urban Design Quarterly*, 68, pp. 35-37

Hillier, B., 1996, *Space is the Machine*, Cambridge, Cambridge University Press

Hillier, B. and Hanson, J., 1984, *The social logic of space*, Cambridge, Cambridge University Press

Moselhy, F. M., 1988, *Tatawor al-Asemah al-Masriah wa al-Qahira al-Kobra,* (Evolution of the Egyptian Capital and Greater Cairo) (in Arabic), Dar Al-Madina Al-Monawwara, Cairo

Newman, P. and Kenworthy, J., 1999, *Sustainability and Cities: Overcoming Automobile Dependence,* Island Press, Washington, D. C.

Penn, A., Hillier, B., Banister, D. and Xu, J., 1998, "Configurational modelling of urban movement networks", *Environment and Planning B*, 25, pp. 59-84

Salheen, M. and Forsyth, L., 2001, "Addressing Distance in The Space Syntax Syntactical Model", *Urban Design International*, 6, pp. 93-106

Willoughby, K., 1994, "The 'Local Milieux' of Knowledge based industries", in J. Brotchie, J. et al. (eds.), *Cities in Competition*, Cheshire, Melbourne