Network Typology, Junction Typology and Spatial Configuration and Their Impacts on Street Vitality in Singapore

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Absract
The aim of this paper is to develop a method for describing urban patter by means of simple mathematical calculations applicable for urban design. Two approaches were used and combined with one another. The first approach was Stephen Marshall's method for calculating T-junctions and X-junctions seen in relationship with a cul-de-sac and network type of street grid. The second approach was to use the space syntax method. Finally the results from these two approaches were overlapped with one another.

The experiment is carried out in Singapore, a country where movement by metro (MRT: Mass Rapid Transportation) and car plays a significant role. The whole city or country is analyzed with the Depthmap software, intelligibility is calculated, resulting with an R2 of 0.06 (R=n). This shows concretely the city is highly dependent on car-traffic and metro network. Since Singapore has a tropical climate, pedestrian movement is naturally deterred. Therefore, on a local scale, some case studies around major transfer nodes where MRT stations are located are used.

The following operationable concepts describing urban pattern based on junctions typologies and networks typologies were used in this inquiry:

1. *Topologically shallow grid network consisted with X junctions*
2. *Topologically deep grid network consisted with X junctions*
3. *Topologically shallow grid network consisted with T- junctions*
4. *Topologically deep grid network consisted with T- junctions*
5. *Topologically shallow tree network consisted with X-Junctions*
6. *Topologically deep tree network consisted with X-Junctions*
7. *Topologically shallow tree network consisted with T-Junctions*
8. *Topologically deep tree network consisted with T-Junctions*

When combining these typologies with space syntax values, the most integrated streets tend to be in topologically shallow grid networks consisting of X junctions. There the location of vital economic centres tends to be. The most segregated urban areas tend to be in topologically deep tree networks consisting of T-junctions. Hence, the above-mentioned concepts are used to define various genotypes with certain urban implications.

1. Introduction

The aim of this paper is to present a method for describing urban *pattern* and *structure* by means of simple mathematical calculations, combined with the space syntax analyses applicable for urban design. Two approaches were used and combined with one another. The first approach was Stephen Marshall's method for calculating T-junctions and X-junctions seen in relationship with a cul-de-sac and network type of street grid. The second approach was to use the space syntax method. Finally, the results from these two approaches were overlapped with one another and tested in a design project.

2. Selection of basic units used for description of urban structure and its underpinnings

Conventionally 'axial line' and 'segment' are the basic units used to analyse built environments from the spatial organisation inside buildings up to metropolitan scales. However, neither the axial line, nor the segment seems capable enough of describing car-based movement, which is more continuous than pedestrian based movements. As Carlo Ratti argues, 'however, the definition of natural movement makes it difficult to validate space syntax predictions: the urban grid is very rarely loaded in a uniform way. Consequently, measured movement patterns will always be biased' (Ratti, 2004, 487-499). Hence, the definition of natural movement needs modification.

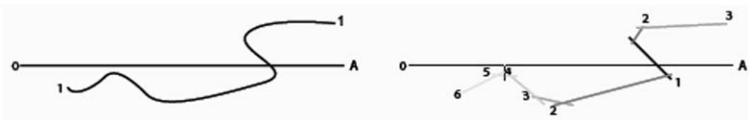

Figure 1
Topological steps by car-based movement and pedestrian movement

In this paper Singapore is used as a simple example for testing. Figure 1 shows how the movement pattern in the curved line 1-1 (left) can be represented as a set of axial lines (right). A syntactic step is defined as the direct connection or permeable relation between a space and its immediate neighbours or between overlapping isovists. In an axial map a syntactic step may be understood as the change of direction from one line to another (Klarqvist, 1993). In this regard, one 'topological depth' can be understood as a turn one has to take to perceive another space, which is beyond one's vista at a point. As tested in the experiment, the concept is apparently not applicable to automobile movement when each topological step is calculated with axial lines. A car driver does not stop on a road to make a choice of direction bases on his or her vista. Traffic light or road signs, seen together with direction choices, rather might guide the car driver to his or hers destination. In fact, there is hardly any kind of movement occurring in a completely 'natural' way.

As several research papers within the Space Syntax community focus on mostly pedestrian based movement, a few research papers focuses on car-based movements (van Nes 2002, Hillier and Iida 2007). Considering the growth of movement by automobile and metro in most cities around the world implies new demands for new and proper methods to integrate spatial analysis on movement at different scales with different transportation modes. In this contribution, axial lines and isovists analyses are applied when analysing the pedestrian based movements, while the continuous line are used when analysing car-based movement. The latter one can best be approached through a segment based angular analysis, recently developed in the Depthmap software combined with Steven Marshall's method.

