SYNTACTIC MODELLING AND ANALYSIS: A GIS ADAPTATION AND ENHANCEMENT FOR EFFECTIVE PEDESTRIAN AND VEHICULAR SYSTEMS

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ABSTRACT

In both architecture and planning, most recent movement modelling and analysis studies have been undertaken on the premise of space syntax and associated techniques. The fact that space syntax is not associated with mainstream GIS applications has somehow tended to undermine the potential of both systems in comprehensively tackling urban design and planning problems. This paper highlights the potentials of adopting space syntax techniques within ArcView GIS for addressing design and planning tasks. The first part looks at a general background of modelling and analysis of both pedestrian and vehicular systems, and some major techniques that have been deployed in the past decades. The second part focuses on the use of 'axman', a Mac-based application for space syntax techniques, and 'axwoman', a windows-based replica within ArcView GIS. Comparative modelling and analysis are presented as well as variations in both graphical and statistical presentations. The final part provides exploratory dimensions for enhancing syntactic modelling and analysis of both pedestrian and vehicular systems within GIS-based applications. The paper concludes with some recommendations on how to avoid major challenges of theoretical rhetoric, platform compatibilities and the need for further research in extending syntactic analysis to the emerging ArcGIS range of applications.

Keywords: *Space Syntax, GIS, movement, modelling, urban design, landuse, planning*

الملخص

إن معظم الدراسات والأبحاث الحديثة التي تعنى بنمذجة وتحليل حركة السير للمشاة والمركبات في المناطق الحضرية والمدن وعلاقتها بالفراغات المعمارية والحضرية استخدمت تقنية Space Syntax أو منظومة الفراغ في النمذجة والتحليل . وكون هذه التقنية الحديثة لإستخدام الحاسب الآلي في النمذجة والتحليل الفراغي غير مرتبطة مع أي من برامج نظم المعلومات الجغرافية GIS تمثّل عائقاً نحو الإستفادة من هذين النظامين المهمين في التحليل الفراغي للمباني والمناطق العمرانية .لذلك فإن هذه الورقة تعنى بأهمية وفوائد ربط هاتين التقنيتين الـ Space Syntax والـ GIS سوياً للقيام بالنمذجة والتحليل للفراغات المعمارية والعمرانية في المدن . وتستعرض الورقة هذا الربط التطبيقي في برنامج الـ ArcView GIS .وتستعرض الورقة في الجزء الأول أساليب النمذجة والتحليل الموجوده لحركة السير في الدراسات السابقة والتقنيات المستخدمه لذلك . كما يستعرض الجزء الثاني من الورقة إستخدام برنامج الـ ArcView وتوضح الإيجابيات والسلبيات لهذا البرنامج مقارنة بالبرنامج الأساسي الـ Axman والمستخدم في تقنية Space Syntax . وتخلص الورقة بتقديم الاقتراحات والتوصيات ليحين هذا الدمج بين نظامي الـ Space Syntax والـ GIS .

1. INTRODUCTION

Optimization parameters for guiding decision making as well as the need to discern certain inherent characteristics of spatial systems is largely responsible for the continuous research into modelling and analytical methods dealing with landuse and related developments. Both pedestrian and vehicular systems, which serve as indicators of how space is used and as means to experience the city, have witnessed substantial advancements to that effect. This trend can be seen in the increasing number of modelling and analytical systems. So far, most of the systems are largely theoretical, with some software to support their deployment in computer environments. Developments such as Space Syntax, Geographic Information Systems (GIS), Cellular Automata and Multi-Agent Simulation (MAS), however, are in the forefront of recent advancements in spatial modelling techniques. The reason for this is underscored by the fact that they provide extensive theoretical backgrounds as well as practical applications, especially those relying on computer environments. The challenges though, are far from being adequately addressed, as continuous research, innovations in lifestyles and other unexpected developments keep turning up new challenges and various perspectives on how to handle them.

