3D City Models Based Spatial Analysis to Urban Design

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Abstract

Urban design is a subject that is concerned with the shape, the surface and its physical arrangement of all kinds of urban elements. Although urban design is a practice process and needs much detailed and multi-dimensional description, the urban designers could only analyse urban space with script and imagination in the past, and only the urban design guideline and some drawing picture were carried out in the traditional design schema. How to improve the quality of urban space effectively and how to express the design schema perfectly are the problems troubling the urban designers for a long time. The 3D city models based spatial analysis gives the possibility of solving these problems. Compared with the traditional applications of 2D GIS in urban planning, the 3D city models based spatial analysis would be more meaningful for the urban designers. The computable analysis models could be constructed under the urban design guideline. Through the integration of analytical models and realistic visualization models, the 3D spatial analysis that is impossible to the 2D GIS can be carried out.

Instead of being described with some adjective words, the designing schema and rules can be presented and analyzed in 3D virtual environment. The change of the urban fabric and the building density could be analyzed through the structure analysis. The noise environment, sunshine condition, heat environment, ventilation condition, and pollution condition could be analyzed through the physical quality analysis. The control of the height, the color and the style of the buildings, and the evaluations of the surrounding environment of the squares and the streets are also available based on the visual impact analysis. The analysis of the distribution of different function parts and its proper place are possible through function analysis of urban space.

Based on the 3D city models, urban designers can express the design concept clearly. With the analysis functions, it is also possible to control and improve the quality of urban space effectually. There would be a great progress when we design the urban space with an operational 3D analytical system, like Cyber City GIS.

I. INTRODUCTION

"The visualization is perhaps the most significant of all activities in the design process that has been affected by the development of digital technologies" (Batty et al., 2000a). How far can we go forwards on the way of the application in urban design? Whether just as a visualization means, or as a decision support tool, a kind of ideation platform? It is the problem that we have discussed for a long time. There is an agreement accepted by most of researchers that the computerized design generation is difficult because of the complexity, the originality and the to-and-fro process of design. So most of the research efforts are concentrated on the space analysis and the decision support.

In this paper, 3DCM is the spatial framework data body of Cyber City GIS (Zhu et al., 2002), and it is different from the three dimensional CAD (3D CAD) models. 3DCM is not simply as an abstraction of various objects of cities. Besides the geometric characters, it also contains the geographic information and other attributes, such as the location coordinate, the building height, colour, texture and so on. Although the primal intention of most 3DCM is for visualization, what we want to do now is to go for on the way of its more valuable applications.

In 3DCM, the major data source is the high resolution satellite imagery, the aero photo and the precise surveying data. With the DEM, the 3D block models can be established quickly, and the small-scale space study can be implement in this block models environment, for example, the change of the horizon outline of the central business district or the space fabric of the whole city. But for the large-scale space study, the 3D block models are not enough. The complex shape and texture of the building should be represented. The traditional data of surveying mapping and remote sensing become helpless. In order to solve this problem, we should extend the range of the acceptable data. Especially, it should read in or input the data of different formats, the DWG data, 3DS data and so on. In addition, the user can also edit the models in 2D environment.

In this paper, urban space study based on the 3D city models (3DCM) is a kind of special application research. Urban design plays double roles in urban construction process: control and guide. To Control and evaluate the form process of urban space efficiently is the primary task of urban designer. The 3DCM is no doubt a powerful tool because of its characters for multi-dimension, visual, and multi-attribute. The objectives of this study are three-fold: (1) Provide an introduction to the meaning of 3D city models application; (2) set up a research framework for the content of application, give the answer to what we could do using the 3DCM in urban design

field; (3) put forward some new viewpoint for 3D city models based visual analysis.

II. THE IMPORTANCE OF THE 3D SPATIAL ANALYSIS FOR URBAN DESIGN

The present development of urban design

Urban design is the holistic ideation and the arrangement for the urban form and the urban environment, and it run through the whole process of the urban planning. It is a subject mainly involving the shape and the surfaces of all kinds of urban elements, and its research focuses on the urban space formed by these elements. It has been defined by Barnett (1982) as "... the process of giving physical design direction to urban growth, conservation and change". In fact, there is no universal definition for urban design, but we can see that the enhancement of the space quality is the origin at the genesis and still is the kernel problem of urban design until now. There is another famous word of Barnett (1982): Design the city, not design the building. "Unlike architecture where the concern is primarily with the construction, appearance, and internal organization of buildings, urban design relates physical arrangements of buildings and streets to functional organization which in turn reflects the social and economic structure which makes the built environment function or dysfunction."(Batty et al., 2000b).

