# THE THREE-DIMENSIONAL EXTENSION OF SPACE SYNTAX

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**Keywords:**

Three-dimensional
The image of city
Spatial cognition

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## Abstract

The purpose of this study is to develop a new space syntax technique by adding third dimension in analysis of urban structure that is important to understand the formation of the cities. The theoretical framework of the study is put forward by integrating space syntax with the theory of the image of city. This entails the essential elucidation of spatial cognition pattern and image and the integration of space syntax and the image of city. The paper analyzes and demonstrates the prerequisite and feasibility of the mutual complementarily between space syntax and the image of city. The three-dimensional space syntax integrated with the image of city is different from the traditional syntax that is only limited to non-figurative two-dimensional spatial cognition. It also emphasizes the important influences of the three-dimensional image points on people's behaviour in space and it is quite close to the accurate description of “natural movement”. Based on the three-dimensional theory, a concept model of the three-dimensional syntax is constructed, and its content includes how to describe forming process of the three-dimensional spatial image pots during the cognition activity, how to construct the objective evaluation model for the three-dimensional image pots and how to put forward the concept of weighted-integration to calculate the concept mathematical model. In the end, the paper carries through three experimental analyses. The paper argues that the extended three-dimensional syntactical model is much closer to people's spatial illation and cognition. It should be more accurate to use the model to describe and grasp the urban configuration.

## Introduction

Space syntax originated by Hillier and Hanson has been a powerful tool to analyze urban form combining organically people movement with spatial configuration and makes use of impersonal, accurate and quantificational approach to depict the spatial configuration pattern of city and architecture. A number of empirical researches have already established the importance of space syntax to predict people spatial movement in city and architecture environments（Hillier, 1996, 1998; Jiang, 1998; Kim et al, 2004). However, at present the syntactical analysis aims mainly at the two-dimensional plane of space. The practical apprehension and experience of space of human beings

should be three-dimensional, which include not only the information of two-dimensional spatial pattern, but also that from the three-dimensions. Moreover, compared to the urban development in history, nowadays the three-dimensional development of urban space influences the urban configuration intensively and its effects should not be ignored. Current space syntax fails to express and explain such a three-dimensional change in space. So it is an inevitable direction for space syntax to integrate the three-dimensional information to analyze urban space configuration so as to apprehend and study urban space roundly and profoundly. About the research for the three-dimension extension of space syntax, Asami and Kubat (2003) have attempted to extend axial line to incorporate the height change by introducing “extended axial lines” in allusion to hypsography of Istanbul. The concept of “extended axial lines” extends the two-dimension to solid space, but it is not realized really the three-dimension analysis in the paper. There are not other correlative researches being found at the present time.

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This paper begins with introducing the nature of space syntax, namely spatial cognition, to put forward a theoretical framework and a concept model of the three-dimension space syntax, and then to carry out three analysis experiments to demonstrate the three-dimension extension for space syntax. This paper analyzes and discusses adequately the prerequisite and possibility and feasibility of the three-dimension extension for space syntax. The first experiment is to test how the spatial information derived from 3D city model (3DCM), such as each image point, influences people's behavioural decision-making in space. The conclusion is the same as the result in the practical environment and it proves the accuracy of the description of the three-dimensional syntactical theory. The purpose of the second experiment is to test the power of the proposed image evaluation model in detecting building with high probability of becoming image points. The conclusion indicates that image evaluation is a very effective approach for analyzing urban configuration, and the image evolution model could menstruate exactly image points in space, and the conclusion also shows that this new approach could consummates the traditional space syntax with the realization of the fact that people's cognition structure is anchored by the three-dimensional spatial information as well as the whole spatial structure. The last experiment is designed to calculate the three-dimensional syntactical model to inspect and analyze people's behaviour in urban space, accordingly to explain the influence extent of image points. The conclusion validates that the weighted-integration could describe and forecast the distribution of people's behaviour in space better than the concept integration. And the extended three-dimensional syntactical model is much closer to people's spatial illation and cognition. It should be more accurate to use the model to describe and grasp the urban configuration.

## Theoretical Basis for Three-Dimension Extension of Space Syntax

### *Spatial Cognition and Space Syntax*

Spatial cognition serves as the theoretical foundation of syntax. People will inevitably have great interest in the spatial organization and relationship during the process of understanding themselves and the relationship between people and environment, especially the city space serving as the spatial carrier of people’s life. The understanding of this kind of spatial relationship reflects the formation and obtaining of spatial knowledge in physical environment, while the behaviour of people in the space can be understood as a process of accomplishing relevant task with the spatial information obtained. The association

here is the pattern of people in spatial cognition and in behaviour. The obtaining of spatial knowledge is originated from the spatial cognition of people, while the spatial knowledge obtained guide the spatial behaviour of people, such as the choice of routes, the judgment of orientation, the strategy of navigation.

The research with space syntax is based on the fact that urban environment is actually a correlated space. People's spatial cognition depends in a large sense on spatial configuration, while spatial cognition decides people's spatial behaviour. Space syntax verifies that it is spatial configuration itself will decide people's motion distribution and behaviour pattern, which is called "natural movement" by Hillier and it is one of the most fundamental applied concepts in the analysis of space syntax for spatial configuration. It is accord with people's spatial cognition behaviour and is best described by parameter integration level, from which a series analysis of space syntax starts.



### *Spatial Cognition and the Image of the City*

The image of the city is another theory in analyzing urban spatial forms similar to syntax theories. It is a theory based on cognitive and Gestalt psychology, and its analysis are directly based on the foundation of residents' cognition on urban spatial form and cognitive diagrams. Although there are many sources for the cognition of urban space based on different tools and technologies (such as map), in actual spatial activities (such as walking and exploring paths), people will most likely turn to their own experiences and memories. Even in a strange environment, people will think on the basis of their experience or an established thinking pattern (Lynch, 1961; Garling et al., 1984; Golledge, 1989, 1999; Ishikawa, 2002). The knowledge can be summarized with the term of the 'image of the city', which is the image created by an individual on exterior environment, a product jointly created by directional sense and past experiences to be used to guide the actual activities. As for individuals, the image of the city has double meanings of reality and emotion; it is decisive during the process of people's spatial behaviour. People will not respond directly to the environment, instead, they will take action on the basis of the image created by the spatial environment.