We present here one of those perspectives of tackling the issues of modelling both pedestrian and vehicular systems. In the first part we make an attempt at getting to grasp with the essence of modelling and analysis of urban systems, chiefly as regards the development of landuse planning and urban design. We then single out the issue of movement, characteristic of pedestrian and vehicular systems that make for successful planning and design. This is followed by the introduction of two key tools that are currently being used to that effect. By alternatively using the tools to model and analyse a particular area of an urban centre, we demonstrate not only the finesse of the syntactic approach to urban system, but additionally show that this can be enhanced within the ArcView GIS environment for fostering integrative analysis in the way of predicting movement or the use of space in new developments. In the final Part, we present rather an exploratory dimension that seeks to broaden the scope of the methodology within the GIS environment.

2. PREDICTING MOVEMENT IN PLANNING AND URBAN DESIGN

Throughout the evolutionary process of landuse planning and urban design, the preoccupation of planners, designers and developers has been to derive a suitable mix of various landuse and urban form that will yield lively environment, and profitable turnover. Yet somehow, this has rarely been successful. One main reason is that most of the models utilized were either too vague, or lack sufficient granularity to tackle developments at the level of pedestrian movements. Despite the adoption of quantitative techniques from as early as the 1960s, research focus and scope differed widely, as well as the specific mathematical form of the models. They tended to incorporate too may variables without specifying their

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interrelationship or lack interactive mechanisms among others (Bernstein & Mellon, 1978; p23). However, these models marked a break with the long tradition of models based on social physics that had been common from the 1860s. They provided a theoretical base for a greater understanding of spatial process, leading to quick successions of statistical mechanics models (1970-1980), aspatial information processing models (1980-1990) and spatial information processing models from 1990 onward (Fotheringham et al, 2000).

Among these models, Landuse-transportation models have received greater attention so far, because of 'some powerful rationales for applying simulation models to the study and management of urban systems' (Torrens, 2000). Their failure in tackling planning and urban design tasks is blamed on the earlier models exclusively relying on gravity models, as opposed to spatial configuration among others. For instance, most infrastructure supporting the transportation system was reduced to engineering rules of thumb and standard off-the-shelf designs, without adequate cross-checking or sensitive adoption to balance trip generation (Kaiser et al, 1994). Another critique leveled at the failure of landuse-transportation models is the difficulty of achieving an optimum design for the transportation system that will account for congestion and externalities. Besides this, aspects such as firms and household location within central business districts, continues to challenge basic assumptions of these models (Mills & Hamilton, 1994). However, Investigations into the reasons for these failures, especially regarding failures of housing schemes in the 1970s in Europe and other parts of the world revealed that there is more to spatial configuration than the metric distance. The importance of spatial configuration in the study of planning and urban design is so significant that it has given rise to a new theory of space, which is the theory and method of space syntax

Space syntax is associated with a 'generic process by which spatial configurations, through their effect on movement, first shape, and then are shaped by, landuse patterns and density' (Hillier, 2001). While it can be argued that traditional settlement in many parts of the world have maintained a fairly substantial configuration for many decades, the introduction of mechanised transportation, and rapid evolution of modern cities has tended to compromised such stable octets. The key assumption is that socio-cultural factors underscored the geometry of local construction patterns, which is seen to vary with novel economic models and social mix. Clearly there is some form of interaction between the geometry of the layout and the way it influences movement, or the other way round. To discern this geometry and its association with certain social parameters, a variety of models have been proposed, for instance, alpha-analysis (Hillier & Hanson, 1984), which is the basis of space syntax, and others that can be directly related to it such as angular analysis (Turner, 2000), and Isovists (Batty, 2000). The rationale of these techniques is evident in current planning and urban design literatures.

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2.1 GIS Techniques For Predicting Movement

The adoption of GIS applications for landuse planning and movement prediction, results from the advancement in spatial data models, increasing computing power and the ability of coupling or associating a wide variety of models. The possibility of examining spatial relationship among features, essentially those leading to the creation of new spatial data from existing ones makes GIS more suitable for landuse planning as opposed to actually predicting interaction of users. However, it has given a solid base for advancing all sorts of landuse and or transportation models. For instance as evident in recent research by Slaven (2001), Christian (2001) and Hsieh et al (2001). Actual prediction of pedestrian movement is now making some headway into GIS applications through the intermediary of agent-based simulation. The ability to simulate terrain, natural phenomena and human interaction lends sufficient flexibility if not credibility to the techniques in enhancing GIS analysis. Agents can now be programmed to decipher geometric properties of complex spaces in either adhoc or structured manner, with results far beyond the capability of conventional operations (Batty & Jiang, 1999). Similar applications reveal that assigning agents within GIS environments provides greater flexibility and far shorter timing in achieving the coupling of and operating complex models previously deployed in the areas of various pedestrian systems (Haklay et al, 2001). These developments point to greater potentials in the long run. However, space syntax methodologies provide quick and effective approach to assessing spatial properties and testing for proposed developments.