This contribution aims not to stress on the discussion on whether a separation of vehicle and pedestrians movements is good or bad, or where and when it can be separated or not. The focus is rather on how these two types of movement flow will condition 'sustainable urban developments'. Firstly, urban development practice implies implementing diverse design programs, concerning different groups of space users. The movement patterns among these users will vary however inevitably interweave. Secondly, 'urban sustainability' has at least implied two dimensions regarding urban development: *efficiency* and *productivity*. *Efficiency* concerns issues as time and energy saving spatial strategies in order to make the various urban functions easily accessible for their users. *Productivity* concerns to facilitate a specifically optimized economic input in terms of a suitable optimal spatial location an urban setting requires in order sustaining its future development. When generating a sustainable urban development, urban interventions must facilitate all space users with their various modes of transportation movement pattern in such a way that all their destinations can be reached efficiently. Noticeably, a misplacement of urban functions combined with a low inter-connected street and road network is likely to generate private car-dependency.

As research with the help of the space syntax method has shown, a dense, integrated and inter-connected road network generate vital economic and cultural urban areas. Hence, it facilitates economic productivity. Furthermore, for all sorts of movements taking place in a certain road network (especially when one is examining an urban centre), a pure dense orthogonal grid structure within a short metric distance will guarantee highest accessibility from which one might conclude high efficiency. The hierarchy of movement is blurred in this particular sort of structure. As concluded, a dense, inter-connected grid-like road network will condition sustainable urban environment. However, in a compact urban environment, an urban network without sufficient well-connected movement hierarchy is unlikely to bring in efficiency but the contrary (van Nes, 2008).

Through the existing Space Syntax techniques, one can find out where the greatest amount of pedestrian movement is most likely to take place through the local integration analyses. As regards the efficiency of car traffic and pedestrian movement, urban areas with a low local integration combined with poor connections between highway and local streets seem to generate private car-based dependency (van Nes 2008). Moreover, the degree of vitality of public transport stations depends on how the stations are inter-connected with the street and road net in their vicinity (Mulders-Kusumo 2005). The next step is to build up a method to clarify the hierarchy among pedestrian and vehicle transport. It can at least help urban planners to specify which urban function to locate at where, as to optimize the benefit returned from strategic projects. As research has shown, there are correlations between rent and land prices and the degree of spatial integration on local and global scales (Min, Moon and Kim, 2007).

3. Method of description of urban structure and urban pattern

Space syntax is proved to be a solid tool to describe the spatial properties of urban structure. As Sonit Bafna describes, space syntax is 'best described as a research program that investigates the relationship between human societies and space from the perspective of a general theory of the structure of inhabited space in all its diverse forms: buildings, settlements, cities, or even landscapes' (Bafna, 2003, 17-29). Somehow it is uncanny that there exists no clear category of description of urban forms when the property of urban forms is widely correlated with social phenomenon by researchers. Although it has been discussed in Bill Hillier and Julienne Hanson's early works on the method of clarifying 'grids' and 'trees' within an urban road network (Hillier and Hanson, 1984, 99-105), the usability of this method is relatively low to urban designers without professional training in mathematics and analytical skills. Considering the formulas to compute are probably concluded from empirical data sets, it makes them even harder to apply in design practice by urban practicionaries.

In contrast to space syntax, Stephen Marshall introduces several simple, but effective quantitative tools to clarify the types of urban network. In a way, he identifies various types of street *pattern*. However, most of the tools suggested in his book "Streets and Patterns" imply a large amount of manual work. His method is not transformed into computer software. Therefore, it can be a time consuming task to apply it in urban research and design practice on metropolitan scales.

In this paper, three different types of urban areas with their variations of their street networks in Singapore are extracted for research. The selection of networks is based on two criteria: Integration value from a preliminary axial-line analysis at the whole city scale and the local integration analysis. Figure 2 shows a global and local integration analysis of whole Singapore. As can be seen in the figure, the city centre has both high local and global integration values. In particular, in the local integration analyses, the Chinatown, the central business district, the Little

India and the Malaysian neighbourhood have high local integration values. The highways located in and close to the city centre have high global integration values.

