Modelling The Spatial Morphogenesis In Cities

The Dynamics of Spatial Change in Manhattan

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Abstract: Applied studies in the area of urban growth have often focused on the apparent physical silhouette of urban form in modelling and simulating city growth. This paper is intended to go beyond such limitations and present a model based on observed dynamics of change in urban structures. Thus the paper translates the spatial laws which govern the process of urban morphogenesis in cities into mathematical rules which represent the change in the configurational structure of street networks. For this purpose, a set of analyses will be made for the sequential development of urban street network in Manhattan. The change in the attributes of the elements under investigation will be judged according to physical and angular metrics. The objectives are to track any regularity in the bottom up growing system and detect the causal forces that took part in the rise of a distinguished structure in the planned uniform grid. The externalised model has the potential to be devised in computer aided design implementations and strategic planning development.

1. INTRODUCTION

Researchers in the area of urban studies have tackled the problem of cities taking different standpoints, thus; marking widely divergent lines of investigation. Some urban design studies have taken a rather narrow perspective being mostly dedicated to observe the manifestations of local phenomena in cities. Such studies have hardly produced any applicable outcomes. Usually driven by self-interests agendas, planning-related studies frequently precipitate in imposing plans without rigorous analysis of the conditions on site. In this way, planning decisions were often dissociated from the real-time life of the city. Moreover, planning studies often followed a generalised approach towards the problem-solution discourse in an attempt to address all sides of the problem at once. By taking such approach, planners often end up not arriving at any responsive and sensible solutions without reflecting on the main problem in a direct and practicable manner. In an approach towards experimental research, generative urban design studies have often been short of a thorough approach towards problem definition of cities. Instead, there is a growing trend marking various implementations of computational techniques without much scrutiny and emphasis on concrete and scientific analysis. In response to all these approaches, this paper attempts to approach the problem of city growth scientifically by outlining an approximate model for urban growth. This model will be built on a through observation tracking the transformational changes in the attributes of the elementary constituents of the spatial system in cities. The paper aims to provide a better understanding of growing spatial structures in existing cities and externalise models that mark the invariants of spatial change in urban regions. Therefore, the effort will be directed in this paper to make explicit the regularities taking action in the spatial growth process. By limiting the approach to study the spatial aspects of urban transformation it makes it feasible to provide a partial answer to the problem of urban growth. The partial answer might lead to broader reflections given that space -by meticulous observation of space-reality relations- is considered to be a causal generator and amplifier of social and economical life in cities (Hillier, 1996a).

1.1 From Urban Morphology To Urban Morphogenesis

Studies in the area of spatial morphology have gone very far in analysing city spaces. Their analyses have been made evident by evaluating the tangible correspondence between spatial configurations and the observed human activity in the spaces under investigation. The findings in that particular field of studies are found to be promising and might potentially be devised to serve as a solid ground for applied urban design research. Some attempts have been made in these respects but they have remained very limited by practise-based constraints and they lacked the experimental side.

One of the most remarkable approaches to understand spatial morphology in cities is Space Syntax theory. Its success is widely notable through its applicable findings and consistent methodology which proved efficient in building a correspondence between space, society and economic activity. Space Syntax research outlines the numerous and ongoing studies that have been made over the last four decades within the frame of a configurational theory of architecture. The most significant two publications which elucidate Space Syntax theory are those of Hillier and Hanson's (1984) and Hillier's (1996). The studies made by Hillier and Hanson (1984) have revealed a certain logic of space which has social potentials. This logic of space represents spaces as networks composed of certain spatial elements. These networks have configurations depending on the depth of a spatial element in relation to other spatial elements. Hillier and Hanson represented visual fields in the city with corresponding spatial elements marking the longest and fewest lines which cover in total all street spaces in a city. Morphological configurations of this network can be represented in the different topological, angular and metric relations between the different constituent elements of the spatial structure in a city.

In view of the idea that cities are morphogenetic structures which allow changes through time; the paper is framed in an approach to extend Space Syntax studies and shift the focus towards investigating the change in morphological configurations of cities through time. In other words, the paper will concentrate on the change in the topo-geometric attributes of spatial elements through time rather than the study of these spatial attributes at one interval in time. The paper will implement the segment angular integration analysis as a methodological tools to measure the topo-geometric attributes. This method weights the spatial depth in a system by considering the angular and metric values. The technique is developed by breaking axial analysis (longest and fewest lines in the spatial structure) into its constituents segments and measuring their angular depth within a physical region. This method allows for distinguishing segment elements that are semi-continuous approximating in total axial lines.