2.2 Space Syntax Techniques for Movement Prediction

The space syntax techniques model and describe spatial configuration and how this correlates with pedestrian and vehicular movement. On the onset is the fact that buildings play a fundamental role in organizing certain kinds of social relations. In-between, different spatial pathways are required by different types of social morphology. The idea of morphology is understood to be some set of observable form with such differences and similarities that portray interconnectivity. To translate this into visual and hence graphical language, certain assumptions are made about the general layout of a settlement or interior spaces, wherein shapes are considered as configurations or composites made up of standardised elements. These give rise to convex and non-convex spaces, or series of solids and voids. By further considering the voids as cells, the number of cells that can be seen from the vantage point of a given cell, is defined as visibility (Hillier 1996; pp 100 & 313). Visibility gives rise to probable lines of motion in a spatial system. By drawing the longest possible lines from given vantage points along these probable lines of motion and across an entire spatial system, an axial map is generated. The axial map is thus, a model of any spatial system, which is processed by a computer system using a number of software. There is a number of such software written for the purpose of analysis, however, in this paper we will be concentrating on the ‘axman’ software.

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One may question the rationale behind having randomly drawn lines as a model of settlements dealing with complex human interaction. However, a number of researches have demonstrated that such predictive models do yield between 70-80% accuracy of movement prediction (Penn, 2001). This can be explained by the fact that the model of analysis considers a settlement as possessing a bi-polarity between its buildings and the world outside it. The spatial structure between these two, which is characterized in this case by the axial map, actually interfaces between local inhabitants as well as between inhabitants and outsiders (Hillier & Hanson, 1984). The two most important factors responsible for this consistency are the degree of connectivity between the individual axial lines and how much each is integrated into the spatial system. A processed model produces readings for each component of these lines, which can then be correlated. A high degree of correlation, points to an intelligent spatial system and therefore, higher degree of the chances of interaction. A further correlation with observed movement is needed in cases where pedestrian studies are essential. There are other mathematical relationships that are drawn from the properties of the axial lines once processed. Amongst these is the point-depth, which determines how far a spatial system can be accessed from a given axial line. To understand the implications of such measures, we shall consider the practical case of a given urban center that constitutes both pedestrian and vehicular movement.

3. SYNTACTIC MOVEMENT STRUCTURE OF AL-KHOBAR CBD

3.1 Background

Here we will briefly demonstrate the modelling and analysis involved in the syntactic study of a neighborhood of a major urban settlement. In the first instances, we consider the major streets (approximately 5 minutes driving distance) as the exclusivity of vehicular system, and then further reduce the coverage to reflect the aspect of pedestrian movement (Approximately 5 minutes walking distance). Though in reality, the systems are actually dual. Our division is thus, one of scale rather than one of physical restriction. The chosen area has been studied by a number of professional planners and graduate planning students for a substantial number of years in the last two decades. As such, it provides interesting basis on which to compare conventional planning studies with the space syntax technique.

Other studies of urban neighborhood along this line have been carried out in the past (Hossain, 1999; Major et al, 1999; Gospodini, 2001; and Nes, 2001), all highlighting the potential of the syntactic approach to analyzing spatial systems. However, we will take a rather critical approach of the methodology itself, as seen through the interfaces of two application-software designed for the same purpose. Earlier studies of a similar magnitude (Jiang & Claramunt, 1999; Batty et al, 2000; among others), concentrated on the structural differences between GIS and Space Syntax, and the development of the software for applying syntactic analysis within a GIS environment.

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In our comparative study of the performance of the two applications, we used axmanV2.25 on an Imac machine running under OS9 and axwomanV1.0 within ArcView3.2a and ArcView3.1 GIS. Each was on a Pentium III machine running under windows 98, of capacities 600MHz, 256MB; and 650MHz, 128MB respectively.