### *Integration of Spatial Syntax with the Image of the City*

The urban space as the main theme of our research is not a stable tableaux but a continuum with three-dimensional spatial consciousness. People can only recognize and experience it during the process of passing through it, therefore, the image of the city created on this basis is the information related to the three-dimensional structure of spatial environment. The theories of space syntax proposed by Hillier and the theory of the image of the city proposed by Lynch are highly correlated and supplement each other. They are both based on the theories of spatial cognition: while the theory of space syntax summarize the cognition and understanding of urban space with two-dimensional axes or visual maps, the theory of city image summarizes the cognition on urban space with five main factors (path, edge, district, node, and landmark). The theory of image emphasizes the functions of different main factors in three-dimensional space but neglects the fundamental structural relationship among different spatial factors; while space syntax theory emphasizes the structural relationship of space yet neglects the functions of different spatial factors. The syntax axis map and the concept of isovist is supplementary to depict reciprocally the main factors of city image, such as path and axis, node and cross-point of axis, district can be expressed with the range scope of integration and intelligibility, edge can be expressed with the dividing line between

axis and isovist, and the landmark can be deducted through “isovist gathering district” expressed by isovist and axis and shall be emphasized on syntax map. As for the correlation study of spatial syntax and the image of the city, many scholars, including Dalton and Bafna (2003) and Zhu & Wang (2005), have detailed discussion (Fig 1, 2).

In view of the development of space syntax theory, the theory of city image serves as its supplementary, for the concept of image is further than the intelligibility of space syntax. All cities with images are intelligible, yet not all cities intelligible can be summarized with image. Moreover, the image contains three-dimensional information, the combination of space syntax theory and the theory of city image systematically describes the city and at the same time also emphasizes the cognition of correlation levels and spatial characteristics of different factors in three-dimensional space of the city; therefore expand the two-dimensional spatial cognition to three-dimensional space. According to space syntax, spatial configuration acts on people’s behaviour and motion through their understanding of the space. In other words, the spatial information contained in urban space has material function on the interaction between people and environment. In many cases, the decision and behaviour of people in space is driven by space structure pattern in accordance with the characteristics of their cognition on environment instead of by actual purpose (Gibson, 1977, 1979; Smith et al., 1982; Mahshid et al., 2003; Krafta, 2003). At this level, the image can better explain the characteristics of space integration forms; in other words, the spatial behaviour and cognition of people is based on the operating passage in free space and shall also take into consideration different spatial nodes, landmarks and comprehensive three-dimensional spatial information. To be specific, just as many scholars have pointed out in their studies, the influence of path, landmark, and node on cognition behaviour is the most obvious and extensive among all factors in city image (Xu, Zhou, et al, 1997), for they affect the frequency of corresponding axes on cognition map and the choice of corresponding routes of behaviour cognition. These factors are named image point, which are tangible objects that will likely call forth strong images among the public and accordingly affect people’s spatial activities. The gathering of image points creates the cognition map, which is the expression of people on the basis of their experience and concepts of spatial position. It is this kind of experience and deduction that make people decide and choose the behaviour route in space.

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According to experience, in many cases, people will tent to choose “preferred routes” (the most favourite one) instead of the “shorted route”, he will go over familiar scenes and pass by all special reference objects in his cognition, such as commercial buildings busy with business or buildings with beautiful architectural forms. The location with these reference objects will be more unique and will attract more people. A scholar used to organize a similar experiment in a virtual environment and the result shows that the place with important buildings will gather more people (Jiang, 1999). All these important buildings can be summarized as image points. In fact, all spatial cognition patterns emphasize the function of three-dimensional nodes, landmark as reference on orientation and cognition, which goes beyond merely visual level and serves as psychological anchor. In a sense, the intelligibility of urban space structure also cast anchor on different reference landmark. It shall be noted that the image point contains three meanings here: individuality, structure, and connotation. The image points affecting cognition activities can be referred as the punctuate space (Krafta & Paula, 2003). The cognition map integrating all these factors is the improved suggestive axial map; it is

different from traditional space syntax that only focuses on two-dimensional space pattern, for it emphasizes the impact of three-dimensional spatial image points on human behaviour in space. It also integrates people's spatial cognition behaviour and is closer to the accurate description of "nature movement".