In the history of urban design development, Camillo (1965) is the first researcher to insist upon the three-dimensional study of city form in his famous work: *City Planning According to Artistic Principles*. He believed that the designers of cities must consider three-dimensional urban form. His work was influential in shifting the design of cities from engineers to architects. "Though planning was concerned with many things, the physical form of the city was a central concern" (Richard, 1999). The urban designer take the urban space environment as the mainly design object.

In fact, all the efforts of the architects and planners are to construct a pleasing, comfortable, and efficient space. People always think that when they plan the city and design the physical form of the buildings, actually they use the space formed by the building entities, whether inside space or outside the space. That is the reason why the urban designers take the urban space as their design object. Saarinen (1943) thought that urban design was the art of 3D space organize. Now urban design has no longer simply been taken as the organizational art of geometric space. The human life and the social meaning contained by the urban space has been recognized more and more, but as the media of the human city life, urban space is the major research object of urban designers all along from the beginning to now. The spatial analysis is very important for planners and designers, but there is no any efficient way to control and design the urban space until now.

The existing problem

Although urban design is a practice process that needs much detailed and multi-dimensional description, the urban designer could only analyze the urban space with script and imagination in the past, and only the urban design guideline and some drawing pictures were carried out in the traditional design project. With the traditional design tools, we can only find the problems firstly, analyze the space with the sketch, put forward the scheme, visualize the design result through the 2D map or picture. How to improve the quality of urban space effectually and how to express the design schema perfectly are the problems troubling the urban designers for a long time. Urban designers and architects need to represent and communicate their viewpoint in a proper way. In the same way, urban managers want to control the urban space efficiently; the owners or the stakeholders of course want to communicate with the designers without any obstacle; for most of citizen, they look forward to knowing the planning or the design process and participate in it conveniently. All these also need a multi-dimensional environment, but the true 3D space or 4D space (to consider the dynamic change) can't be expressed and designed in 2D plane because of its multi-dimensional characteristics. That is the reason why the 2D GIS has been used in urban planning field for so long time while urban design hardly have any new application in this domain. For urban planner and the urban designers, the development of 3DCM just can make up the lack of traditional GIS. Urban visualization is proved to be a valuable tool for designers and planners. The 3D city models based spatial analysis gives the possibility of solving these problems. Comparing with the traditional applications of 2D GIS in urban plan, the 3D city models based spatial analysis would be more meaningful for the urban designer.

III. THE THEORETICAL FRAMEWORK OF THE APPLICATION OF 3D CITY MODELS

Instead of being described with some adjective words, the designing schema and rules can be presented and analysed in 3D virtual environment. There are three evaluation principles for the urban space quality: comfortable, pleasant to the eye, and convenient. The range of urban space study is so great that it can be classified into three aspects based on the three principles mentioned above.

Physical quality analysis of urban space

The physical quality analysis decides the comfortable degree of the people's sense. The noise environment, sunlight condition, heat environment, ventilation condition, and pollution condition could be analyzed through the physical quality analysis. In 2003, the HK news media reported that the reasons why SARS break out in the Taoda Garden residential area, one of the reasons is the poor ventilation condition, especially the "wind curtain" between the tall buildings. It

was discovered through the airflow dynamics analysis in computer by Pro. J. Y. Zhou of the Chinese University of Hong Kong. This research suggests that the physical quality analysis of urban space might often have a social impact on the human life. The arrangement and properties of the buildings and the urban space around us could affect our behaviour.

Based on the 3DCM, we can choose any date and get the sunlight time of any place on any building of a day (sunlight analysis), such as, the windowsill of the first floor. If the sunlight time below is the set time, this building will be highlighted and show the lacking time. Especially, we can see the dynamic change of the building shadow in the range of time set, thus the sunlight condition can be evaluated in 4D environment as shown in Figure 1.

