071

Integrated sub-regional planning informed by weighted spatial network models:

The case of Jeddah sub-regional system

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Abstract

Existing Space Syntax methodologies provide the tools to measure the impact of proposed spatial changes, but are strongly dependant on the quality and availability of the spatial data. This becomes particularly more complex when major land use changes or development projects are proposed in a large region and there is no or vey little spatial layout data available for them. To counter this problem it is suggested that an 'integrated urban model' can be developed by using land use and demographic data to supplement the lack of spatial layout data and create a more realistic model for evaluating planning decisions. This paper explores the use of a 'weighted space syntax' model to contribute to the process of integrated urban planning for a large urban region in a major planning exercise in Jeddah, Saudi Arabia. The study aims at identifying the growth pattern and development potentials of the Jeddah Sub-regional system along with testing planning proposals for its growth over the next twenty years. The method for allocating the weighting to the segments of spatial networks by dividing the city into 'superblocks', identified by the foreground network and morphological similarities or spatial conditions such as existing municipal districts and major development boundaries. The weighting is then applied to the segments per unit length since longer segments have a higher probability of having a higher number of plots. The output is a spatial analysis impacted by the land use distribution, which adds the attraction or repulsion to movement generated by certain land uses to the spatial configuration and provides an accurate depiction of the functioning of the city. With this methodology we are able to estimate the impact of any number of projects of varying scales, at different time periods. This model has been integrated into the planning process through working with the lead planners in Jeddah at different stages of the project in both informative and evaluative modes. The result is an iterative, evidence-based approach and a collaborative framework for the planning and decision making, which could be adopted in future planning for Jeddah or elsewhere.

Keywords

Planning process, sub-regional plans, integrated urban models, weighted space syntax analysis, planning option testing, rapid urbanisation.

1. Introduction

Large scale space syntax models have been used in previous research to identify the key structural characteristics of large cities and regions (Hillier & Penn, 1996; Hillier, 1996, 2001; Penn, Hillier, Banister, & Xu, 1998). These studies have also established a strong correspondence between variables such as vehicular movement, land use distribution, centre hierarchies and other variables with various measures of spatial network analysis, such as space syntax 'Choice' (or betweeness in graph network analysis) and 'Integration' (or closeness in graph network analysis). Such strong relationships have suggested that space syntax analysis could be used not only as a explorative model to understand large spatial systems better, but it could also inform the processes of urban planning and design (Hillier & Stonor, 2010; Karimi, 2012; Penn, 2008). However, there have not been enough studies towards making a systematic contribution to regional or large scale planning processes. Furhtermore, existing Space Syntax methodologies provide the tools to measure the impact of proposed spatial changes, but are strongly dependant on the availability and quality of the spatial data. Lack of any available information on the spatial layout of the proposed land use zones, or regional scale developments, sometimes known as 'mega projects', makes it difficult to use the model in the planning process. This paper intends to establish the viability of using space syntax models in informing the planning process for very large systems at regional, or metropolitan scales. In that sense, the main focus of this paper is not to find correlations between the spatial network measures and socio-economic phenomena, but to investigate the applicability of an integrated model in the process planning for large cities and regions.

The study described in this paper is in fact part of a real planning project undertaken in the past two years to produce a Sub-regional Plan for the city of Jeddah in Saudi Arabia[1]. The Sub-regional Plan is a higher level plan developed on the basis of a Strategic Plan, which itself had benefitted from advanced space syntax analysis (Karimi, Parham, Fridrisch, & Ferguson, 2013; Karimi & Parham, 2012). The current study responds to the unique challenge of measuring the impact of various on-going and proposed mega-projects in and around Jeddah, such as the King Abdullah Economic City (KAEC) and Kingdom Tower, as well as the changing land use mix of large areas of the city on a regional scale. The mega projects are in varying stages of their development and there is a significant lack of spatial layout data for them. The available data is limited only to the proposed overall land use mixes and demographics. To counter this problem a weighting-based spatial analysis was developed by using land use and demographic data to supplement the lack of spatial layout data. The resulting model is a powerful tool to diagnose the impact of proposed planning decisions on the spatial system. This model has been integrated into the planning process by informing the planners about the characteristics of the region, in the initial stage of the work, and by assessing the planning options proposed by planners at various stages of the project.

This paper is shaped around two main objectives. Firstly, it investigated how the space syntax model could be enhanced to inform the planning process at sub-regional scale; and secondly, it explores how the influence of planning decisions on a regional scale, including landuse allocation, jobs and residential densities, mega projects and other attractors, could be tested by a specific space syntax methodology developed for this purpose. These objectives entail more detailed questions such as:

i. How could the population and employment data be used to supplement the lack of spatial data in Space Syntax models?
ii. Can the weighted methodologies be used to add the impact of an entire city outside a region without being modelled spatially?
iii. How can the impact of land use and population be integrated into a model to capture any changes on the activity and movement patterns of the city?
iv. In which way can 'integrated model' be used in testing major planning decisions and evaluating different scenarios?

The context of this study is the Makkah Province of Saudi Arabia. Jeddah and Makkah are the major settlements of the province, with Jeddah being the largest city and Makkah its provincial capital. The

[1] This study has been undertaken by a team of researchers and consultants led by AECOM, an international planning consultancy firm.

holy city of Madinah, located abut 400 km north of Jeddah also has a significant regional impact since Jeddah is an economic hub and a major point of entry for the pilgrims travelling to both Madinah and Makkah.

Jeddah is Saudi Arabia's second largest city and its largest port. It is located on the eastern coast of the Red Sea, roughly half way between the Arabian Peninsula and the Suez Canal. Historically Jeddah remained a traditional Arabian city till 1950 with a population of around 35,000 (Figure 1), living within a city wall (Daghistani, 1993). However, since then Jeddah experienced massive growth and reached a population of half a million by the 1970's and 1.3 million by the late 1980's (Daghistani, 1993). The sub-regional system of Jeddah now has an estimated population of 3.6 million and is predicted to reach an estimated population of 6 million in 2033 (AECOM, 2013, 2014).