3.2 Modelling And Analysis

The basemap for the study area consisted of a scaled tourist map of the central area of the city of Al-Khobar and its neighborhoods. In the first instance the map was scanned with a high-resolution colour scanner at a high resolution. For the GIS studies, it was necessary to prepare and project the map for various GIS analysis. However, in applying the map to the syntactic study, the map was used as scanned.

The modeling was carried out in two phases. The first covering the assigned vehicular area and the second, covering the pedestrian restricted area. The drawing of the axial lines was undertaken manually, and then processed using the two applications within their respective operating platforms. For the sake of convenience, we will limit the graphical illustrations to the connectivity maps and scattergrams, as these are the only ones that can be directly obtained from both axman and axwoman. Figures1 and 2 show the connectivity maps of the vehicular systems as processed by axman and axwoman respectively. Figures 3 and 4 show their respective scattergrams

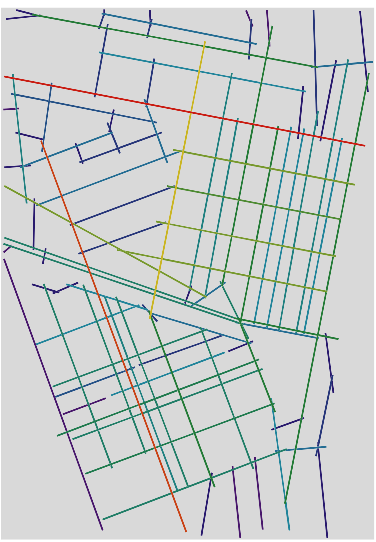

Figure 1: Connectivity Map (axman)

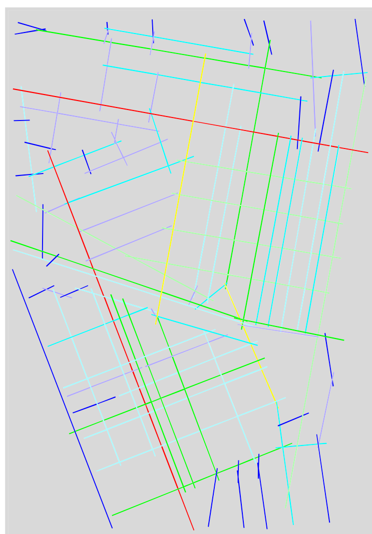

Figure 2: Connectivity Map (axwoman)

In the two figures, the difference in the intensity of the colouring scheme is quite evident, though the processing suggests similar properties for the overall structure of the layout. Without the legends that clearly show the range of connectivity in each case, it is difficult to assign the two maps to the same structural system. This may be misleading to any casual observer familiar with such maps. There are other differences as can be seen from the scattergrams below.

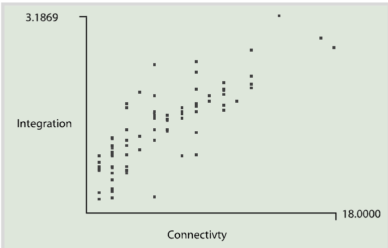

Figure 3: ScattergramVS1 (axman)

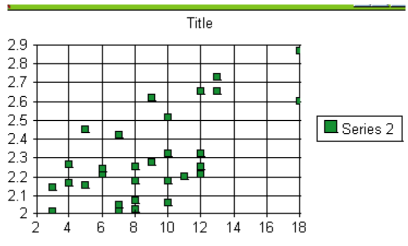

Figure 4: ScattergramVS2 (axwoman)

The scattergrams do not have a similar structure as was evident in the case of the connectivity maps. While there is a clear indication of some measure of intelligibility in figure 3 due to the close fitness of the distributions, it is not the case in figure 4, although the highest number of connectivity (18) is the same in both cases. This can be explained by the difference in the integration values among other things. While figure 3 shows a maximum value of 3.1869, the maximum from figure 4 is just 2.900. In some cases, this may be overlooked, depending on the purpose of a study. Another problem with scattergrams generated from the axwoman process is the limitation of the range of dataset that the current ArcView application allows (somewhere in the vicinity of 30-50).