Another potential application of 3D city models is the ventilation analysis. With the merge of more and more skyscraper, the ventilation problem appears. Negative pressure behind the windward of a tall building is good for the inside ventilation, but for outside it would make people discomfort especially in cold winter. How to compute the airflow activity and control its change accurately is a big problem for the architecture and the urban designer. With the 3D city models, we can construct the analytical models to simulate the airflow activity.

Visual quality analysis of urban space

The visual quality of urban space decides the pleasant degree of human's mind which is evoked by the vision. In practice, urban designers are concerned with the physical arrangement of the basic components that make up the built environment at the level of buildings, streets and landscape details. Therefore, visual thinking of space is necessary in the design process. At the same time, the designer should take the user feeling as the central point to analyse the location and the relationship of different urban element. Visual analysis is no doubt a powerful tool. Through the virtual reality presentation of
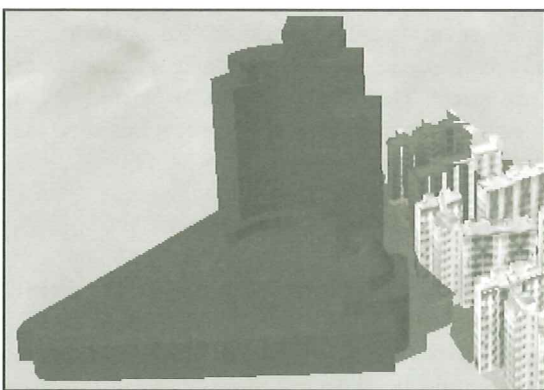
Figure 1. Computation of building shadow, achieved in the CCGIS software which developed by the LIESMARS of Wuhan University.

multi-dimensional urban models we can carry out the "true" visual analysis that is impossible to the traditional 2D GIS. The control of the height, the colour and the style of the buildings, the evaluations of the surrounding environment of the squares and the streets are also available based on the visual impact analysis.

Structure analysis of urban space

The analysis of the distribution of different function parts and their proper places are possible through structure analysis of urban space. Besides, structure analysis can also control the change of the urban horizon contour and the building density. Optimizing the urban space structure is an important content of urban morphology. Spatial analysis is one of the key features that differentiates GIS from other forms of spatial information systems such as spatial-databases, computer cartography and computer aided design (CAD). "Space syntax models the spatial configurations of urban spaces by using a connectivity graph representation. Such a configuration of space identifies patterns that can be used to study urban structures and human behaviour. Over the past two decades, space syntax theory has provided important computational support for the development of spatial morphological studies, in particular for the analysis of urban systems" (Jiang et al., 2000).

In china, there are a lot of old cities like Lijiang of Southwestern China. They are formed with the natural order in a long history. The urban space of it is full of life interest. Their urban structure has a high research value. Analyzing its urban space structure can help us improve the space quality of present cities.

IV. 3D CITY MODELS BASED VISUAL ANALYSIS AND PRESENTATION

For urban designers, the most significant application based on 3D city models is the visual analysis. In 3D dynamic virtual environment, through the visibility computation according to the simulation of human vision and the visual analysis for the visible field can make the design process more realistic and scientific.

Visual analysis and the visibility computation

Visibility as a term—-along with some related terms, such as viewshed, visual quality, and visualization is very much evident in the literature and practice of landscape planners and designers. The visible field with certain eye-level and view-angle can be computed, and it is a possible field we can see at a certain point of observation. But what we can see is not equal to what we have seen. What we have seen among what is visible may depend on the purpose and preconceptions (Ervin and Steinitz, 2003) and depend on the weather, the colour and so on. Visibility computation is the premise of the visual analysis. Of course, the view field we can see is a subset of
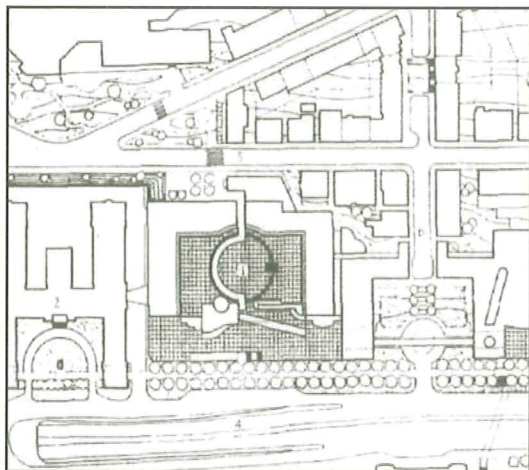
visible view-field. In order to present the visual impact properly for urban design, the visible field and the visual scene should be visualized, so that the user can extract the visual information themselves and implement the evaluation. Multimode and real-time dynamic presentation is a good choice.