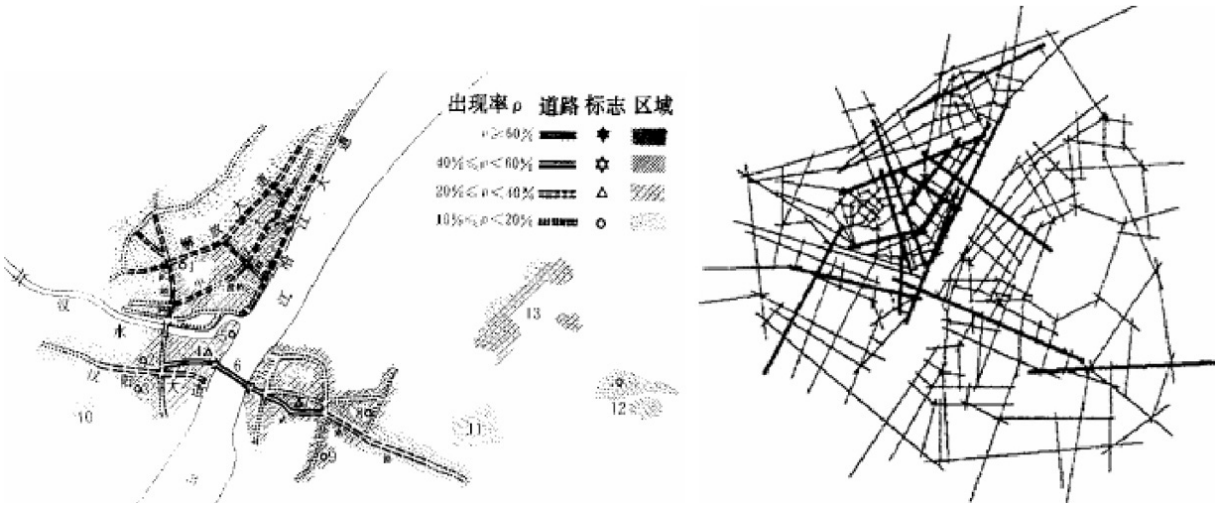




***Figure 1:***

*The image map of wuhan city (1999) the axial map of wuhan city (2004, the darker color refers to higher integration)* [i]

## Concept Model of Three-Dimension Extension of Space Syntax

On the basis of the theoretical research mentioned above, the districts in the syntactical map of the city system with the same integration might vary greatly due to the existence of image points. For example, the places attracting more people (e.g. squares at nodes), functional public buildings (e.g. large scale shopping mall and theatre), buildings and constructions with distinct characteristics along the path; the districts with these image points might attract more people, and people will tend to gather or pass by these places. According to the analysis of syntactical parameter calculation, they shall be different from other districts. Accordingly, this paper studies to construct the concept model of three-dimension syntax extension and proposes the concept of weighted integration to solve the imbalance in people flow distribution caused by the existence of different image points and to accurately describe the "natural movement". In the district with image points, the amount of image, namely the degree of its impact on people's behaviour, will be used to process the corresponding axes in syntactical map. The integration is the leading and direct parameter to describe people flow in space syntax and therefore shall be modified with weight coefficient so as to make it in accordance with the actual spatial status.

The three-dimension syntactical concept model contains various elements involving the research on cognitive image, including the description of the process that spatial image points during the process of cognition (the organization and description of spatial information and the information unit hierarchical structures and interaction rules), the construction of an objective evaluation model for spatial image points (that is the quantitative measurement of impact of spatial image points created during the process of cognition on people's spatial activities) as well as the concept model, calculation and analysis of syntax three-dimension extension constructed on the basis of this.

### *The Formation of Three-Dimension Spatial Image Points*

During the process of cognition, the choice and decision of spatial image points is based on the understanding and the organization of spatial information. While the evaluation and measurement of image points requires specific expression of spatial information, that is, the

division of information units. There are certain hierarchical structures and interaction rules for the division of information units during the cognition of spatial environment; and environmental image elements are created and become evident after the impact of interaction rules among different levels before forming environmental public images.

(1) The organizing of spatial information

Environmental cognition has long been recognized as a systemic process (Barker, 1963; Lynch, 1960; Rapoport, 1977). General structure is dependent on the interactions or relations between diverse elements. Neither the person nor the environment alone determines what is perceived; codification of information depends on the interplay between both (Gibson, 1979). An analysis of statements in perception and cognition indicates that the elaboration of environment representations includes process of selective information pickup, clustering processes in the organization of information, simplification of available information, categorization processes, incorporation of related information and meaningful information, etc. The processes serve as the more general framework for the elaboration of the interaction rules and environmental variables to be used in the spatial cognition information measure.

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(2)Representation of spatial information - division of information units

In the representation of an urban environment, the spatial continuum needs to be divided into discreet perceptual units. These must be congruent not only with environmental characteristics but also with apprehension of environmental information. This makes the spatial units reflect what we called information units: discrete spatial units with attributes and associated behaviour (the image of the city). The environmental cognition for people will be formed from the aggregation of information units. The urban environment is represented by (Fig2):

Set of cells - From the point of view of the integration space syntax with the image of the city, the urban environment is divided in two types of cells: β cells that represent information units by urban lots and buildings; and α cells that refer to information units given by fragments of open urban spaces through which individuals circulate and experience the city. These fragments integrate to form the axial map of space syntax. The associated attributes comprise physical characteristics (concrete and measurable feature), relational properties (due to the relative position in the environment), and social and culturally shared information (meaningful categories and specific meanings).Apart from these attributes, α cells also carry properties due to events (like movement and activities) that occur inside them and information about all connected β cells.

Connection network - Analogous to the connective map of space syntax, that makes explicit the physical and spatial structure of the environment by the representation of the relational structure of the connections of all possible interactions between the information units of the system;

Neighbourhood districts - The located regions in the connection network that represent the spheres of influence of each cell within the system, and it is within these pre-defined districts that interactions among information units occur. Neighbourhood districts are specific for each type of cell and hierarchical level of the system.

(3) Hierarchical levels and interaction rules of spatial information units

Environmental information units emerge in the cognitive model in accordance with a given hierarchical level, usually three levels corresponding to lots and buildings, small-scale spaces, and large

environment wholes. These levels represent specific perceptual and cognitive interactions between people and the environment, and are also representative of different aggregation levels of environmental information. The interaction rules of the information units existed during the process of cognition are of extreme importance to environmental cognitive structure, for they explain why only part of the spatial elements such as landmark and nodes are remembered and become images and present in people's cognition structure, while other elements only exist as the general background environment. In each level, cells are processed by a set of interaction rules, i.e. algorithms that codify the behaviour expected to be responsible for information structuring, and define the cells state value at different hierarchical levels.