Considering the case of the pedestrian sub system as defined, we again notice that there is some similarity in the overall structure of the connectivity maps processed by axman and axwoman respectively. Except that as pointed out earlier, the range coloration, seems somewhat different. Except for the line at the extreme left which is actually composed of two separate entries in the axman map, as opposed to one in the axwoman case, the two maps might as well provide some measure of reliability in the interpretation of the structure of the covered area. This lapse can be attributed to the degree of quality control in the scanning process. Otherwise this provides a satisfactory result for syntactic analysis. However, due to the number of axial lines, somewhere in the vicinity of 229, there was a marked difference in the processing time, particularly in the axwoman operation. As the number of lines approach the current maximum of approximately 256, the operation tends to freeze or even crash. However, no clear pattern is available from this study. On the contrary, the axman operations do process a grater number of lines, depending on the configuration of the operating system. But equally suffer from crashes, particularly in the case of what is commonly known as type II and type III errors. In the course of this relatively simple excise, the program unexpectedly quitted for a number of times.

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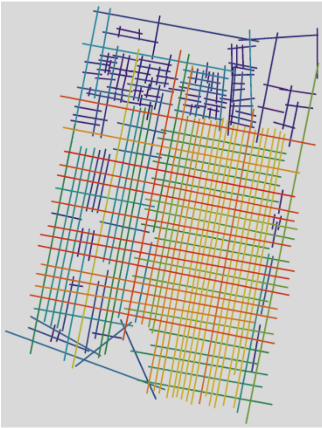

Figure 5: Connectivity Map (axman)

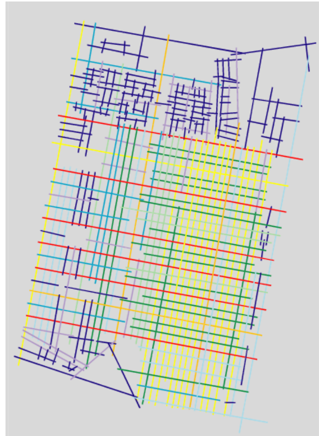

Figure 6: Connectivity Map (axwoman)

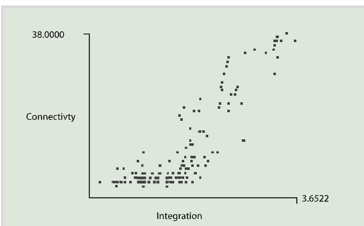

Figure 7: ScattergramPS1 (axman)

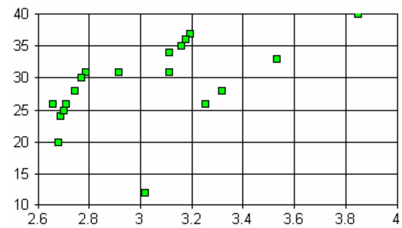

Figure 8: ScattergramPS2 (axwoman)

Here again we attempted producing another set of scattergrams from the connectivity maps of figures 5 and 6. The major difference between what we have in figure 7 and that of figure 8 is the range of data. For a maximum connectivity of 38 from the axman, we have a corresponding figure of 40 from the axwoman process. Equally, the highest integration value is 3.6522 on figure 7 as opposed to 3.800 on figure 8 although somehow, the distribution is similar, unlike in the previous case of figures 3 and 4. However, due to ArcView's limitation, we could only produce data for the 10% must integrated spaces in the case of figure 8. This corresponds to approximately 30 axial lines, or the portion to the upper right of figure 7.

Aside from these graphical aspects, some interesting differences do exist in the two software. While axman is highly scalable due to its generic nature, with extended abilities in processing and displaying graphical entities such as point-depths, local integration within same layout as a substitute operation to the integration map or connectivity map, we couldn't do the same with the axwoman program. Equally variable was the range of statistical data that we could display in the form of scattergrams. Notwithstanding, the ability to work with multiple views, floating palates as well direct superimposition of other themes on our axial map did provide

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some positive potentials in having the syntactic study alongside traditional GIS operations such as spatial analyst's model builders and network analyst, besides other extensions. To get around the problem of data range, we had to export our data to db4 and subsequently import it into excels spread sheets.

3.3 Enhancing GIS syntactic applications

What is immediately apparent from the foregone exercise, is the shortcomings of effectively translating syntactic studies within GIS applications. Given the current developments in the field of GIS, the axwoman program we have demonstrated in our study is not in line with the pace of change. Although both axman and axwoman are being developed for web-based applications, we will like to point to some of the aspects that can enhance such developments.