Segment attributes of spatial elements have been used frequently in outlining the morphological characteristics of urban regions. However, understanding spatial change within the context of an axial lines network has started long before introducing the segment analysis. Hillier (1996) theorised about the characteristics of local and potentially generative changes in urban grid. He recognizes the tendency of longer lines to continue straight and shorter lines to be blocked or intersected with other lines in right angles (Hillier, 1996, page 282). He identified that as the "centrality and extension" rule and suggested that this rule have a local effect on the globally random process in which cities evolve. Building on Hillier's morphological analysis of cities, several attempts have been made to characterise the morphogenetic change in urban structure. One attempt was made by Griffiths (2009). In his attempt Griffiths was mainly concerned with axial analysis and he studied the change of distribution in different maps in terms of line length and integration. His focus was centred on the relationship between spatial growth and historical development of industrial cities. His interest was to investigate the hypothesis that growing urban systems absorb their suburbs as they expand. Another attempt was made by Shpuza (2009). His attempt was marked by tracking the change in the statistical distribution of integration and connectivity in a sequence of historical maps. Both Griffiths and Shpuza have targeted a different objective compared to the one investigated in this paper. To examine their hypotheses they have approached the growth problem by analysing the map as an aggregate whole. The fact that no detailed analysis was made to observe the change in the attributes of the elementary constituents of the spatial structures may not give a clear idea of what is taking action on the local level. Tracking the change in each single element is particularly important if one's objectives were to devise these changes in a generative urban design model. In fact, building a model that represents the collective local changes of spatial elements is probably the only way to construct a computational model that reflects the actual process of growth. In a previous study, Al_Sayed et al (2009) made an attempt to mark the generic regularities in the spatial growth of Manhattan and Barcelona. It was evident that these processes involve a bottom up spatial growth process marked mainly in the organic grid. Alongside that process, there seems to be a process of spatial optimization which plays role in distinguishing structure within the order of a uniform grid by means of deforming its regularity. This was particularly noticeable in the case of the Central Park in Manhattan. The current study therefore builds on some of the findings in Al_Sayed et al (2009) study and goes further to outline the trends of change in urban form. For this purpose, a sequential observation of change in the attributes of the constituent elements in the spatial system will be made. The aim is to highlight regularities in the change of segment integration and the disappearance, mergence and division of spatial elements throughout the process of growth. These method will be instrumental in externalising a model of spatial change along with any rules that represent causal forces of change. By modelling urban change behaviour, it will be possible to collect data and construct measurements which will make the ground for future applicable results.

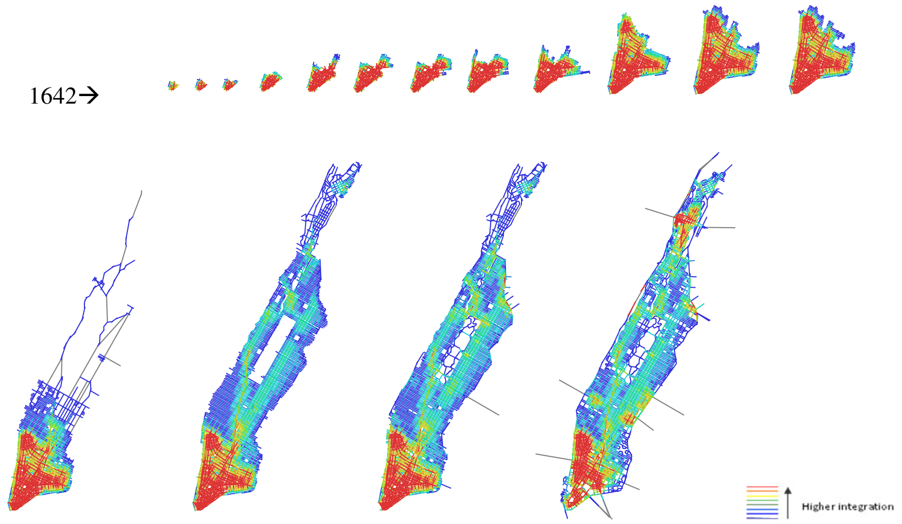
2. THE CASE STUDY OF MANHATTAN

The preference of Manhattan as a case study is mainly reasoned by the fact that it accommodates a large population in a relatively small urban region. This fact might be highly indicative of its success in terms of spatial form. Besides that, Manhattan's urban grid is an amalgamation of an organic grid and a uniform grid, an organic grid resulting from a bottom up emergent process and a uniform grid which is a consequent of a top down decision that took action in 1811. The grid has suffered from several deformations due to the topography of the island itself along with other factors. Manhattan in its current situation is divided into downtown, midtown, and uptown. Midtown Manhattan is mainly consisted of a regular uniform grid with two main interruptions, one of which is the Central Park situating in the heart of Manhattan, a massive green rectangle. Another main interruption is Broadway Street which is the only smooth line that cuts through –diagonally on some occasions- the midtown and uptown areas. Downtown and uptown suffer from some irregularities within the grid which mark their organic structure. In spite of the imposition of an artificial grid, the street network has allowed for interruptions and deformities in the overall grid to simulate the patterns of natural development in cities. In effect, the rigid regular grid started to incorporate elements of differentiation which stimulate the emergence of a structure amid the homogeneity of a pre-planned order.