The rapid development to of the city and region in the past 60 years, created major problems for planning and managing urban growth in Jeddah. The rapid physical development of the city was not always in accordance with the planning principles adopted to counter the problems related with large-scale and sustained growth (Daghistani, 1993). As a result, Jeddah now faces many urban challenges. The uncontrolled growth post 1947 has left the city with an extensive, poorly focused structure. This urban context has resulted in an overdependence on car travel, on increasingly overcrowded roads; and a service infrastructure, which does not reach all citizens (El-Shafie, 2010). This urban expansion is still ongoing and many 'mega projects' are being constructed at the moment with more planned ares to be built by 2033 and beyond (AECOM, 2014).

Figure 1: The City of Jeddah before modern transformations c.1947, left, and in the early stages of rapid growth, right (Space Syntax Limited, 2006).

2. Towards a sustainable regional growth model

The 'Sub-regional Plan' of Jeddah was commissioned by the Municipality of Jeddah as part of a larger bundle of planning projects to revise and update the 'Strategic Plan', Sub-regional Plan', Structural Plan' and Local Plans of the city in 2013. The main objective of the Sub-Regional Plan, which is the main focus of this paper, is to spatialise national policy within a regional context and to influence physical relationships at the urban scale (AECOM, 2014). The particular issues that need to be addressed in the Sub-Regional Plan concern accommodating the population that is required to support economic targets. These issues impact on the physical relationships between boundaries of growth, the location and hierarchy of centres, and overall distributions of population and employment.

A major concern of the 'Sub regional Plan' has been to develop a sustainable growth model for Jeddah for the year 2033. The issue of sustainability was initially emphasised by the brief for the project, but during the course of the project it has evolved to become the core of the planning approach (AECOM, 2013, 2014). The study described in this paper is part of the larger effort to make sure the spatialisation of the national policy and high level planning decisions proposed on a regional scale is in accordance with the principles of urban sustainability.

In his definition of 'spatial sustainability', Hillier (2009) focuses on the geometry and configurational ordering of spaces in a city. He defines that the generic form of a city as a foreground network of streets, centres and sub centres at all scales embedded in a largely residential background network, which is a by-product of the micro economic and social forces acting on the city. The combined effect of the economic and social forces with the natural process of minimising travel effort by increasing accessibility between spaces in a city potentially results in a self organised sustainability in a city (Hillier, 2009). Hillier (2002) argues that the foreground network represents the invariant patterns noticed in all cities and is shaped by micro economic forces, while the background network is defined by the socio-cultural forces and varies depending on the prevalent cultural and social practices in the city. The relationship between the high activity foreground network and relatively low activity mainly residential background network, results in a generic spatial pattern of multi directional linkages between centres and sub centres in an area approximating a deformed wheel in syntactic appearance. This pattern is found universally in most cities (Hillier, 2002).

According to Hillier, the balance between the micro-economic and socio-cultural forces defines the spatial growth of settlement (Hillier, 2002). Hillier et al (1993) also explain that the inherent spatial properties of the urban grid or 'global pattern' of the streets network influence the movement of people in the city. The configuration of the urban grid generates movement and results in some streets being preferred as routes and destinations more than others in the city (Hillier, Penn, Hanson, Grajewski & Xu, 1993). Hillier et al (1993) further argue that high movement-seeking functions, such as retail and commerce, locate themselves on streets with a high potential for natural movement, while streets with lower potential natural movement are inhabited by low movement-seeking functions such as residences. Furthermore, functions like retail and commerce attract even more movement, contributing to the inherent high movement potential of the street. This cyclic process results in such streets or centres acting both as routes and destinations and have a high 'to' and 'through' movement potential in the urban grid. Griffith et al (2008) refer to this high movement-generating potential as the 'vitality' of the street which has direct implications on the 'viability' of the street or its potential to economic investment by attracting functions seeking to take advantage of the high movement potential (Griffiths, Vaughan, Haklay & Jones, 2008).

Space syntax research has also observed invariant patterns in the spatial structure of planned systems during the analysis of New Towns in England (Karimi, 2009). Most New Towns have been found to have some similar spatial features, such as a mismatch between the topological spatial centre and the centre of urban activity, over-dependence on a car based systems, and a background residential network dominated by 'inward facing urban islands' separated from each other by the global structure (Karimi, 2009). These spatial patterns lead to an accumulation of socio-economic problems in these cities resulting in undesirable living conditions. The urban growth pattern of cities like Jeddah has shown similar trends to the New Towns in the UK, with mono-functional land use zones, inward facing urban blocks and a motorway dominated movement network. These trends coupled with a disregard for the existing organic spatial structure, while planning has caused deterioration of parts of the city and led to unorganized growth on Jeddah (Bahaydar, 2013).

The spatial patterns observed through space syntax analysis of traditional and New Towns provide a framework to study Jeddah in order to understand their growth and the implications of the planning principles adopted. The complexity of using these concepts in Jeddah Sub-regional Plan, however, is the scale of region and the lack of spatial data that you normally find for smaller scales of urbanism. The main challenge is not only making the model usable at very large scales, but making it relevant to conventional planning process. In other words, the idea is to use the concept of spatial sustainability in planning of the large region by adapting the space syntax model to be responsive to decisions about land uses, densities and future mixed-used projects.

3. Developing a 'integrated urban model' based on weighted space syntax analysis

A major challenge of this study has been an acute lack of data on the spatial structure of the proposed 'mega projects' in and around Jeddah. Furthermore, the methodology had to respond to regional land use zoning, used by planners, and the impact of other cites in the region such as Makkah and Madinah. The methodology had also the challenge of taking into account major regional issues, such as airports and ports, which in normal syntactic analysis would not create any impact, but are influential in regional planning. Thus the aim of the study was to develop a methodology that could allow for an in-depth analysis of the Jeddah region within the given context of data limitations. This methodology has to provide the basis for planning investigations even though there is an inherent lack of conventional spatial network data for syntax analysis.