***Figure 2:***

*Division of set of cells and description of their relationship (connection network) and districts*

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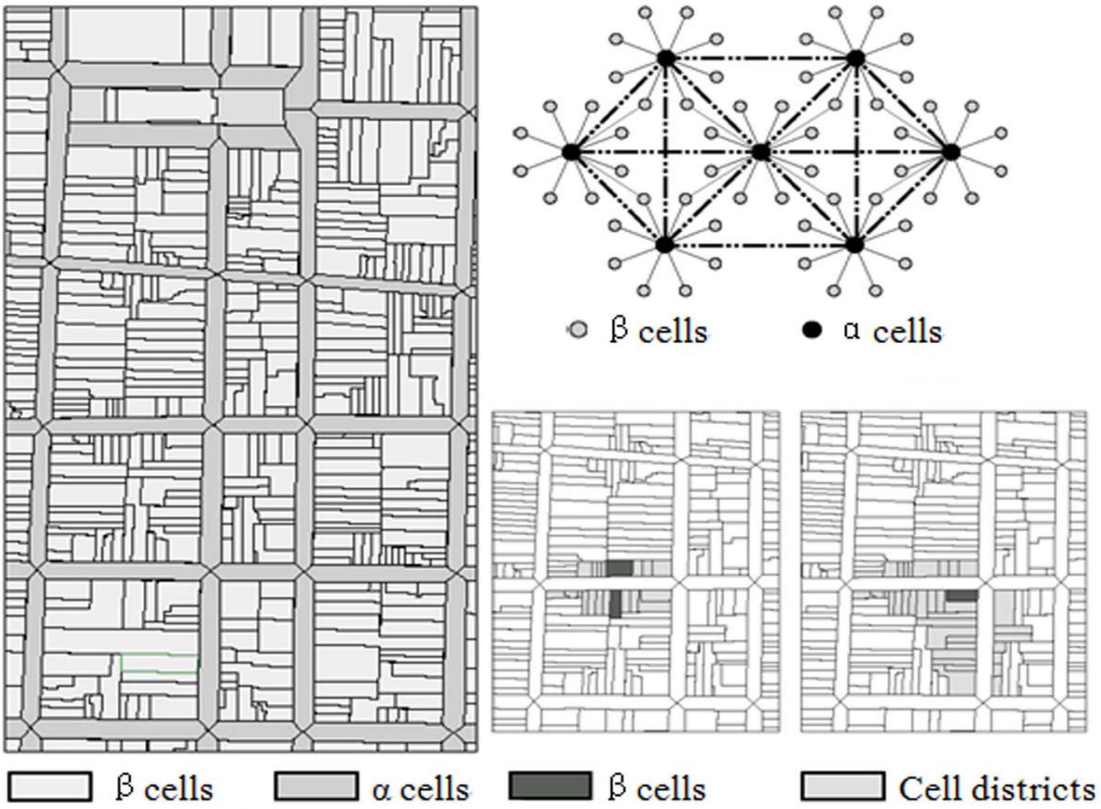


In general the proposed interaction rules consist of three consecutive processing modules including preparatory procedures (module 1), competition processes (module 2), co-operation processes (module 3). These modules are applied in parallel α and β cells and the interaction process of, and β are emphasized particular on in our research. The hierarchical levels and interaction rules have accounted for the forming process of the image information units in course of people cognition. The measurement variable for the image information units depend on both the physical attributes and the cognitive attributes. The physical attributes of information units include building height, volumes shape, colour, texture, surface treatment and other spatial three-dimension information. And the cognitive attributes are paid attention to visibility, formal categorization, functional categorization, socially shared name, localization in the block, and α cells of access. Scholars including Paula and Krafta (1998, 2003) used to evaluate and measure the cognitive characteristics of the environmental elements used during the process of cognition. Their research is systematic, thorough and complete. This paper borrows their research in the measurement of the image of information unit and makes certain adjustment and extension.

### *Measurement Model of Three-Dimension Image Points*

It shall be noted that the image points can be categorized into two types in terms of the characteristics contained by the objects themselves in appealing image and affecting people's choice of spatial behaviours:

1) Functional image points: this type of image points appeal to people due to their functions. They serve as an important functional element for people to understand urban environment;

2) Formal image points: this type of image points usually becomes the anchor for people in cognitive orientation due to their strong visual characteristics or special connotation (such as social and cultural significance). They can be regarded as an important symbolic element for people to understand the city.

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The concept of people on spatial environment in a city is actually the combination of functional element and symbolic element. In terms of the degree of gathering people, the changes of people's cognitive behaviour made by the first type of functional element are more obvious in comparison with the second type of symbolic element and therefore are easier to be evaluated. The second type of symbolic element tends to be the psychological anchor of people's cognitive behaviour due to its special connotation; therefore the evaluation on it is more comprehensive. In general, the range of image of an object can be measured by its prominence, visibility, typicality, and special meanings. The menstruation parameters include PV(prominence value),VL(visibility and localization), LT(categorization and level of typicality), UM(unique membership of the category),SM(specific meanings),EV(evaluation),etc.

### *Constructing a Concept Model of the Three-Dimension Space Syntax - The Integration with the Image Point*

Processing with module 1 of the interaction rules will account for the calculus of the values for each cell variables, and processing with module 2 will define the state value of each cell. State value makes explicit the tendency of each cell standing as an individual information unit (detachment) in the next level of the model, or being incorporated (ambience) in the more general information of the environment. This tendency is measured by the general distinctiveness (GD)[ii] of the cell in its neighbourhood, and it assesses synthetically the elements which effect upon the information cell (the image point). With the GD values, cells compete with each other in their neighbourhood districts, and those that have the highest GD values, values unit 20% smaller that the highest, or even values bigger that the minimum level are understood as being more easily coded individually and receive state value "detachment". The cells that do not satisfy these conditions receive state value "ambience". Only the cells with state value "detachment" remain in the next level of the model as valid cells for processing with module 2 of the interaction rules. All β cells that still have state value "detachment" after the application of interaction rules in the third level of the model represent the potential environmental elements defined as the image points we need to weight (including landmark and node).