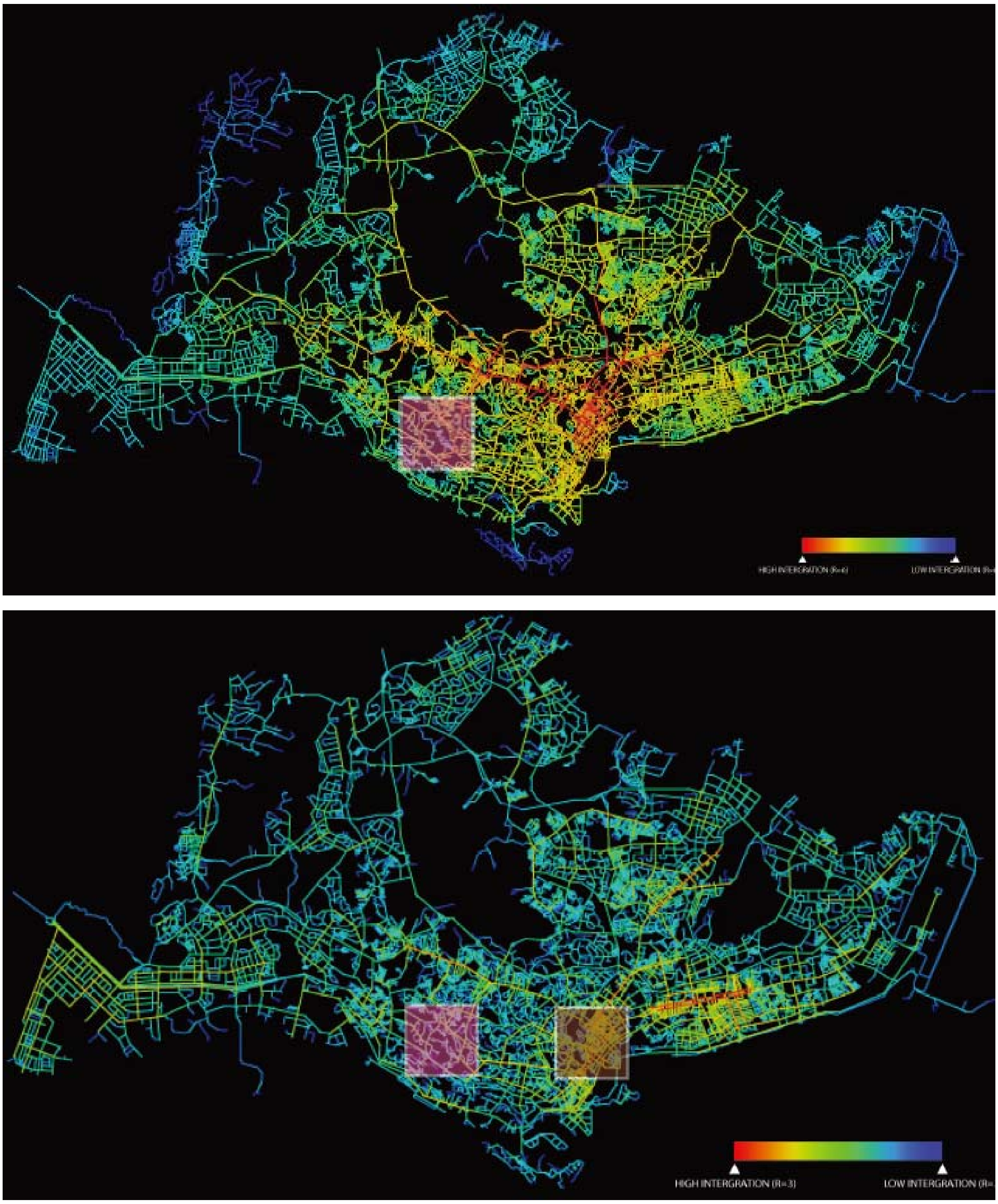

Figure 2

Spatial analyses of Singapore: Left, global integration (r=n); right, local integration (r=3

The first case study area is the Little India area located in Singapore centre. In this area several shops and shopping centres are located and cars and pedestrians crowd the streets. It is known to be a lively urban area, with a mix of traditional Singaporean small-scale buildings and modern high-rise buildings. The area has a network-structured street net. All streets are well connected to one another and consist of 'T-junction' and 'X-junctions'. The number of T-Junctions occupies 65% of junction types. The second case study area is a typical Singaporean residential area for the rich inhabitants located north of Dover MRT station. The area has a cul-de-sac street net, consisting mostly of 'T junctions' (91%). At present few pedestrian activities takes place in these streets. The third area is an urban area with variations of functions such as companies and luxury dwellings. These functions are poorly inter-connected to one another. The area has both a tree structure and a network structure on the street and road net and it consists of mostly ‘T junctions’ (75%). Most movements occur with vehicle transport. The municipality plans to make an office cluster in this area in the near future. Figure 3 shows some images of these areas.

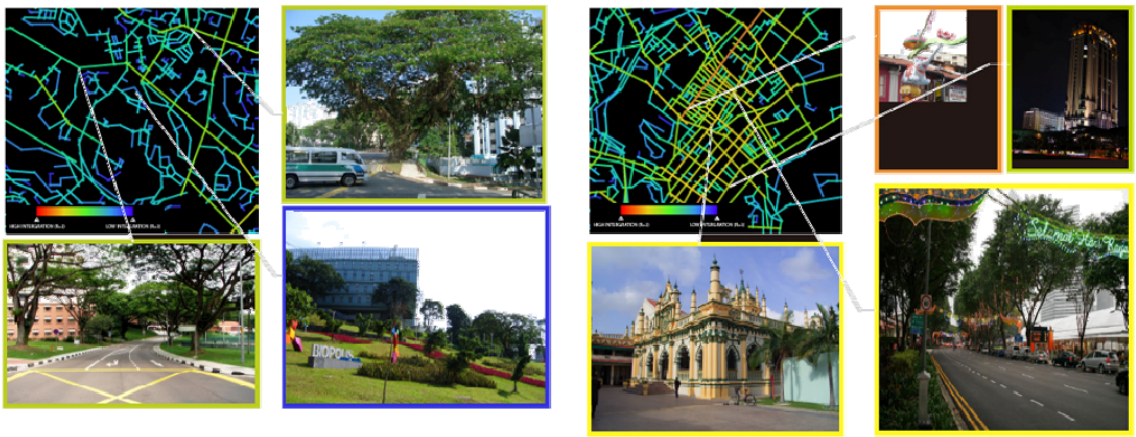

Figure 3
Left: residential area and future office cluster; right: existing urban center