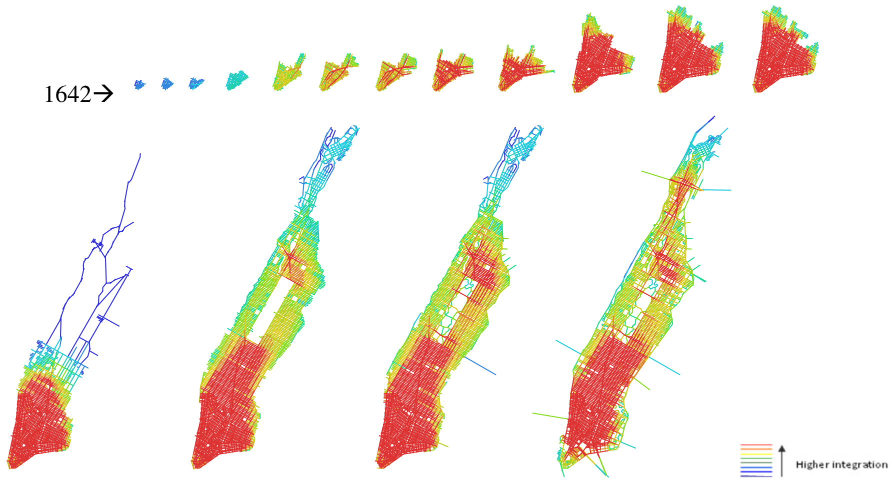
2.1 The Mathematical Model of Growth

This section will be directed towards externalising the model embedded in the bottom up process which has led to the formation of Manhattan in its current state. For this purpose, several iterations of growth have been analysed in the form of segment maps. The maps were observed in the years; 1642, 1661, 1695, 1728, 1755, 1767, 1789, 1797, 1808, 1817, 1836, 1842, 1850, 1880, 1920, and 2009. The selected phases of growth are subject to the availability of comprehensible and complete historical maps.

In a previous study, Al_Sayed et al (2009) used the angular segment integration analysis in the segment maps of Manhattan to show that on the whole the local and global integration values increase as the system grows (see figure 1, a & b). The local value is calculated within 500 meter radius which almost equals five minutes walking distance and the global value is calculated within 2000 meter radius which approximates half the maximum width of Manhattan area. Higher radiuses were not considered in this study as they might generate erroneous results given that the calculation at the long edges of the area might be distorted when using a radius that approximates or exceeds the width of the whole region. In all phases of growth, high local integration values seem to concentrate in the downtown and Washington Heights areas whereas high global integration values concentrate in the downtown area. In later phases of growth, elements of high local integration values are smaller in numbers and are more noticeable compared to other elements within the system. When measuring on the global radius, the system seems to generally spread high integration values as it grows.



a. Segment angular integration with radius 500m.



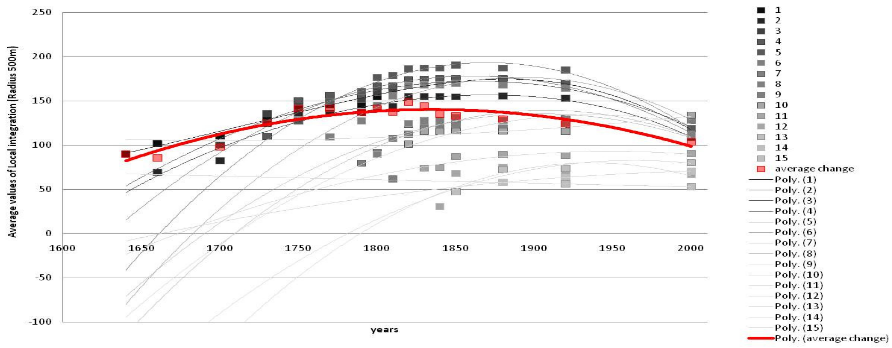
b. Segment angular integration with radius 2000m.

Figure 1. Global integration values in Manhattan area between the years 1642 and 2000.

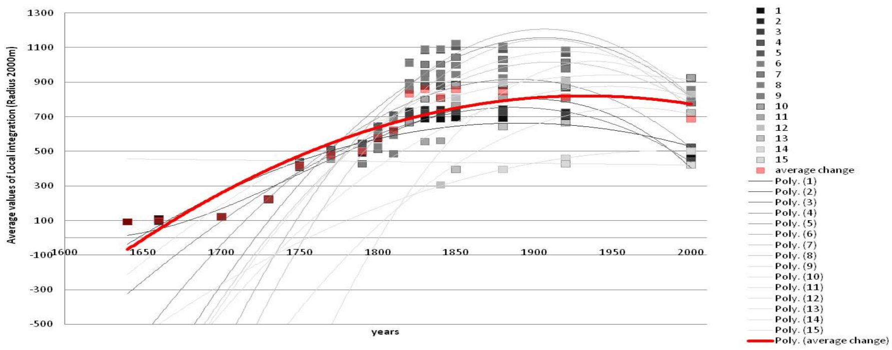
Nonetheless, the findings in Al_Sayed et al needed to be outlined in a computable form. Therefore, the current paper is an attempt to make explicit the relationships between the different spatial attributes of segment elements within the growing system. Additionally, effort will be made to mark the circumstances in which emergence, mergence, division and disappearance of elements take place. The study will go further to investigate whether these four local processes could possibly relate to the change in the topo-geometric attributes of the segment elements.