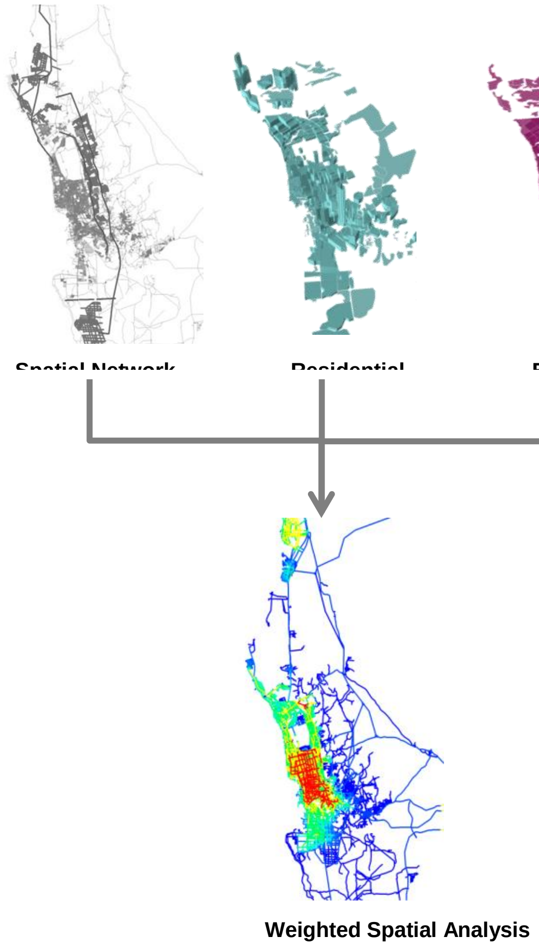

Figure 2: Components of a weighted space syntax model.

The methodology develops a weighted space syntax model in which each street segment would be weighted by the number of trips it generates as an origin or destination within the sub-regional context. The system of weighting is based on a the potential of each land use in attracting or generating movement, which then can be assigned to the associated street segments. In this approach, the impact of land use and population is transformed to a currency of movement, or 'urban activity', in a spatial network model. By doing that we will have a tool which is sensitive not only to spatial changes, but other changes that we cannot easily determine due to a lack of spatial information (Figure 2).

The principles of weighing space syntax measures has been explained in another publication (Karimi et al., 2013), but in brief, the non-weighted Angular Choice (or angular betweenness centrality) is calculated by obtaining the shortest angular trips between all segments, and then counting the number of shortest trips that go through each segments, or: $B_{\theta}(x) = \sum_{i=1}^{n}\sum_{j=1}^{n}\sigma(i,x,j)$, such that $i \neq x \neq j$; where the function $\sigma(i,x,j)$ equals 1 if the shortest path from i to j passes through x, and 0 otherwise.

Choice, or angular betweenness can be weighted by letting the function σ depend on the weight if the shortest path passes through x, rather than being equal to 1; hence the weighted betweenness is:

$B^{w}_{\theta}(x) = \sum_{i=1}^{n}\sum_{j=1}^{n}\sigma^{w}(i,x,j)$, such that $i \neq j$; where the properties of the origin as well as of the destination contribute to the weight. Here, the weight of the origin ω_o (the number of residential trips emitted from this segment); and the weight of the destination ω_d (the number of trips attracted by a segment). The total weighted function σ^{w} equals

- $\omega_o + \omega_d$ if the shortest path from i to j passes through x and $i \neq x \neq j$
- $\omega_o/2 + \omega_d$ if the shortest path from i to j passes through x and $i = x$
- $\omega_o + \omega_d/2$ if the shortest path from i to j passes through x and $x \neq j$
- 0 if x is not on the shortest path between i and j

This weighting is implemented by a DLL module that works with Depthmap software (Karimi et al., 2013).

The spatial model of Jeddah used for the analysis was a user drawn axial model. Although there are logics behind using other types of spatial models, such as the road centreline model, in regional studies (Dhanani, Vaughan, Ellul, & Griffiths, 2012), the user drawn model appeared to have the right level of details required for the purposes of this study. The wide multi-lane motorways were modelled using single axial lines. Furthermore, spatial features of the urban grid like roundabouts and highway exits were modelled using simplified representations. Land Use data was available is a GIS format from 2006. This was available at the resolution of plots. No data regarding the building stock was available. The land use data was supplemented using satellite imagery to bring it up to date with the 2013 scenario.

The total population for the year 2013 was 3.6 million as per the 2013 census. Population for the 2033 scenario was generated using growth assumptions by lead planners and was estimated at 6.2 million. This was distributed spatially with respect to the growth options which were developed for the city (AECOM, 2013, 2014).

Population was distributed across the city based on the type and amount of residential land use .The population per housing type was available per municipal district. This data was firstly allocated to the individual plots based on their Gross floor Area and housing type. Plot Area was converted into Gross Floor Area based on Floor area ratio assumptions (AECOM, 2014). Then the population per municipal district was divided amongst the respective plots as a proportion of their GFA (Gross Floor Area). The distributed population was not an indicator of the exact amount of people living in those plots, but a proportional indicator of residential densities across the city. The following housing types were used for this calculation: Low Density Housing, or Villas, High Density Housing, or Apartments, and Unplanned Settlements.

Employment data was distributed in a slightly different way from the population data. The total employment from the 2013 census data was divided into various sectors based on assumptions provided by the planners. Once each land use category had its own allocated employment, it was then distributed to the plots based on their Gross floor area. The plot areas were converted into GFA's by applying FAR assumptions provided by the planners.

On top of census population and employment numbers, huge employment and activity centres such as the airport and port also act as points where additional users or travellers are introduced in to the city. The model deals with these inputs in the same way as the population and employment figures, such that that these areas generate and attract movement at different times of the day. The port and Airport were allocated values based on data showing the number of international/national flights/passenger boats arriving per year (AECOM, 2014).

Since the area of study was the entire sub-region of Jeddah, it was crucial to add the impact of large cities in the wider region, i.e. Makkah and Madinah. The population and employment for Makkah and Madinah were allocated to the segments from which these towns are accessed from Jeddah. The data regarding the ‘mega projects’ was treated similar to Makkah and Madinah and their population and employment weightings were applied to the segments they would be accessed from. No extra spatial layout was added for these projects.

4. Distributing the weightings and weighted space syntax measures

The method to assign the population and employment weightings to the segments was a crucial step. Linking plots directly to the segments was not really viable since the available data was not to the required resolution for such an approach and even if such data existed the direct link method would have only increased the computational time significantly without providing any additional information which could be realistically used for the particular scale of the project. The selected approach therefore, was of aggregating the data and then distributing it within the segments enclosed within the aggregated boundary. Currently the data was aggregated at municipal district level. However the spatial definition of these districts did not follow any typological or morphological patterns. For instance, some districts combined low-density villas and high-density unplanned settlements. To resolve this issue the data was aggregated by defining smaller parts of the city that share similar morphological characteristics. These areas were called ‘superblocks’.