Firstly, three maps of topological depth from the MRT stations are produced (figure 4). The axial line with step 0 is chosen as the line (or street) where the metro stations are located. The area’s degree of accessibility to the MRT stations is important, as the flows of movement in Singapore are highly dependent on an advanced MRT network. The preliminary conclusion from this analysis is to show how shallow or deep an area’s street pattern is from the stations. In order to show how deep or shallow a street net is in the area itself, justified maps are made according to the principle introduced by Marshall. As can be seen in figure 5, Little India has high accessibility to the MRT station, while it is low for the other two areas. The justified graphs of the street net of the three areas are shown below in figure 5.

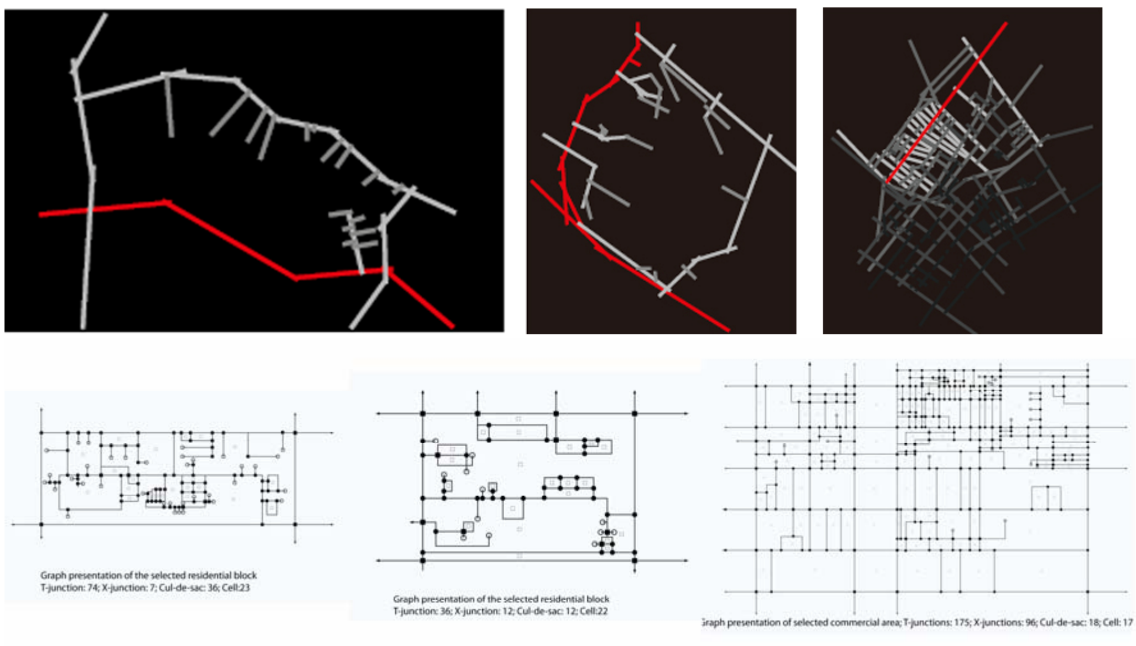

Figure 4.
Above: topological depth from MRT stations; Below: justified graph of the three patterns

The result from this analysis is illuminating when the numbers are located on the chart where the composition of different junction types is shown (figure 4). The degree of being a ‘tree’ type pattern or ‘grid’ type pattern is somehow brought into light. With other words, it is possible to analyse how topologically shallow or deep various types of street grid is, depending on the types of junctions. One has to make a distinction between the network *pattern* and network *structure* and to reveal how they are interaction spatially and, hence, their impact on urban movement and functions.

4. Result and implication

As discussed above, the result from the step depth analysis shows in terms of pedestrian movement whether a network is easy accessible or not. However, the *depth* analysis does not have the implication regarding the network's *form*. The justified map shows, to some extent, the topological depth in terms of car-based movement because the idea of continuity is introduced. As illustrated, the concept of 'topological depth' might be less sensitive to automobiles due to their destination-oriented movement pattern. The justified map in this sense helps only describe the network in a quantitative way with number of 2 different kinds of junction and cul-de-sacs and cells formed by the junctions. In another word, by combining the results from two different methods we can describe a network possibly as:

- Topologically shallow grid network consisted with X junctions
- Topologically deep grid network consisted with X junctions
- Topologically shallow grid network consisted with T- junctions
- Topologically deep grid network consisted with T- junctions
- Topologically shallow tree network consisted with X-Junctions
- Topologically deep tree network consisted with X-Junctions
- Topologically shallow tree network consisted with T-Junctions
- Topologically deep tree network consisted with T-Junctions

The result shows types of urban networks with concerns of natural (pedestrian) movement and car-based movement.