Current GIS applications thrive on their ability to handle huge databases at both personal and enterprise levels, any such development of syntactic application must be flexible enough to allow for modelling and analyzing such data ranges. One approach is programming to take advantage of dynamic segmentation encoding found in most GIS applications. This has the potential of directly converting centerlines to axial maps, while serving at the same time as a source for network analysis. Again, ASCII files can provide another outlet for generating axial lines, especially from standardized zones with some sort of projected data. Although most axial lines will continue to be drawn based on traditional rule of thumb, there is every need to believe that those targeted for existing street networks will be far faster and more accurate when so automated.

Another consideration is the ability to overlay such axial maps for the formation of new data sets. This can inform a grater aspect of decision-making ability. What is needed here is the ability to transfer processed axial maps as encoded data without loosing their syntactic properties. Currently this is not the case, especially when loading an existing project on a different systems or workstation. Additional to this point is the support of collaborative and participative decision making through the web. For instance, any one using a common web browser should be able to manipulate such data the way other feature data is currently handled through ArcIMS and similar map servers.

To address the last aspect, however, the challenges of metadata, such as providing adequate validation and syndication must be incorporated into the system. Since 'spatial statistics are notorious for generating analytically intractable problems' (Fotheringham et al, 2000; p242), it is imperative for such decision supporting tools to reflect useful innovations such as Bayesian MCMC techniques of analysis.

4. CONCLUDING DISCUSSIONS: IN LINE WITH THE LINES

Most of urban development today is driven by various schools of thoughts, some of which do not see the fine lines of our spatial systems. The issue of spatial analysis is one of importance, as it has significant influence on people's livelihoods. Yet, it has in the past suffered from both oversimplified and overcomplicated interaction models. We believe this can be avoided by simply being practical if not critical of some of the 'exciting' theories about spatial models. For instance early applications of statistical models in urban analysis caught many unaware of the effects of multiple variables in time series data. Similar challenges are common today in prepackage analysis packages.

It is difficult to say we can pinpoint any such packages, however, the point here is caution in application. This extends also to the use of projected or non-projected data in GIS. One way of getting around this, is getting insights from users' groups dedicated to a particular field, even though it is not all that straight forward. The Internet proves beneficial avenues for data and application sharing, thus will bridge the problem of platform compatibility if next generation axman/axwoman is developed for the web. Some scholars have advocated for the retraining of planners in the way of adopting curriculum to given national needs. On this issue, we suggest a wider and deeper coverage of entities that relate to and or make up our movement systems, while at the same time maintaining a continuous background updating of systems and personnel.

Configurational models have been hailed as the basis for researching into the multidimensional dynamics of cities or as layered representation of space into a single entity. This has equally been pitched alongside environmental sustainability of cities. This may seem contradictory, yet it is just what we recommend for being in line with the lines. That is, the picture of the whole urban system from its parts is a result of moving from one part to the others (Hillier, 1994).

In this somewhat brief study we have been constrained by both time and resources to do justice to the topic that seeks to broaden the scope of syntactic analysis within GIS applications. This has meant that we couldn't explore some areas that could have refined our basic models or those that could have broadened the subject matter. For instance some of the questions that could have given more impetus to the study include but not exclusively:

What effect do graphics cards, ram, processing ability and degree of loading have on a system regarding the rate of processing axial maps?

Would other versions of software, operating systems (such as windows2000, Unix or Linux) faire better?

The human aspects, such as relative experience, background, motivation and knowledge of the coverage area, can determine the way the axial lines are actually drawn, and hence, the final numerical count, which in turn determine the statistical outcome.

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As regards the range of statistical analysis, it will be interesting to investigate what happens with third party packages such as statistical, SAGE and others. Variation could also have been introduced in the confidence limits and other parameters. This, we believe could have given another dimension to our findings.

We figure that there are many more challenges in adopting syntactic analysis within the greater GIS environment that goes beyond ArcGIS range of applications, which operate on various platforms and distributed services. It will be an added dimension for both space syntax and GIS models, to be able to complement each other at such scales and levels.

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