Superblocks were defined through the following analytic process (Figure 3):

1. Blocks have been defined by the major routes or the foreground network. This was identified to be all the street segments with a value of Normalised city-wide Choice (NACh Rn) above 1.3. This figure was arrived at through an iterative process using Hillier’s work on the normalisation of the Choice values in the un-weighted space syntax models (Hillier, Yang, & Turner, 2012). The street segments of the foreground network were outside the superblock boundaries.

2. Where significant changes to morphology occur these blocks have been sub-divided - this allows unplanned settlements or large single use plots to be incorporated,

3. Existing municipal district boundaries were used as a constraint to ensure ease of implementation in latter stages of the project.

4. Mega projects being built or to be built by 2033 were also defined as superblocks

This process created 520 superblocks covering all the parts with the Jeddah Governorate boundary.

Figure 3: Components used to define Superblocks.

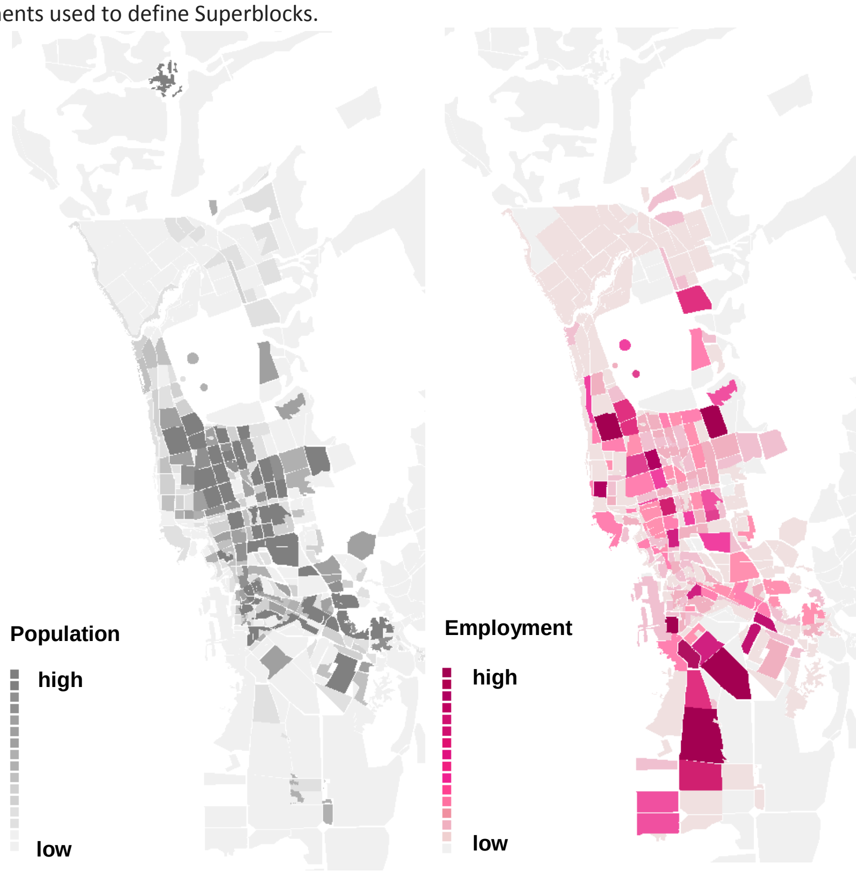

Figure 4: Distribution of population per superblock.

Two approaches were tested for the distribution of the weightings from the superblocks to the segments. In the first approach the weighting per superblock was averaged based on the number of street segments contained within the superblock, but this methods had some flaws. For instance, the street segments of the unplanned settlements were highlighted with very high values of Normalised Choice at the global scale, which were even higher than the motorways. This did not make sense as the spatial structure unplanned settlements would be expected to contribute to local rather than global movement in the city (Karimi & Parham, 2012). This irregularity is due to the fact that this method of distribution results in all segments within a superblock to have the same amount of weighting assigned to it, overloading the unplanned settlements with too much weight in proportion to the other segments in the model. To correct this problem the second approach averaged the weightings per superblock based on the total length of the street segments contained within the superblock. This approach was based on the assumption that the longer street segments will have a higher probability of having more land use located along them and thus should be allocated a higher weighting. The average weighting per street segment length was then allocated to the street segments in proportion to their length, such that the longer street segments got a higher weighting and vice versa.

It is important to note that since the motorways and highways, which are the longest street segments, were not included within the superblocks boundaries no weightings would be applied to them. The reason for this was that it would not be possible to access any land use from the motorways and thus they would not generate or attract any movement by themselves, but only act as routes.

Once the weightings are applied to the street segments, the model is processed in Depthmap software. In an un-weighted segment angular analysis the Choice value of a segment is a result of the angular change during a trip from origin to destination and the final Choice value is the summation of all the trips that pass through the street segment (Hillier & Iida, 2005). However, in a weighted segment angular analysis the Choice value gets multiplied by the product of the origin weighting of the street segment the trip started at and the destination weighting of the segment where the trip ends (Karimi et al., 2013):

For n number of trips passing through a segment
O representing the origin weighting
D representing the destination weighting

$$\text{Weighted Choice} = Ch \times O_1 \times D_1 + Ch \times O_2 \times D_2 + \ldots\ldots\ldots\ldots + Ch \times O_n \times D_n$$

Weighted Choice was further used to calculate 'Normalised Weighted Choice' by dividing the log of weighted Choice by the log of 'Total Depth' at the same radii, as suggested by Hillier (Hillier et al., 2012). This algorithm has shown promising results at global radii. The global measures have been the most suitable measures for the sub-regional scale, but if the methodology is to be applied to more local scales, further research is required to understand the behavior of weighted choice at local radii's. It should also be mentioned that other syntactic measures, such as 'Integration' could also be weighted, but in the current paper, we focus on the Weighted Choice since it appeared to be the syntactic value that has worked best for this study's sub-regional model.

5. Application of the integrated model: key Findings and improvements on the un-weighted spatial model

The weighted methodology was developed with the aim to create a tool to help the planners develop and implement the planning policies for Jeddah's growth till 2033. Even though the focus of the methodology was to test future scenarios it has also provided deeper insight into the functioning of the existing city. It helped explain urban phenomena such as the impact of unplanned settlements, vacant subdivided areas and so on to a higher resolution than pure spatial analysis could not have delivered. If the results of the two Un-weighted and Weighted Normalised Choice are compared at the global radius it becomes apparent that the weighted model can improve the ability of the model to explain particular aspects of the city structure more accurately than the un-weighted model. Below we discuss some of these improvements.