Overall, if we consider a series of statistical distribution analyses of integration values in all the maps, the trend of change in the growing spatial system does not mark the local processes involved in the emergence of the city structure. When compared, the ranges within each map are found to fit in a LogNormal distribution curve. The goodness-of-Fit for the local integration values (radius 500m) ranges between (0.023 and 1). The goodness-of-Fit for the global integration values (radius 2000m) ranges between (0.03 and 0.21). The trend of change in the distribution of local and global integration values in terms of statistical mean seems to follow the increase in the range on the whole and stabilise at the latest stages of growth.

This analysis does not distinguish the local processes which take part in the deformation of the spatial structure. Even when this analysis of aggregate data is broken up to reflect the average values of integration, it seems to follow roughly an analogous trend. Figure (2, a, b) outlines average changes in the aggregate integration values calculated at the end of each stage of spatial growth, thus; marking the average change within each new spatial expansion. The fifteen stages of growth are represented with fifteen trend lines. Darker ones represent early stages of growth and lighter ones stand for average integration values calculated within the latest expansions of the grid. On the whole, average local integration values seem to start at a value close to 100 and increase to reach a value close to 150 in the year 1850. After that it decreases slowly to approximate the same initial value. Local integration values seem to be relatively higher in the early growth stages and lower down at the end. Average global integration trend increase exponentially and they reach their highest levels in the 1850s. Afterwards they seem to settle down around the same value. All the different stages of growth seem to follow roughly the same pattern, although the middle stages seem to witness an increase in the average global integration values. In addition, the last stage of growth marks a fall in all the average integration values. This substantial change in the trend from an exponential increase to stabilization is probably a consequence of the imposed uniform grid plan. Some irregularities, however; do arise as shown in the outlier analysis in (Figure 3, a, b & c). An outlier analysis is a statistical measure. The observation in this type of analysis deviates to a large extent from the rest of the data. Thus, marking significant changes in the sample where it occurs. This measure depends on estimates of the mean, standard deviation, and correlation for the data. This analysis is tested against data which represent the sequential change of each segment element within the whole system. In the two charts in figure 3, it can be seen that there are some events at which the values deviate massively from the rest of the system. In ellipse 1, the integration values have fallen dramatically between year 1920 and year 2000 and have almost doubled the values between year 1728 and year 1755. From year 1642 to year 1728 the values increase gradually. In ellipse 2, the change in the outlier distance is a result of change in values between years 1808 and 1817. The elements in this zone also appear at the edge of the system in year 1789. They also seem to have suffered from a considerable loss in values or disappeared in year 2000. In ellipse 3, the change in values is a result of sudden expansion of the grid. The elements which represent this change in the form of an outlier distance first appear at the edge of the spatial system in the year 1842. later on, they have witnessed a dramatic increase in their values. Apart from these three cases the changes in the spatial system seem to follow a consistent pattern.



a.Radius500



b.Radius2000

Figure 2. Average trend of aggregate integration values marking each stage of spatial growth