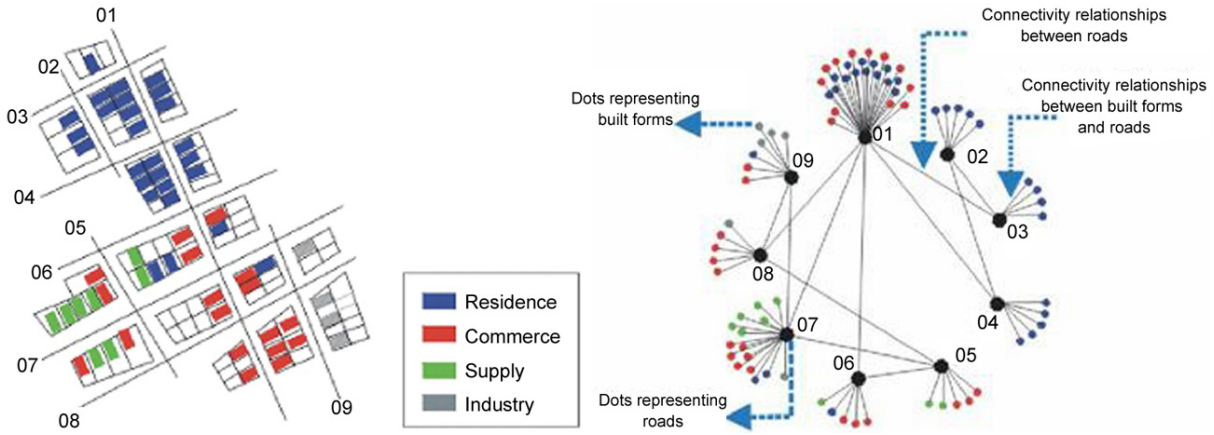
The existence of these image points affects people behaviours in space, therefore to integrate image points in space syntax can better predict and describe people's behaviour and activity in city spatial environment. In terms of spatial cognition, the three-dimension spatial information of image points supplement and complete the two-dimension information of syntax. The original syntactical model is created on the basis of graph theory. The free space divided in the

model is described as the points in the diagram; the relationship among them is the connection of the diagram; on this basis, the syntax three-dimension extension model incorporating image points with space syntax makes certain adjustment. According to the spatial cognitive information mentioned above, the information units can be divided into α cells and β cells, among which α cells express free space, while β cells contain building (construction) cells. In fact, to explain urban spatial configuration with space syntax also divides space into two parts: the public free space and building (construction) objects, which is in line with the division of image information units. To combine the information unit expression in the study of images and the spatial expression method of space syntax can establish a new and complete model in describing the spatial structure of the city.

***Figure 3:***

*City space (street, lot and building types) and city spatial structure description model (the description of relationship between streets and buildings)*






As shown in the Figure 3a, the complete urban space is composed of streets (free space), lots and different types of residential, commercial, and industrial buildings. As shown in Figure 3b, the urban space is described as the comprehensive connection relationship among streets, and between streets and all buildings. This model not only express the relationship among streets, but also revise and improve the relationship between streets and buildings (constructions or lots) so as to elaborate the impact of lot construction and development on urban space configuration. It depicts the complicated urban system network more completely. In the three-dimension syntactical extension model, the paper focuses more on the main image points with important impact on streets instead of on all buildings (constructions).

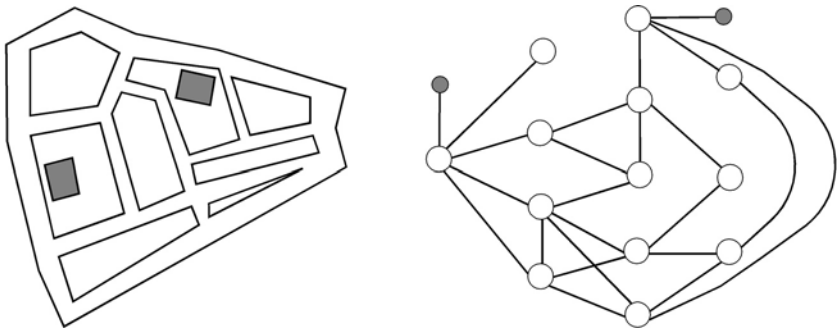


***Figure 4:***

*Extended syntax model City Spatial Structure, the grey parts are environmental image points -left Syntax Connection Diagram Incorporating Image Points, the grey points are weighted image points (β cells)-right*

For example, as for a city system as shown in Figure4a, in case of two image points of building objects (as shown with two rectangles in grey in the diagram), taking reference of the model shown in Figure4b, adding two special points in the corresponding axial connection diagram to stand for image points and to shown them with grey points in Figure4b, this is a syntactical model incorporating image point extension and a discrete model about continuous system in the city. The spatial behaviour of people can be deducted and calculated based on the connection diagram, the introduction of image points can

decide the weight value based on its influence on people's spatial behaviour.

In the newly constructed syntactical model, the paper focuses on the study of integration, and is therefore introduced as the weighted integration describing image points. The weight coefficient is to correct the impact of the existence of image points on people's spatial behaviour and activities in city. In addition, the impact of image points on people's behaviour shall also be corrected by taking into comprehensive elements. The GD value shall be used to measure the range of image, the types of function or forms shall also be taken into consideration in terms of their attraction to people. Based on these, the calculation of integration is shown as follows:

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$$I_{wi} = \delta I_i = \delta \frac{1}{RRA_i}$$

$$\delta = GD \bullet \gamma$$

***Table 1:***

$\gamma$ *correction value*

| Correction Value | Functional Image Points | Formal Image Points |
|---|---|---|
| $\gamma$ | $1 + (P_{av} + \sum_{k=1}^{n} P_k / n)\%$ | $(P_{av} + \sum_{k=1}^{n} P_k / n)\%$ |

Among which $I_{wi}$ is weighted integration, $I_i$ is original integration, $\delta$ is weight coefficient, GD is general distinctiveness of the element, $P_{av}$ is the weight value for EV, $P_k$ is the weight value for the variables (including PV, VL, LT, UM, SM), $\gamma$ is the correction value taking into comprehensive consideration of the impact on image points by all elements. The $\gamma$ value above is for reference. As for actual application, a comprehensive adjustment shall be made on the basis of actual situation.