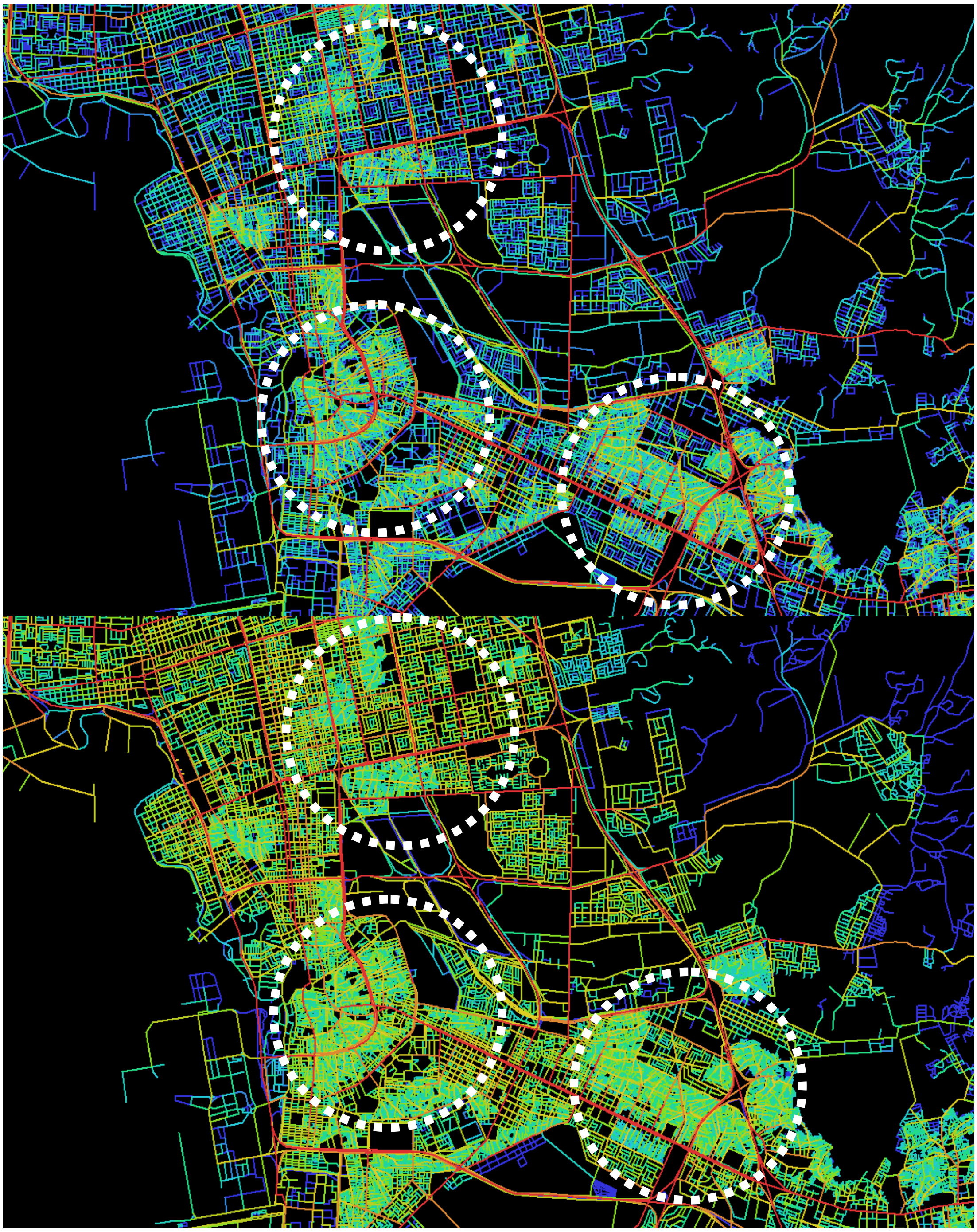

Figure 6: Comparison of the movement potential of unplanned settlements with the rest of Jeddah for the un-weighted (top) and weighted model (bottom).

In the un-weighted spatial model of Jeddah, the segments of the unplanned settlements had a high global movement potential in comparison to the Normalised Choice values of the rest of the model. This was an unexpected result as the influence of the unplanned settlements on movement was expected to be more distinguished at a local scale not at a citywide scale (Karimi & Parham, 2012). It was inferred that the high density of streets (node count) of unplanned settlements distorted the results of the un-weighted model and overestimated the movement potential of some of the street segments. The adopted methodology corrected this by weighting the segments with population per segment length. As the unplanned settlements have short streets in comparison to other parts of the Jeddah, distributing the weightings per unit length of the street segments resulted in a realistic representation of the spatial properties of the unplanned settlements at the global scale (Figure 6).

A general weakness of the un-weighted spatial model, which highlights the movement potential based on only the spatial configuration of the street network, is that it treats all street segments equal in terms of the activities, with which they are associated. Space syntax theory explains that streets with a high movement potential attract movement-dependant land uses (Hillier, 2009), but that is not always the case in many parts of Jeddah. For instance, Falastine Street is a commercial street with many eateries and shops along it, but due to a recent physical intervention the western end of it has become configurationally a dead end (Figure 7, top left). As a result, this part of the street shows a low potential of urban activity on a citywide level, but due to the presence of established land uses, the street is very active indeed. The weighted model compensates for this type of issues by adding the influence of the commercial land use to its natural movement potential. This accentuates the role of the street as a destination and generates more movement that what configurational properties suggest (Figure 7, bottom left).

The un-weighted model of Jeddah also overestimates the movement or urban activity potentials of some street segments, which have no buildings, or active land use along them. In Jeddah, many vacant parts of the city are sub-divided into plots, which have not been occupied yet. Since an un-weighted model does not distinguish between street segments with or without land use along them, the street segments act as a destination/origin, as well as a connector and thus generate both 'to' and 'through' movement in the model. This results in overestimating the impact of the street segments on the movement pattern in the city (Figure 7, top right). The weighted model corrects this problem by allocating an origin and destination weighting of zero to segments with no land use located along them. The street segment thus acts only as a route and does not generate any movement as an origin/destination. This results in the segments with a Choice value of zero unless they are the shortest route between other origins and destinations (Figure 7, bottom right).