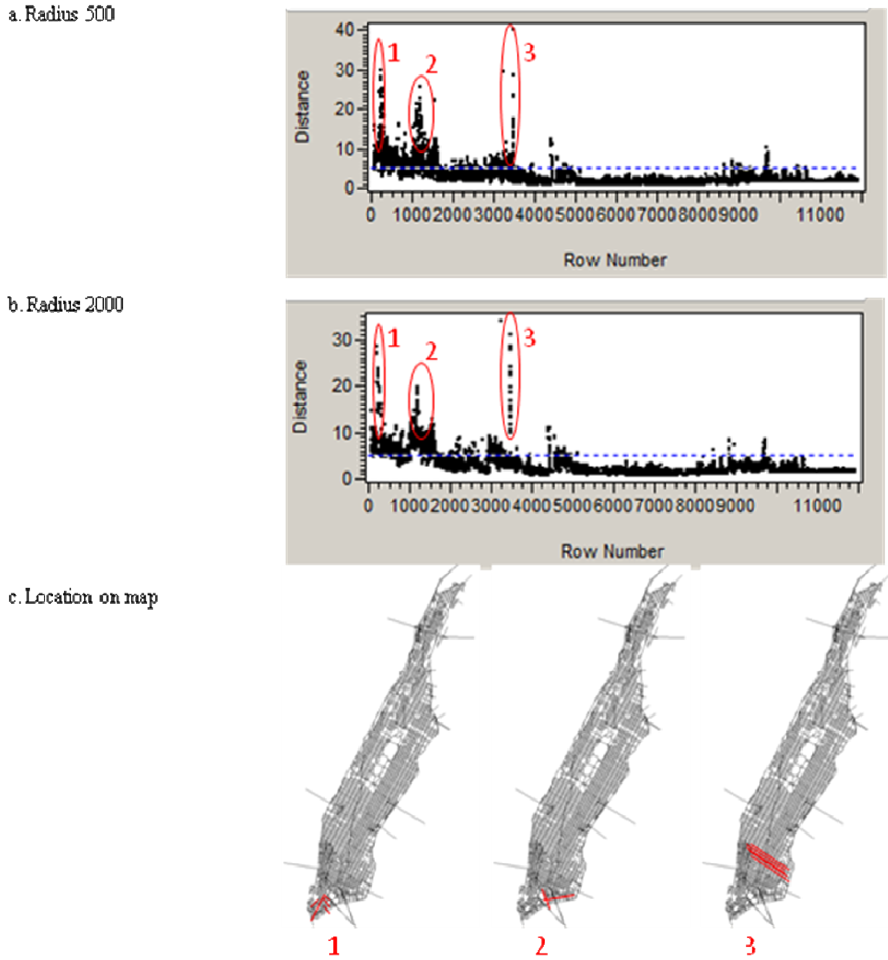
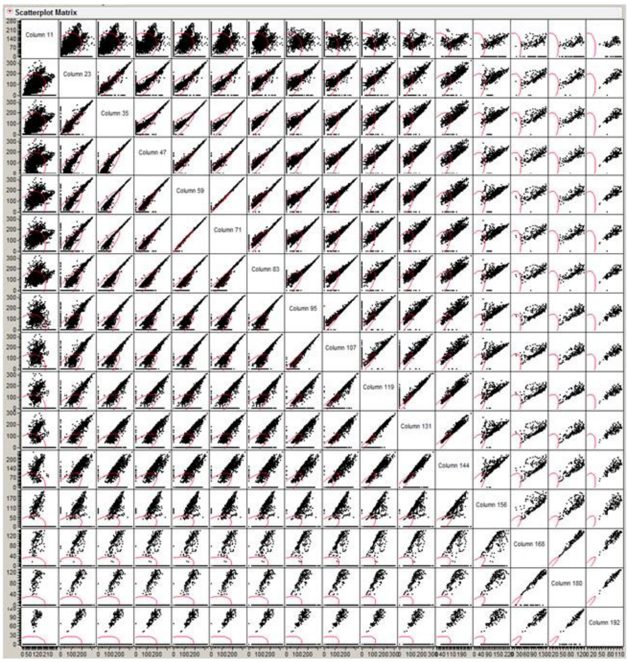


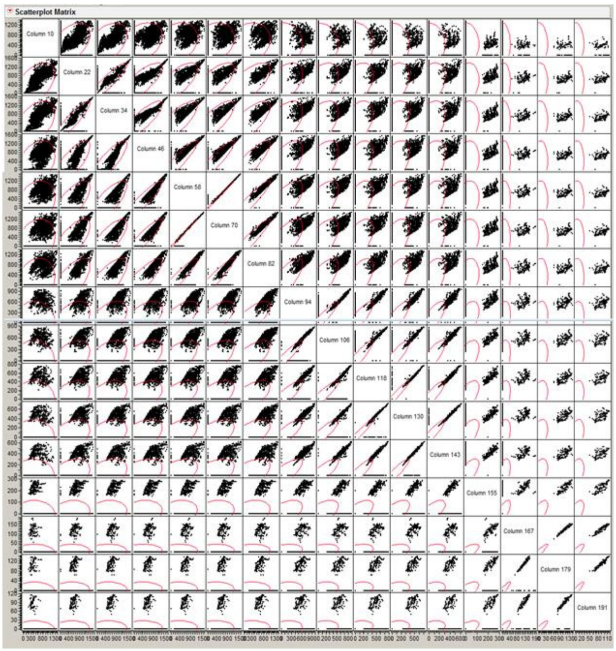
Figure 3. Outlier analysis.

A categorisation of different stages of growth is probably necessary at this stage to indicate points of distinction where changes in segment integration values are highly remarkable. For this purpose, Multivariate Analysis is applied to the sequence of maps considering radiuses 500m (Figure 4, a) and 2000m (Figure 4, b). This method is applied to organise the correlations in a Scatterplot matrix. Obviously, due to the weakening of the correlation at two points in the series of observations in Figure 4, the growth can be subdivided into two categories; map 1642 to map 1842 and map 1850 to map 2000. It is noticeable that the correlation within each category is so high that even the furthest stages of growth within each category are still quite correlated. This means that local segment integration values are quite close to each other apart from one point in the system where change in values occurs. That point is understandably the stage at which the planned grid was introduced to the system. The observed correlation between distant stages of growth indicates that -on the whole- the spatial structure has sustained its local pattern throughout the growth process. Obviously, due to the weakening of the correlation at two points in the series of observations in Figure 4, the growth can be subdivided into three categories; maps 1642 to 1789, maps 1797 to 1842 and maps 1850 to 2000. Again the correlation within each category is so strong seeing that the furthest stages of growth within each category are quite correlated. The distinction in the spatial structure on the global level is highly remarkable indicating massive changes in the global spatial structure as it grows. It might be visible that there is some regularity in the way correlation between different phases of growth within the same category does fade away in a systematic pattern. By doing that, it highlights a possible model to characterize the change of integration values in the growing system.