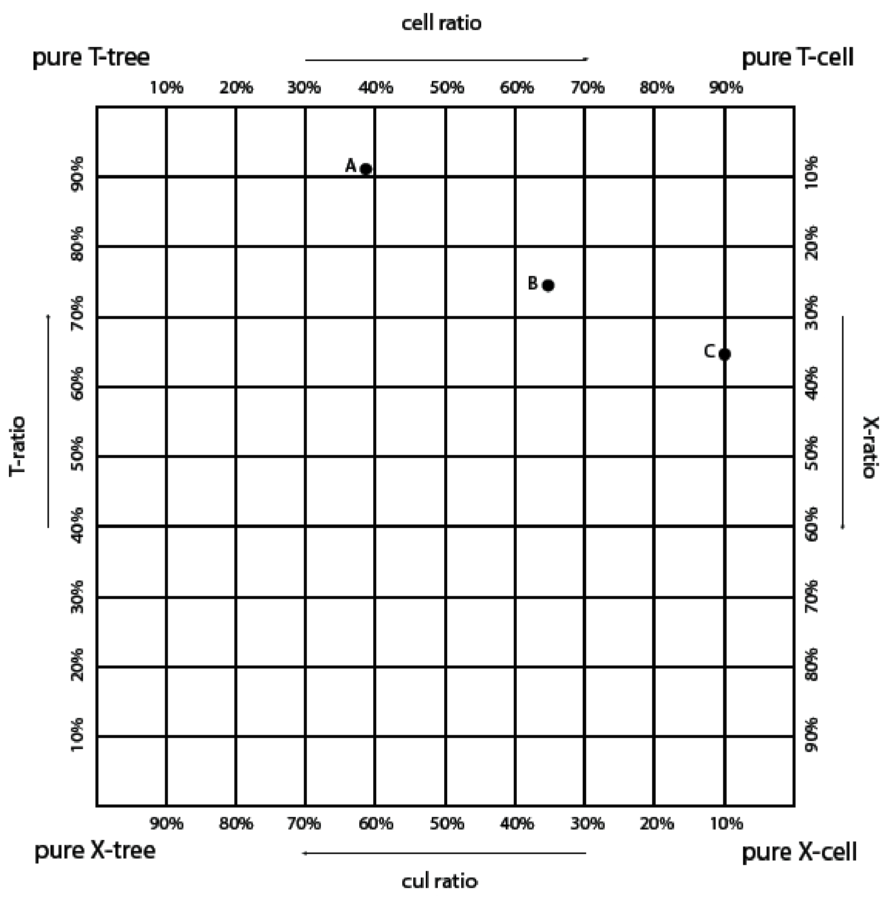

Figure 5
Degree of inter-accessibility of street patterns in the chart street pattern descriptor

A further step can be made when building up relations between these forms with topological quality and existing functions. That is to mean, from a designer's perspective, it provides typologies of design applicable to specific context. In order to reveal it further, one can try to imagine fictionally an Arabian city centre and an American city centre of the same size. In an Arabian city, we all know there might be a high number of total depths of its street and road net while it consist of more T-junctions than American, Asian and European cities. Conversely, in an American city centre one can easily expect a high number of X-junctions with fewer topological depths. If a designer is commissioned to design a new centre in an Arabian country, it is likely for the plan to fail if a model from American city centre is applied. In this sense, the types with concluded from the combined method can be used with concerns of local knowledge such as existing functions, planning policy, cultural preferences and trends.

In the case of Singapore, the three selected cases shows that a residential area tends to be in the form of topologically deep tree network with T-junctions; an office cluster topologically deep grid network with T-junctions; an existing vital centre topologically shallow network with a high number of X-junctions. The residential areas tend to have low local integration, while vital urban centres with a network with many X junctions tend to have both high global as well as local integration values.

Figure 5 shows the location of the three areas in a matrix. As can be seen in the figure, the residential area (point A) is dominated by T-junctions in a cul-de-sac street grid, while the Little India area (point C) is with relatively more X junctions than the other case study areas in a network grid. The proposed new office area (point B) is located in-between. Hence, if one aims to implement a new vital urban centre in Singapore, then knowledge from the street pattern from existing successful city centres can function as a strong reference for proposing new solutions for the new office area. To conclude, the higher number of X junctions, the more economical vital the area tend to be.

5. Experiments with the space syntax methods

With scant, although growing, appreciation of how space affects society, it would seem premature to argue that we are in a position to provide a method of design that might have certain albeit basic, but societal outcomes. As Edward Soja argues, we should be careful not to exceed the limitations of spatial description. As he declares, an exact explanation of social behaviour is beyond any theory due to the number of social variables in existence and the complexity of their interactions with each other and the environments. However, this does not imply that there is not a set of socio-spatial relationships existing in the world that cannot be modelled or applied into design (Turner, 2003,15.1-15.12).