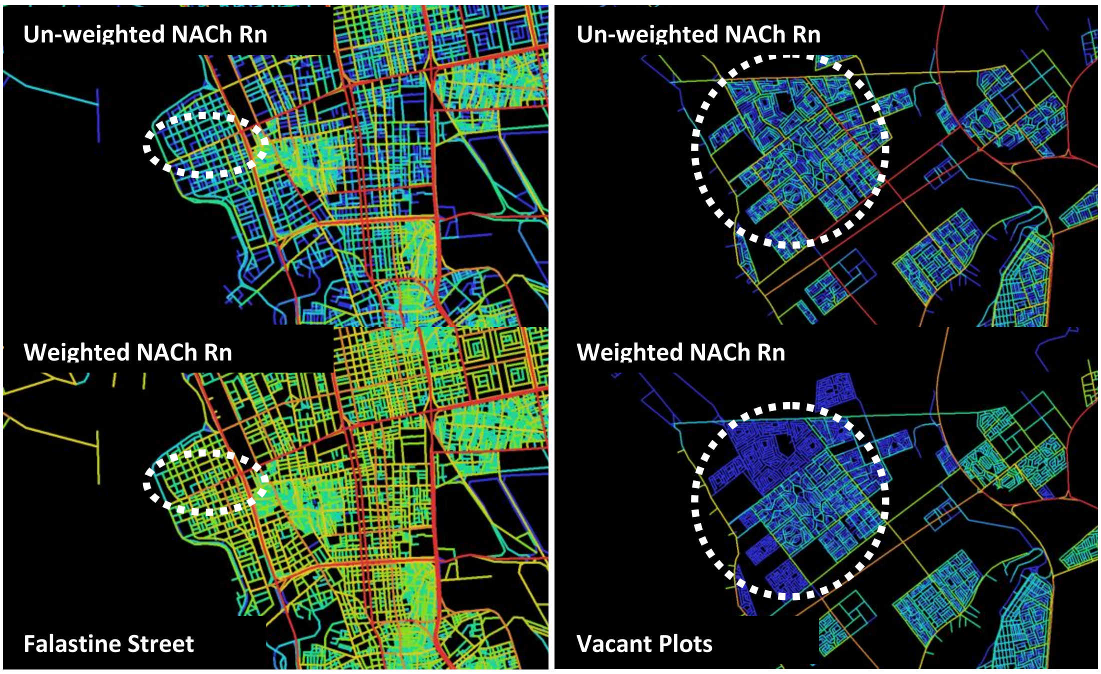

Figure 7: Comparison of the movement potential of Falastine Street (left) and Vacant sub-divided lots (right) in the un-weighted (top) and weighted (bottom) models.

The weighted methodology also helped the analysis of the regional movement potential of Jeddah. As the context for the project was the Jeddah's sub-regional system' it was important to include the impact of Makkah and Madinah on the regional movement network. This would only be possible with un-weighted space syntax methodology by spatially modelling the two cities and analysing all three cities as a part of the same model. The weighted methodology, however, allowed this analysis to be undertaken without modelling any of the neighbouring cities. The impact of the two regional cities was added by representing the two cities as superblocks and transferring the weightings of the population and employment to the street segments that connect them to Jeddah. Since the focus of the project was to understand the spatial configuration of Jeddah sub-region, modelling and processing the two cities spatially would have taken a long time without providing any extra information for the study. Figure 8 shows how the entire sub-regional system is impacted when the weight of regional cities are added to the model.