The multivariate analysis can tell about the changes in the system on the whole. Yet, an in depth categorisation is required to reflect on the fine-grained changes within the system and how these changes contribute to the production and eradication of segment elements. This can be made through marking the different levels of change in the growing system. Around half the segment elements record slight changes on the local level ranging between -11.46 and 39. 813 (see Figures 5and 6). On the global level, three bands of integration change can be distinguished (see Figures 7 and 8). Apart from the last three phases, a significant portion of elements do persist to change. In some cases, they exceed half the total elements. This band is less distinguished in map nine marking the transitional change between the years 1808 and 1817. Another band can be distinguished from looking at the distribution of integration values in all the maps. It highlights medium changes in the system and in some occasions the change is so slight that it resembles the range in the abovementioned band. A third band marks high positive and negative changes in the growing system. Generally, more elements seem to gain integration values rather than losing them seeing that the ranges of integration values are distributed on a higher level along the positive axes compared to the negative axes. Most of the subtle and medium changes appear in the positive zone. These trends can be more comprehended when plotting them on their physical coordinates. For this purpose fifteen maps were extracted from an all-lines map locating all the elements in the whole system. Each map renders the changes between two years from (Figure 1 , a and b). The maps are illustrated in (Figure 9 a and b).



a. Radius 500m



b. Radius 2000m

Figure 4. Scatterplot matrices highlighting the correlation between segment angular integration values for a series of maps from year 1642 to year 2000

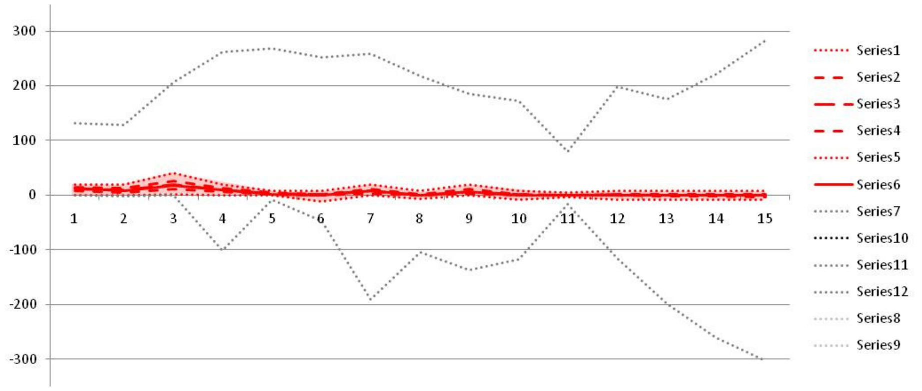


Figure 5. Distribution of values marking the change in local integration

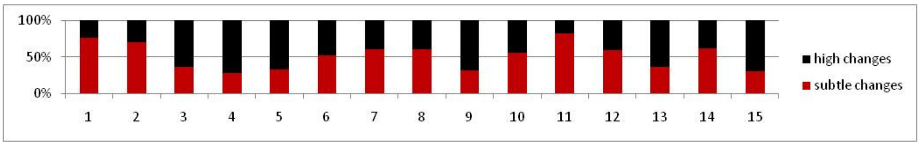


Figure 6. Number of elements which suffer from subtle, and high local integration changes.