## Empirical Analysis of Spatial Syntax Three-Dimension Extension

According to the research framework of the paper, the following experiments are designed for the purpose of verification, including to examine how spatial image points affect people's spatial behaviours, the formation of spatial image points, the verification of measurement model, and the description and calculation of integrating three-dimension image points in space syntax.

## The First: The Demonstration for the Theory of 3d-Syntax

Conroy (2001) adopted a large amount of experiments to verify that in virtual environments people's different cognitive behaviour characteristics including finding path and navigation are basically in line with their behaviour characteristics in real environment. 3D city model (3DCM), an important part of virtual environment, is the direct description of spatial form of the city and a tool and platform for people to recognize the space as well. The experimental purpose of the paper is to examine the impact of spatial environment information on people's behaviour on the basis of 3DCM is to analyze the spatial images of people. Our initial hypothesis was that varying the strength of spatial cueing (the spatial image point) would significantly affect search performance and environmental perception. More specifically, we expected that more spatial cueing would result in better understanding of the environment's information items and spatial

structure. Accordingly, a set of 3 corresponding simulated scenes are designed to describe the general spatial environment (for example there is no landmark, no detailed description of objects) and then to describe the detailed information of the environment. These virtual worlds had different levels of visual intensity for virtual objects, but consistent textual labels and spatial structure. The data set was chosen for interest to participants and the research community. The fundamental of the design is Virtual objects were laid out to maximize imageability by Lynch's guidelines[iii].

The experiment investigates the cognition of survey participants familiar or unfamiliar with the environment. The approach adopted here is the same as space syntax perspective that takes people walking in the space as the benchmark for cognition. The parameters for testing cognitive levels include: the accuracy of spatial orientation, the difficulty in finding path (measured by the speed and time), the understanding of spatial relationship; and the final result of the experiment is the combination of all these parameters. But these parameters are in relative value instead of an absolute one. The conclusion of the experiment is that, in virtual environments, the application of landmark and structure is of vital importance to the readability or intelligibility of the environment. In this space, without the understanding of spatial structural framework and the sense of direction and orientation (such as different landmarks), people will be lost easily and cannot find destination or cannot create correct cognition map of the environment. The confirmation of landmark makes the environment easier for people to comprehend and accept people will tend to choose the path with their specific cognition marks to reach the final destination. The degree of detailed description of important spatial cognition information by three-dimension model affects people's cognition on spatial environment; the more detailed the description of landmarks (accurate position, the measurement of heights, the description of their colour and texture), the easier people will recognize them. As for the non-landmark background objects, the description can be simplified, for they have little impact on people's cognitive behaviour. To recognize the space from the perspective of people walking in the space, the description of environment with landmark information is important for the creation of cognition map. When the space is viewed from multiple perspectives including the bird's view, then the detailed description of objects will have less impact on the cognition. The conclusion of the experiment conducted on cognition in virtual environment is in line with that of conducted in real environments.



### *The Second: The Validation for the Concept Model of the 3d-Syntax*

In urban space, the first step for people to form the spatial image is to select the spatial image point, i.e. to detect the information patterns originated by β cells. The rule for selecting is based on hierarchical levels and interaction rules of spatial units. The final aim was to test the power and veracity of the model in detecting building with high probability of becoming image point (landmarks). In order to verify the universal application of the method, the selected district (which is located between the urban core and the urban edge of Wuhan, Fig6) has a relatively regular grid and a flat topography, ensuring minimum influence of urban design on the β cells. The study district covers a public plaza and multi-blocks, and it has many internal sub-districts and diversity of building types and functional uses. These qualities are important because they guarantee variability of spatial contexts, making possible a better verification of the proposed methodology.

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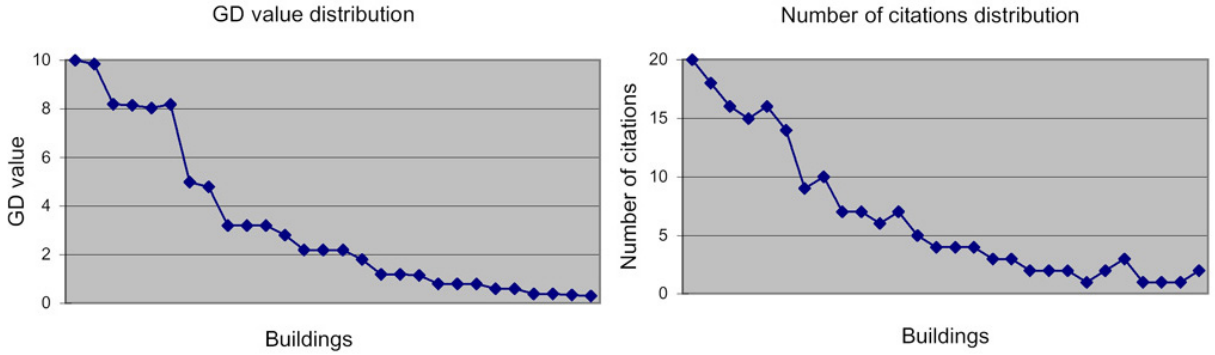
The attributes selected for the β cells were based on reports of urban environmental cognition and on the specific characteristics of the building set: building height, volumes shape, colour, texture, formal categorization, functional categorization, socially shared name, localization in the block, and α cell of access and so on. Analysis of GD values in experiment (Fig5) indicates a high degree of correlation of the variable measurement with the buildings in district. Moreover, the process of the experiment integrates feedback information of cognition and makes corresponding adjustment to the variables. The feedback information is originated from the cognitive map of people. All important buildings or constructions appearing many times in cognition map or being cited by people for many times will be found out correctly with the method. In addition, the experiment also considers cognitive feedback of people and the results are relatively satisfactory. This reflects not only in the total number of the buildings accurately found out, but also in the highly correlation between the number of citations of these buildings or constructions in people's mind map and their GD values. As shown in following figure and table (Fig5, Tab2), the distribution of GD values shows that the cells with high GD value account for a small amount among all buildings or constructions, i.e. there are a few landmarks serving as the cognitive reference for people and most elements exist as the background. According to the figure, the higher the GD values the higher the possibilities for it to appear in cognitive map.