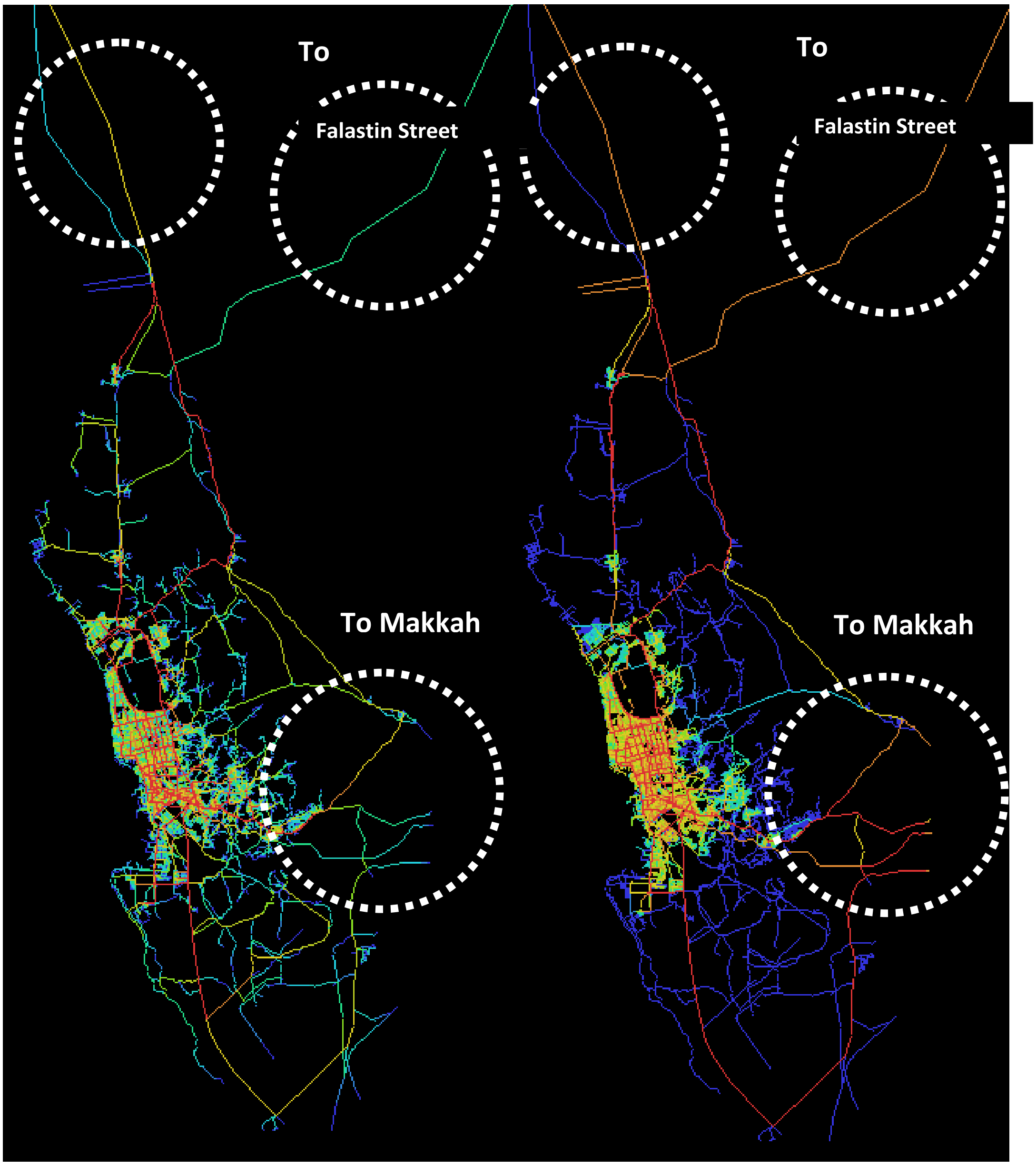

Figure 8: Increased movement potential of sub-regional system in the un-weighted model (left) compared to the weighted model (right).

6. Testing future scenarios

One of the greatest advantages of the space syntax methodology is that it enables us to test and evaluate spatial scenarios (Hillier & Stonor, 2010), but the un-weighted space syntax analysis can only test the impact of proposed spatial changes. This was an improtant limitation for the Jeddah Sub-regional study since the future scenarios had a very strong non-spatial elements, such as land use, density and policy allocations. The weighted methodology provided the means to test future land use zoning and 'mega projects', which had no spatial data available due to being in different stages of development.

The process of interaction between planning decision and the weighted model is an iterative process (Figure 9). Decisions made by planners would be applied to the weighted model by changing the spatial connections, land use system, densities and other factors. The impacts then mapped by a 'Difference map', which shows the intensity of the impact in various parts of the city (Figure 10). To generate a difference map the weighted values of the segments of the existing model of Jeddah were subtracted from the weighted values for various scenarios respectively to see how the movement, or urban activity potentials are changed and by what degree. The impacts then are assessed against the defined objectives and principles of the Sub-regional Plan. If the impacts are desirable, they would be accepted, but if the impacts are negative, they would be rejected and have to be replace by new decisions. This process continues until a balanced result is reached (Figure 9).

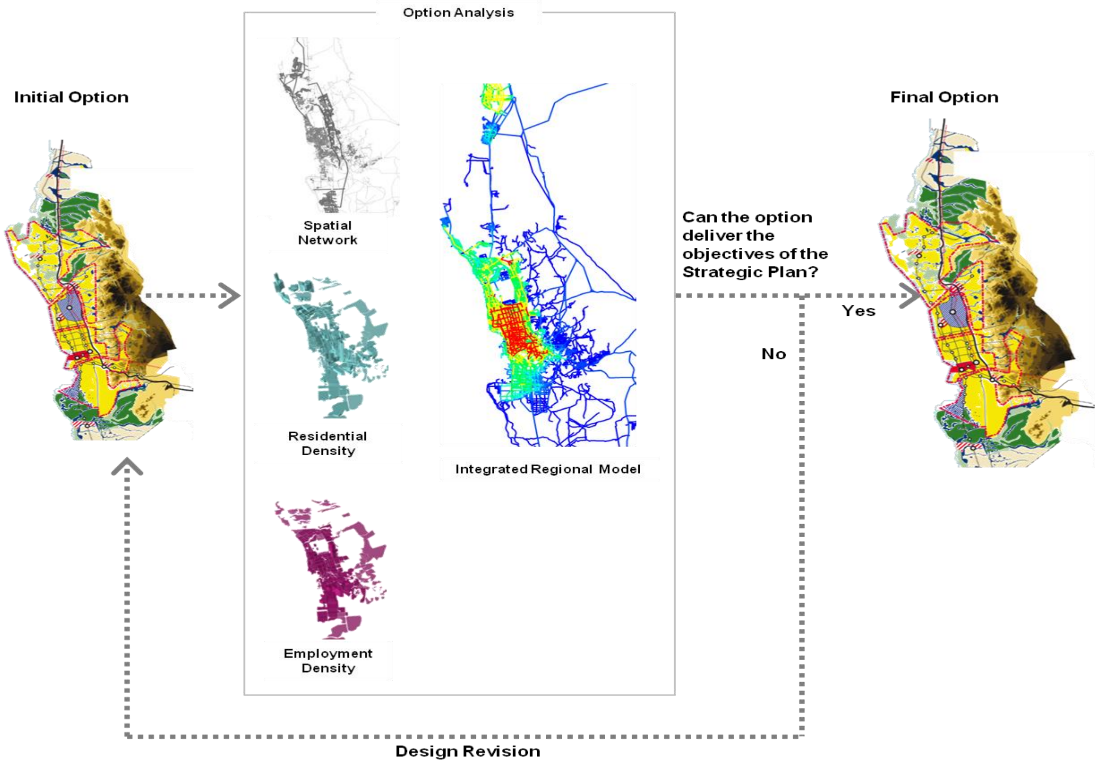

Figure 9: The iterative process of 'option generation' and 'option testing', using the integrated urban model, to create the optimised final option.