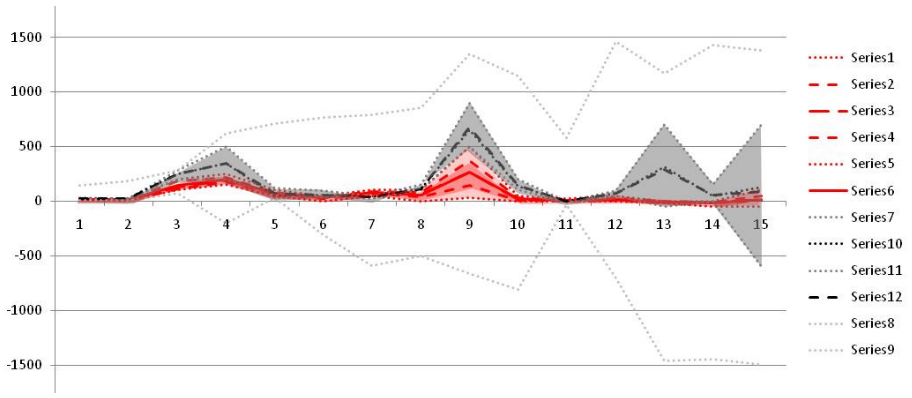


Figure 7. Distribution of values marking the change in global integration

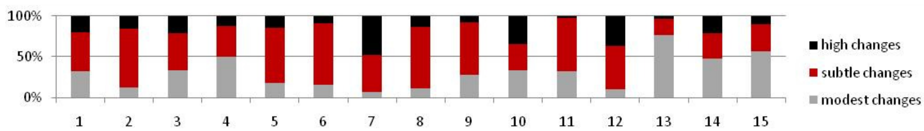
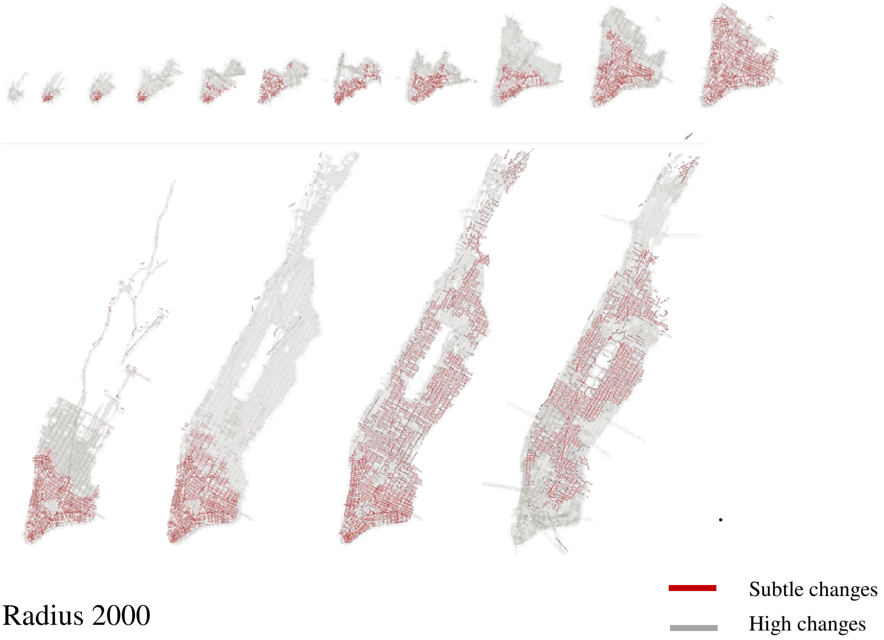
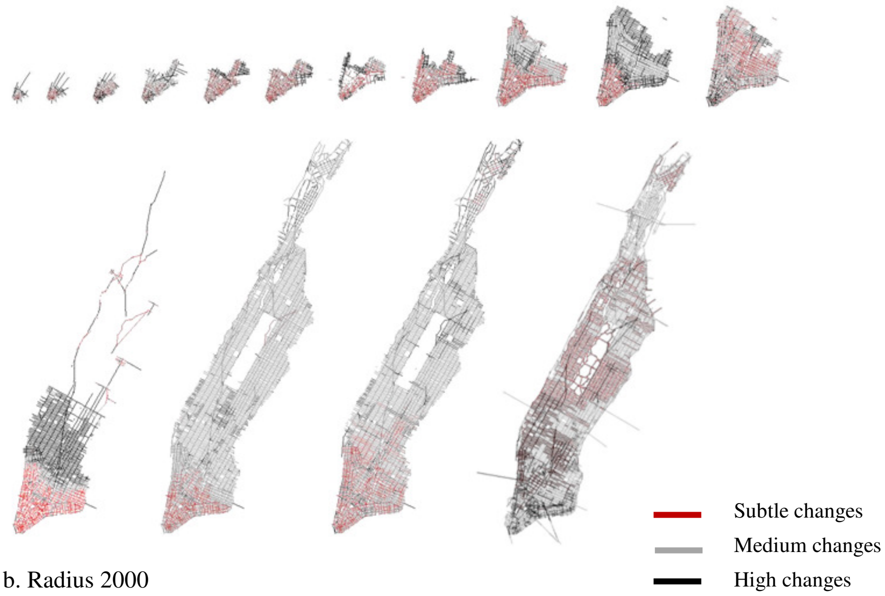


Figure 8. The number of elements which suffer from subtle, medium and high global integration changes.



Radius 2000



b. Radius 2000

Figure 9. Change in the integration values of the growing spatial structure. Each map represents the transitional state between two maps from Figure (1, a & b)