Based on the results from the three areas' analyses, a design experiment is carried out for a new local urban centre in Singapore. However it can be still too gross grain when one superimposes simply the typology onto the existing context. Therefore, there are several parameters concerning the design process that should be clarified. Through a simple experiment by deforming an extreme 'topologically shallow grid structure', we found out that the influencing factor to topological depth by pedestrian movement can be the relative openness of a build environment. From the experiment's results, shown in figure 6, with an isovist analysis, one can conclude that the more relatively open one place is the more integrated the axial lines which go through this area will be. With other words, the highly integrated axial lines can be the best routes for pedestrian movements. Deducted from the result we can generate an inverse image for car-based movement. Therefore a hierarchy of street nets, serving hierarchies of movements, can be proposed. Furthermore, it is possible to propose a high density of functions along well-connected and highly integrated streets in the design proposal.

In the experiments with various design solutions for the new local urban centre in Singapore, the method presented above is applied. Some small model studies are carried out. When applying a relatively homogeneous grid upon the location, it can contribute to stimulate a more extreme case of vital well inter-connected streets than what it is at present. Places with strong identity tend also to be place with greater relative spatial openness. The more deformed the street grid becomes a hierarchy of movement is generated. Hence, through an un-equal distribution of isovist values, it can be used to propose the degree of density of the built mass. Along the highly integrated streets, high density of the built mass is proposed, while a low density of the built mass are proposed in the segregated streets. The results are shown in figure 7.

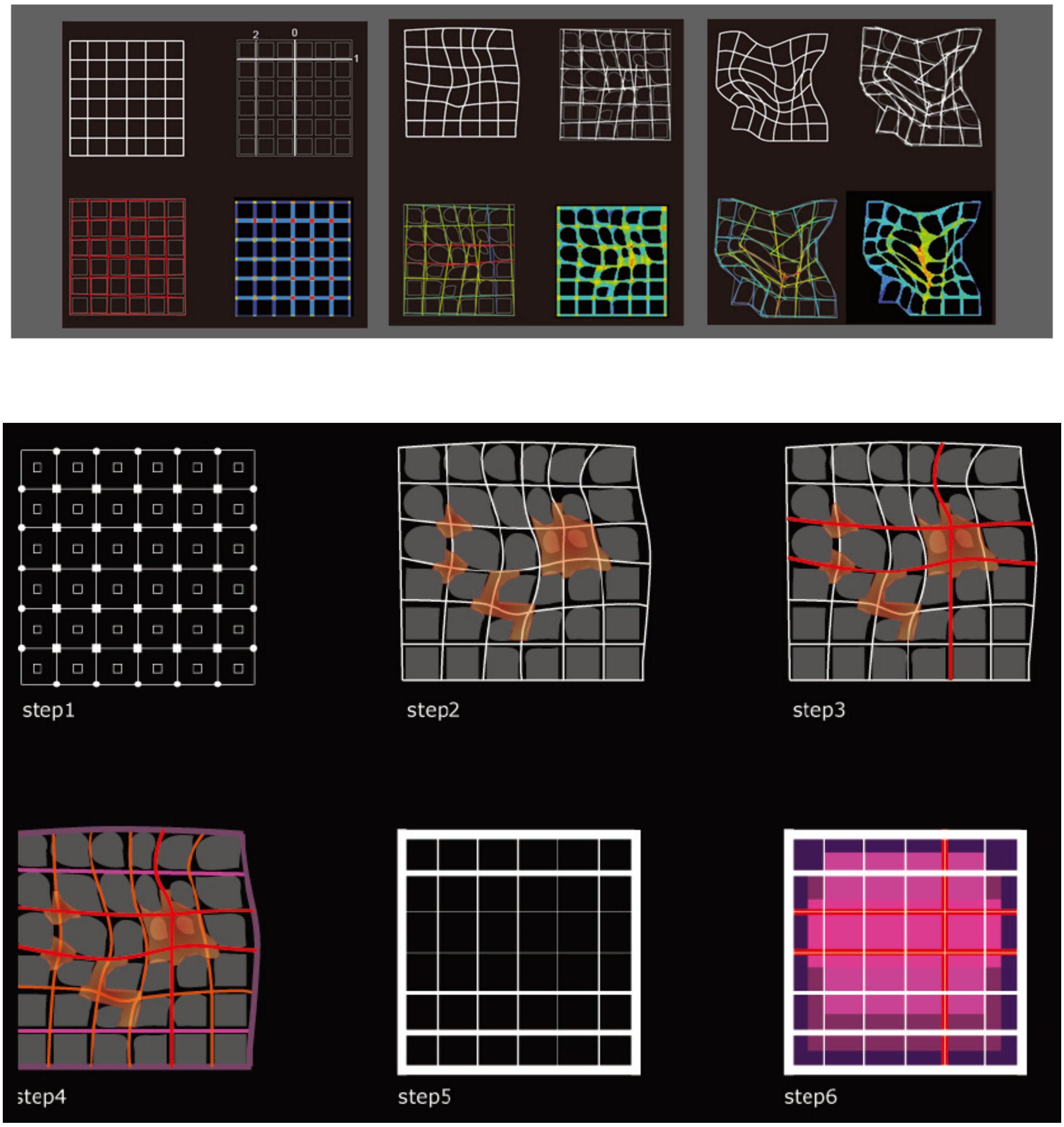

Figure 6
Above: experiment with various deformations of the grid; Below: model of a city center