***Figure 5:***

*GD value distribution of buildings and number of citations of corresponding buildings in cognition map*




| Cell Form | GD Values | Specification |
|---|---|---|
| A Cells | Weight Integration | The open space in environment is mainly road structure, shown as the path in cognition process |
| β 1 Cells | 0 - 5.5 | The characteristics are not obvious and tend to merge into the surrounding environment, shown as the background of cognition structure |
| β 2 Cells | 5.5 - 8 | With distinct characteristics, prominent in surrounding environment, shown as the element in cognition structure |
| β 3 Cells | 8 - 10 | With extremely distinct characteristics, very prominent in surrounding environment, shown as the landmark in cognition structure |

***Table 2:***

*GD value range and property of environment cognition units*

There are some problems to be discussed and solved. The data base is far too extensive, making the model, in its actual formulation, intractable for practical use. Though, preliminary analysis of correlations between attributes and variables and variables and between these and final results seems to indicate the possibility of reducing the number of attributes. At present, there are not uniform criterion to define the attributes and variables of the cell in the experiment. All the existent problems need to be kept on researching the theory deeply and demonstrating a significant number of tests in different urban districts. Though all the problems have some effect on

the final menstruation result, the results obtained with the experimental module may be considered quite encouraging.

In the representation of the cognitive structure for environment, assessing the image points with the evaluation model, which emergence as the object of reference in the mental maps of people and influence people activities remarkably, seem to be both possible in theoretical and practical terms in this paper. The created instrument, even though in a preliminary and partial version, indicated the possibility of simulating the cognitive structure urban environment. The proposed methodology points to the possibility of measuring and quantifying the cognitive structure, and that also shows it is the possible pattern for the image point being as the basic configuration element to represent urban space. The work elaborates some hypothesis on how space prompts people's perceptions, and therefore, how three-dimensional spatial intelligibility is actually built up. The work improve the space syntax is that urban spatial cognition works as a sort of relay system based on both channels of movement (open space) and built form references. The proposed methodology integrated with syntactical methodology provide with the possibility of not only capturing and representing, but also measuring and quantifying the cognitive structure.



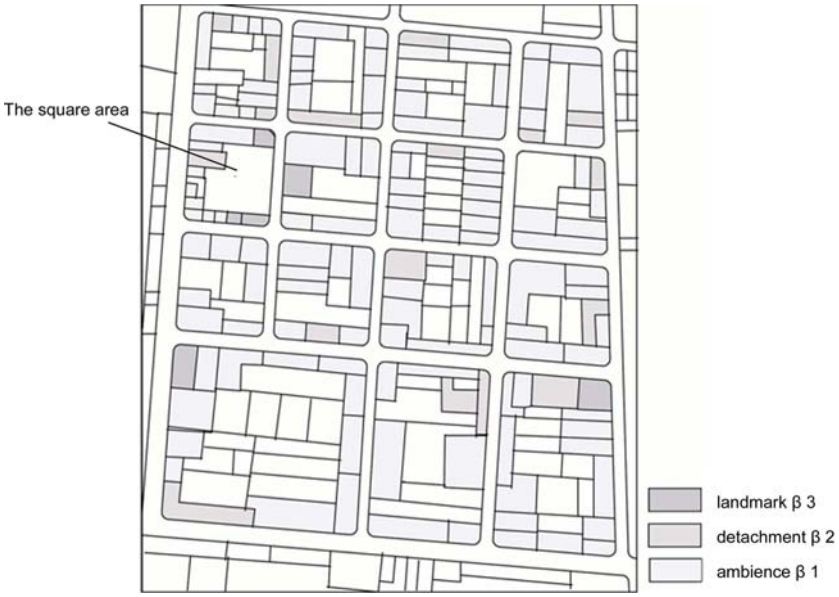



***Figure 6:***

*Hierarchal levels of elements during the process of cognition*

## *The Third: Calculation and Analysis for the Concept Model of the 3d-Syntax*

The two former experiments emphasize particularly on the image point how to influence people's behaviour and how to be formed and measured. This experiment emphasizes on how to integrate space syntax with these image points and then how to evaluate the spatial configuration, i.e. calculating the extension model of space syntax to inspect people's behaviour in space, accordingly to explain the influence extent of image points. The former extension syntactic model is the best mathematic abstract to represent the urban configuration, which abstracts the connective graph to describe synthetically the topology relation of urban spatial system elements. The calculation scale of the model depends on individual weight variables, which is to describe or analyze the system closer to actual situation through corresponding weight coefficient of the syntax axis integration. At the same time, the experiment shall verify whether the model is more in line with the process of people's space deduction and cognition.