The maps plotting local integration changes seem to sustain subtle changes at the tip of the spatial region whilst recording higher changes at the expanding edges. This pattern seems to apply for all the stages of growth apart from the last two phases in which subtle changes seem to spread all over the region and high changes appear within certain spots. That is when the uniform grid starts to deform in order to distinguish a spatial structure. Global integration changes seem to record a different pattern of distribution in terms of subtle, medium and high integration changes. Subtle and high integration values switch their locations on the maps between the tip of the spatial structure and the spreading edges. At the stage in which the uniform grid interferes with the spatial structure, a large sector near the growing edges records high integration values. After that, the change in integration values decreases. Higher integration values interrupt areas of subtle change to outline a deformed structure. Yet, the change in integration seems to be at its smallest rate in the downtown area. In the last map midtown and uptown Manhattan seem to record relatively minor changes, whereas the highest changes shift to the downtown area where the urban structure witnesses huge changes marked by the emergence of bigger blocks to replace the smaller ones. This change in block size proceeds parallel to a process of emergence, disappearance, mergence and subdivision of segment elements (Figure 10). As the spatial system grows, the number of elements to subdivide increases slightly, however, the number of elements to merge increases to double the subdivided elements. The number of disappearing elements rises steadily and goes slightly beyond the number of merging elements. These structural changes are mostly visible during the last three phases of growth. Therefore, these phases are the ones to be considered for further examination. Whether these structural transformations in the grid are associated with the change in integration values or not can be tested by counting the numbers of such changes within each band of integration change. Merged elements (see Figure 11) seem to occur in all the bands in variable rates, thus; marking no clear trend. Contrary to them are the elements which unmerge and subdivide into more elements(see Figure 11). This particular process occurs more often within the bands that distinguish higher changes in global integration values. They happen in almost twice the quantities in the band where medium changes in global integration as in the band where subtle changes take effect. They double again in terms of occurrence within the band of high global changes in integration. This association is yet more noticeable when measuring on local integration values. Most of the unmerging elements appear in high local integration segments. The disappearing elements also tend to be associated more with the higher changes in local and global integration.

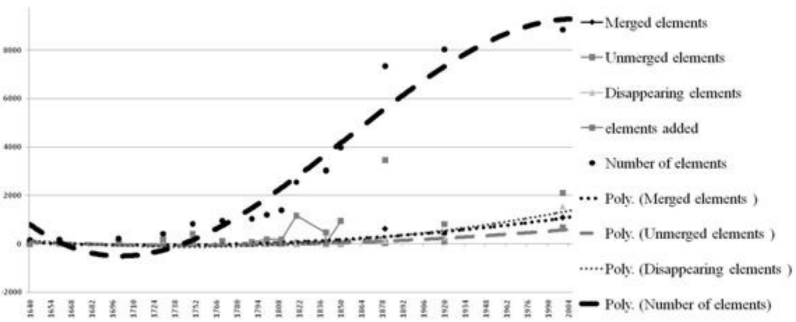


Figure 10. Changes in the constituent elements of the growing spatial structure.

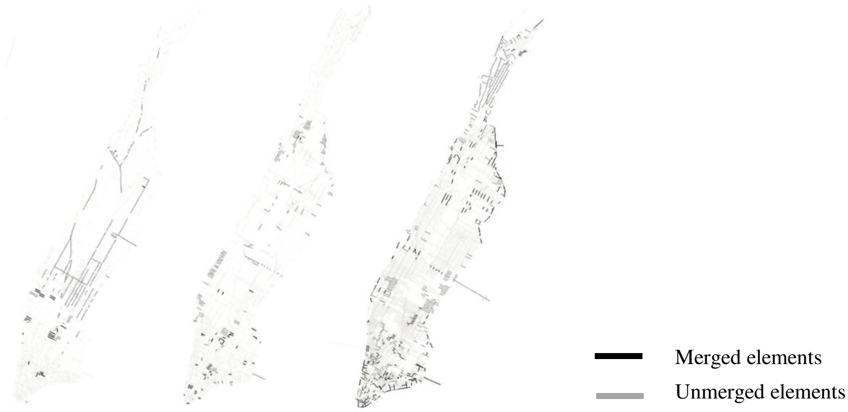


Figure 11. Merged and unmerged elements in the last three phases of growth.

3. DISCUSSION AND CONCLUSIONS

Overall, the analytical approach to externalise a mathematical model out of the spatial morphogenesis process in Manhattan's growing structure faces several limitations. These limitations arise with the particularities of the case study and the historical circumstances of urban growth which has undeniable effects on urban form. In spite of all that and by excluding some abnormalities, the observed regularities can be approximated to a reasonable level to construct a model of spatial change. They might potentially assist in predicting urban transformation. The region under examination in this paper seems to be directed by certain forces that direct the change within its spatial structure. This means that urban growth process is not completely random and might be subject to a set of topo-geometric rules which direct its emergence. In fact, the possibility is highly present that there might be an approximate trend outlining spatial change. Firstly, the local and global integration values seem to increase remarkably parallel to the addition of new elements. This increase seems to settle down once the uniform grid is imposed on the system. The change in integration appears to be consistent on the whole with rare occasions of outliers. Secondly, the local structure tends to sustain its pattern throughout the growth process, whereas the global structure does only sustain its pattern within a short period of time and changes massively in-between. Thirdly, more than half the local and global integration values seem to go through slight changes on the whole. High changes in integration are clearer and less frequent on the global level compared to the local one. High changes in local and global integration are also largely associated with the unmerging and disappearance of elements. Fourthly, high changes in local integration appear mostly around the edges of the growing structure and might be associated with the process of expansion. Regions within the spatial structure seem to constantly switch between high and subtle changes in global integration marking a continual dynamic of change in the global structure.

The findings thus far show reasonable potentials for application purposes. However, careful considerations should be made of the study limitations. The findings, therefore; should be supported by further analysis and testing in order to arrive at reliable results. The findings in total must be measured on other case studies in order to generalise the results.

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