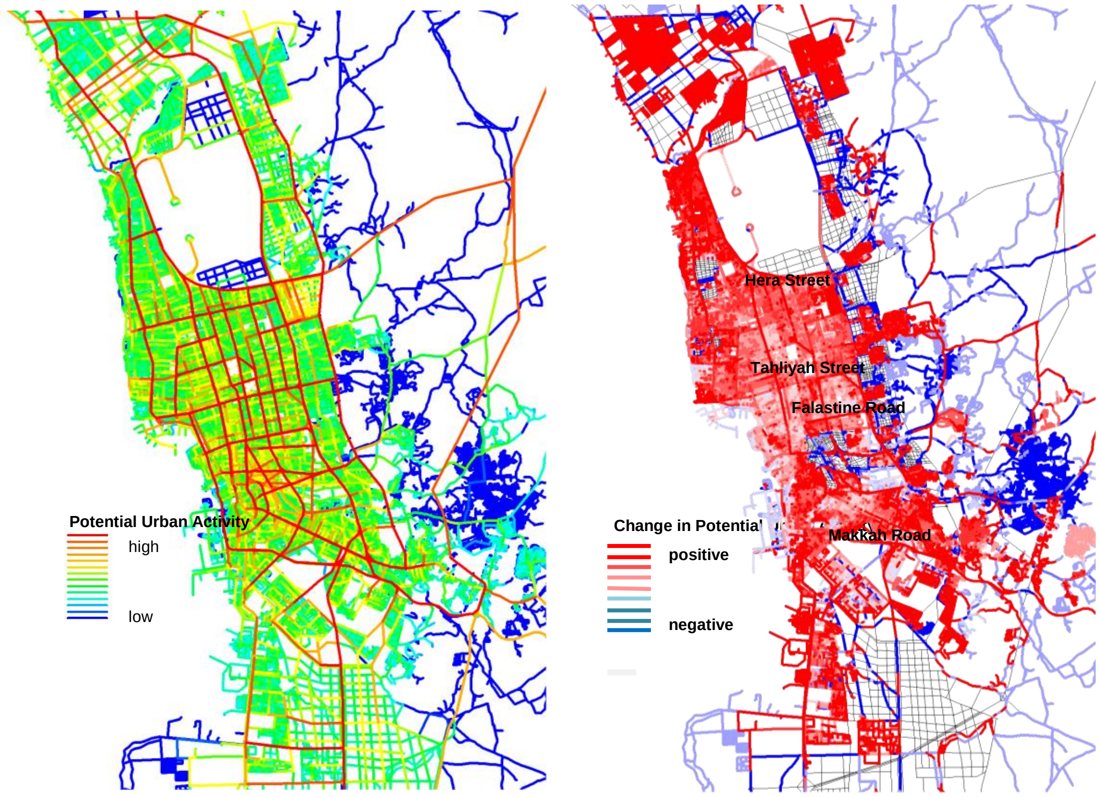

Figure 10: Planning scenarios are modelled, using the Weighted Choice Model (left) and the measures are compared against the existing condition, using 'difference maps' (right) to understand the impact of the planning decisions.

At the final stage of the planning process, three different options for the growth of the city were developed and assessed. The planning policy developed by the planners for 2033 identified issues such as the coastline, unplanned settlements, the port, movement network to be improved in the new Sub-regional Plan (AECOM, 2014). The scenarios with varying distribution of population and employment were tested to understand the impact of the resultant movement on these strategic parts of the city. The analyses of the future scenarios were compared with the existing city and the results were ranked against each other to identify the strengths and weaknesses of each option. The three options were then ranked against each other under the planning policies to see which option performed better at achieving the aim of the policy. This system of ranking the options formed the framework for developing a combined option, which incorporated the strengths of the three scenarios (Figure 9).

7. Discussion and conclusions

The main focus of this paper has been the development of an approach to link the fields of spatial network analysis and regional planning through a space syntax model that could take into account the location and magnitude of land uses, densities, attractors and other non-layout attributes of a plan. This objective has been achieved in two ways. The first was to enhance the power of spatial network analysis in explaining planning phenomena. Further verifications are still needed, but so far the integrated model has shown significant improvement over the pure spatial model, which itself had been proved a great investigative and predictive tool in Jeddah (Karimi et al., 2013; Karimi & Parham, 2012; Space Syntax Limited, 2006).The second objective that has been fulfilled in this research is that the developed model has been used successfully in an iterative planning process, in which the planning decisions are modelled and their impacts are measured by the integrated model. The degree and distribution of the measured impacts then are used by planners to revise, change or optimise their decisions.

The weighted sub-regional model proved to be capable of reducing the dependency of existing space syntax models on the availability of spatial layout data. The result is a spatial model impacted by land use distribution, which adds the attraction or repulsion of certain land uses to the movement, or urban activities, generated by the spatial configuration of a city. This is a powerful tool to diagnose the impact of proposed design decisions on the spatial system and to optimise such decisions. This has implications not only for planning studies, but also for all types of studies that deal with sparse spatial layout data.

The analysis of the weighted methodology enhanced our understanding of the spatial configuration of the existing city by taking into consideration the spatial anomalies in Jeddah, such as the unplanned settlements, vacant sub-divided plots and major land use attractors like retail. This integrated approach helped inform the planners of the opportunities and constraints of the existing city and assisted them to form the planning guidelines, which identify the framework for the growth scenarios in Jeddah. The methodology also helped streamlining design decisions by testing the impact of proposed spatial or land uses changes. This methodology in fact narrows the gap between the theoretical planning approaches and their realisation leading to an efficient way to choose the right growth direction and to develop an appropriate strategy for phasing the future development of the city.

A by-product of this research has been the introduction of 'superblocks' as a tool to help disaggregate the population and employment data spatially. Not only did the superblocks help in distributing the weightings from the land use to the street segments, they also helped in coordinating and communicating the spatial network analysis with planners and the decision makers in the city. Superblocks profile the city into defined spatial entities based on movement patterns, morphology, development and municipal boundaries. Each superblock contains urban information, such as average Choice and Integration values, existing land use distribution, projected demographics and employment, amount of vacant land available, average FAR, ground coverage and so on, which provided a comprehensive framework for the planners to design future scenarios and develop planning policies for the city while respecting the existing context of Jeddah. Superblocks also helped incorporate a bottom-up space syntax analysis with the top down planning approach adopted by the planners.

Similarly, the 'difference map' method, which used to map changes revealed by the integrated model, proved to be a very useful way of understanding or interpreting the results on the one hand and communicating them with planners and decision makers, on the other hand. This device played a strong role in the iterative process introduced in this study and enhance the use of the integrated model.

Finally, it is very important to emphasise that in order to improve the applicability of this model it will be very useful in future to conduct further research on how the results of the 'integrated urban model' could be verified against certain social or economic data, such as vehicular movement, land prices, social deprivation and economic prosperity. Statistical methods, such as regression or multi-regression analyses and Principal Component Analysis (PCA) are some of the tools to be used to improve the validity of this model. However, such studies on a regional level and in the context of cities like Jeddah, in which any coherent database is scarce, would be a major challenge. It is also essential to continue this research to develop further the weighted network methodology, along with the development of the new methods of network analysis, to see what other measures or scales could be integrated into the model.

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