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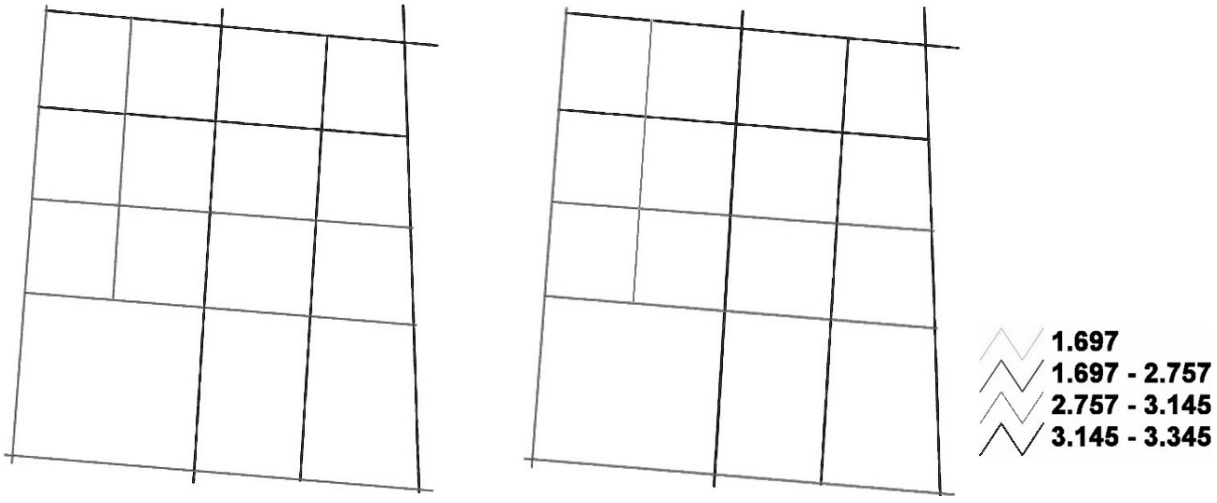
The experiment area (Fig6) is selected to be coincident with the area in the second experiment. The district is composed of several residential communities and a public square, among which the public square (left corner in Fig6) has been evolved from a residential public area and is not located in the core area with high integration. Yet since it attracts dense people flow for providing a pleasant place for exchanges and public activities, the business buildings and facilities are distributed in the area surrounding it, which in turn further intensifies its importance in the ordinary life of local residents. In comparison with other district enjoying high integration, the public square district shows its vitality and attractiveness. During the investigation, examination and analysis of city images, it appears as a prominent public image point, and both the Public Square and business buildings surrounding it appear frequently in cognition map of the residents. In comparison with other districts, this one attracts people mainly with its functions and tends to gather more people (vehicle) flow than other formal image points. Based on this phenomenon as well as the investigation and analysis of the district, the original syntactical map has been modified so as to give corresponding weight value to the street axis closest to the square. The conclusion of the experiment shows that the relationship between weight integration and people flow in extended syntactical model enjoys higher correlation in comparison with that in original syntactical model (Fig7, 8). It shall be noted that the experiment and analysis is based on part of the district with two trunk roads along its southwest edge that enjoys relatively high integration in the entire syntax map of the city. But the integration of the district is not high and there is difference in terms of integration in the entire district and in part of the district. The weight integration applied on the entire public image of the city is also applicable in both general and local integration.

***Figure 7:***

*Original Syntax Map and Extended Syntax Map (The corresponding light grey axis in right extended syntax has been weighted)*

Due to statistical reason, the experiment is restricted in certain district and only verifies the impact of the existence of this image lot on surrounding environment. Although it is impossible to explore its impact on general environment of the entire city, it is reasonable to conclude that the impact of the large-scale similar functional image point on the entire city is not negligible[iv].




The conclusion of experiment verifies the initial hypothesis of the extended syntactical model and shows that the image points (especially the functional image points) existing in the city affect the gathering behaviour of people in space, while the weight integration describes and predicts people's behaviour distribution in space better than integration. In other words, the urban system integrating space syntax with city image points describes urban configuration more

detailed and real (the integration and spatial image points also undergo a process of mutually intensifying).

## Conclusion and Discussion

The integration of three-dimension syntax with city image theory is different from the description of space with traditional two-dimensional space syntax: it integrates the information of three-dimensional space and is closer to the accurate expression and description of "natural movement". Its weighted integration describes and predicts the distribution of people's behaviours in space better than regular integration. It shall be emphasized that these public image points are not merely the expression of people's cognition structure forms; they are also related to other social, economic, and cultural elements. Taking into full consideration of people's behaviour model, the integration of syntactical structural cognition framework with space image points accumulates people's behaviour tracks in space and also describes relevant city activities, which reflect the social and economic relationship of a city. Similarly, the real significance of describing the form of a city lies in its close relationship with human behaviour in space and with the geographical core of the city, the economic behaviour, while the pure analysis of spatial form has no significance. Last but not the least, as a theoretical method, space syntax itself is based on many empirical studies and the three-dimension syntactical model proposed in this paper also requires the verification of a lot of examples, especially the confirmation of its weight coefficient. Due to the restrictions of both time and experimental data, this study is only fundamental and needs to be consolidated and to introduce more empirical study and analysis in the explanation of spatial behaviour and environment.



***Acknowledgment;*** This paper is supported by the Science Foundation for Post-doctor of China (20060400064), Beijing Natural Science Foundation (4063038), and Tsinghua University Sustainable Urban Mobility Project.

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**i.** Due to incomplete statistics, the public image map of Wuhan city in 2004 is not available; the common image or memory of a city will not change too much in a short term. It shall be noted that the two bridges did not exist on the image map in 1999 and they serve as one of the landmarks of Wuhan now.

**ii.** The calculation for GD and other variables could be referenced the research of Paula and Krafta (2003).

**iii.** Research on navigation in VR began with urban design studies of the physical world. Work on legibility (imageability) showed that resident efficiency and enjoyment is enhanced by a design with landmarks, paths, districts, nodes, and edges in a strong hierarchy. Recent research concludes that the design principles for intelligible space from the real world often apply to large virtual environment. （R P Darken & J L Sibert 1996, 2002）

**iv.** In view of the development of the city, some of them can turn to the investment of important projects, the construction of these important public facilities (buildings) has profound impact on the development of these districts, and this is also one of the topics people usually discuss during both planning and research. The completion of some significant projects, including shopping centre, sports stadium, theatre, will readily become the image points for people. On the other hand, the city image points also serve as the measurement of the potential that the district enjoys in certain degree. For a district, although its current transport accessibility is not satisfactory, yet with attractive potential including business centre and scenic spots naturally formed during ordinary life of the residents, then the planner will consider creating more favourable development conditions for the district.