Since the degree of spatial integration has implications of land value (Min, Moon, Kim, 2007), it can be also considered an indicator of possible functions and degree of density of the built mass. As indicated in the model studies, high density of the street net with a large variation of urban functions generates high local integration. The streets are then highly inter-accessible and well connected. Hence, high density of the built mass can be implemented among the highest integrated streets for an optimised usage of urban areas.

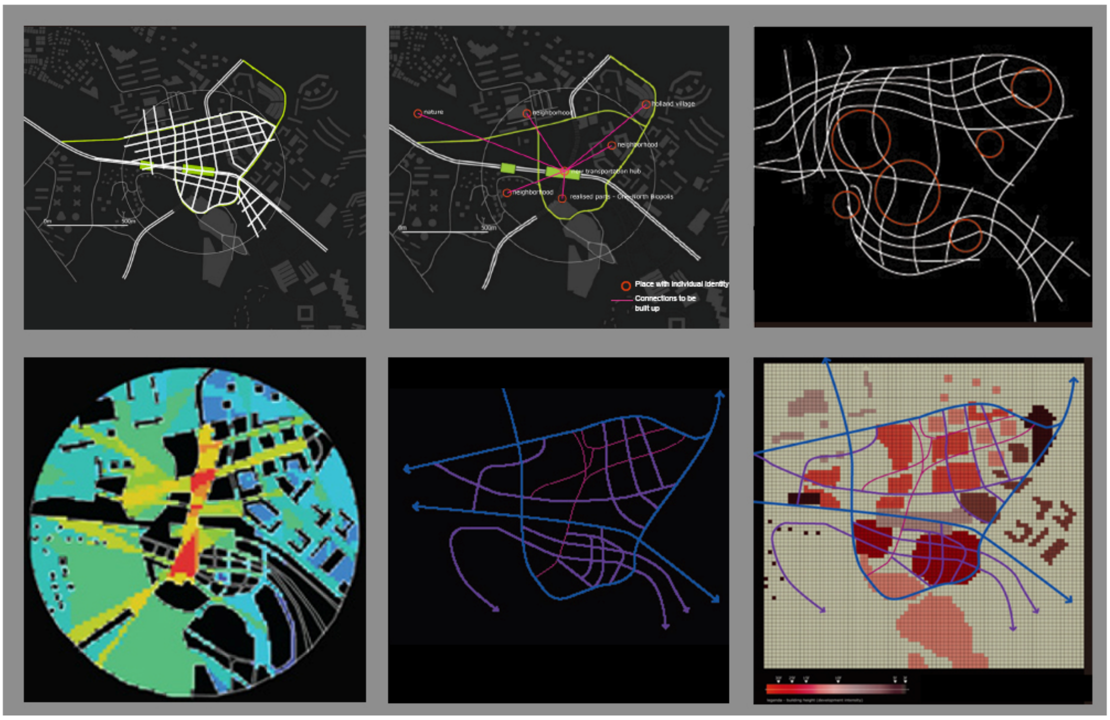

Figure 7
Model studies of a possible local urban centre in Singapore

6. Critical reflection

A design does not follow unequivocally and reproductably from a programme like a scientific prediction repeatable from its basic assumptions, *'ceteris paribus'*. When making an urban design project, the preliminary investigation and its conclusion, the programme of requirements, direct only partly the design solution. Even within the boundaries of a strict programme, unexpected and unpredictable alternatives are possible in design. Most design decisions about form, subsequent structure must be made without empirical evidence (de Jong and van der Voordt, 2005).

Spatial modelling is a process with a circle of induction and deduction. The inductive process results in a theory generated by sufficient amount of empirical data (statistical data), while the deductive process can be understood as a test to the theory that in return adds complexity to the theory. Even though space syntax is a tool heavily relying on empirical data, its compatibility to design must be scrutinized. If design is about to imagine a possible future rather than merely a probable one, then space syntax is at risk to underestimate the possibility of design. It is seemingly to be a researcher's urgent task to find a way to at least manipulate existing theories with concerns of design practice in a proper manner.

7. Conclusions – challenges for future research and applications on urban design

In this paper, the experiments carried out concern the concepts such as topological depth, integration, and convexity. However, more concepts are probably to be introduced in the phrase of design that enables a design to be strictly reviewed therefore retrievable.

Probably, with the application of 3-dimensional isovists analyses developed by Egbert Stolk and Arthur van Bilsen (van Bilsen and Stolk, 2007) into urban studies, the relationship between the building heights and a street net's spatial pattern and structure can be revealed. Several small experiments are carried out in a design experiment (figure 8) only with a 2-dimmensional isovists analysis. The highest density of the build mass is chosen in the design proposal where the highest integration values are from the isovists analyses. The total density index of the built mass is maintained according to Singaporean practice, while the shape and dispersal of the built mass is adjusted according to the dispersal of the spatial local integration values. The intention is to respond to the existing image of Singapore, but apply it according to the degree of street vitality as indicated in the isovists analyses. One can easily notice the place identity has changed dramatically in different scenarios while the spatial structure maintains. It is in question how a design research to build up scientifically reliable correlations between space and place, in another words, structure, form and identity. In this regards, the developing 3-dimensional isovist analytical tool might provide invaluable assistance. At present, it has not been tested out yet sufficiently yet in order to draw reliable conclusions.

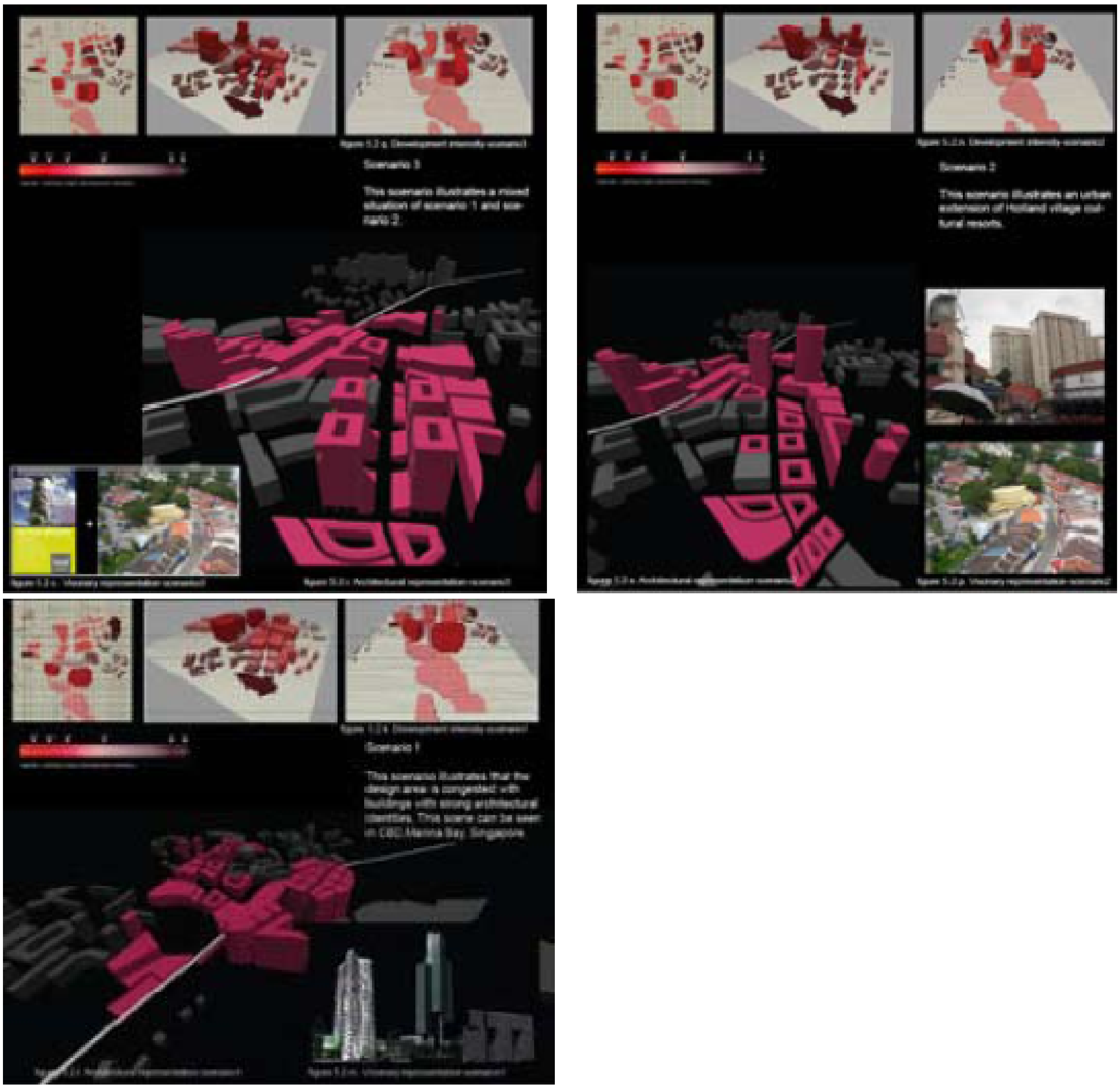

Figure 8
A design experiment of a new urban centre in Singapore in the new future office area

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