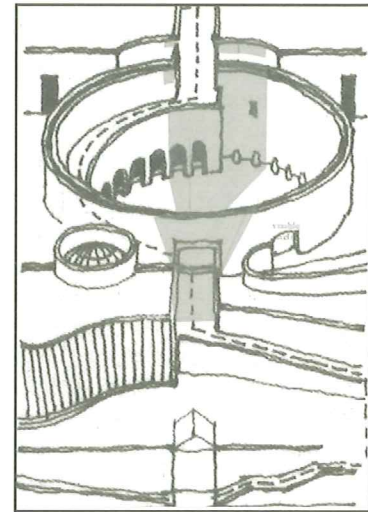## Multi-mode and real-time dynamic presentation

In 3D dynamic environment, people usually can not ascertain the right orientation because of the rich visual information. However the 2D map can present the real orientation efficiently, and it is a powerful navigation tool in 3D dynamic environment. At the same time, the computed visible viewfield should be outstanding through the way of giving highlight or different colour to the surface of visible object. This is the way we present what we can see in 3D environment. But how can we present what we have seen? The visual scene at special viewpoint, which could change the eye-level and the view-angle so that to fit different users, should also be supported. The different user can get what they have seen through the custom-built visual scene. The above description gives full presentation for the visual analysis environment, and these three presentation modes may be viewed in real-time through dynamic link. Here see an example to this kind of presentation as Figures 2, 3 and 4 which coexist in one interface. Only in this way can the visual impact of urban space be fully expressed. In order to implement the visual analysis effectively, the 3D city models should be editable, and the space attribute of the models like colour, texture and so on should be changeable.

Visual spatial analysis

The visual analysis concept model and the analysis criterion come from the urban design project. Based on the 3DCM, the designer can carry out the alternative design in it, and embed their scheme into the 3DCM. For example, in some cases, the


Figure 3. Sketch map of the visible field (black field) based on the visibility computation (the gray-filled field shows what we can see)

building should be back off the road red-line for some distance, and have the height limitation. Then the urban designer can convey their design result with the form of 3D control models, and evaluate the visual effect through the visual analysis. Selection of appropriate building types could be also guided by querying the associated database under the urban design guidelines. In Seattle, USA, the urban design guideline includes the concept map of height limitation as shown in Figure 5 (Jin, 2001). If we embed the quantitative criteria of urban space like this in our analysis models, we can control the urban space more efficiently.

Through the height limitation of impressible area, the back-off distance control of the street building, or the open space control, the designer can either give an fully presentation for the urban design result or give an effective control and analysis


Figure 2. Stuttgart art gallery –plan, (the black point shows the orientation of observe point)
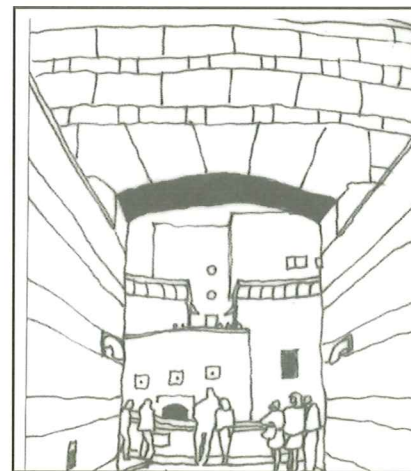
Figure 4. Sketch map of the visual scene in which we can get what we can see

for the visual quality of urban space. "Enthusiasm for automated visibility analyses has grown significantly over the years because of marked improvements in hardware and software algorithms. The future advances in this field will eventually help solve the elusive visibility analyses in three-dimensional urban and natural environments" (Sanjay, 2003).

V. CONCLSION

A successful decision support system should be easy to operate. The design process is complex, and it involves in all the aspects mentioned above: The physical quality, the visual quality, and the function quality of space. Generally, they need several analysis functions to do one decision. In one Spatial Decision Support Systems (SDSS), in order to adapt the design process, all the necessary analysis functions should be integrated. Computer-aided visualization can change both the way we think and the way we work. For the architects and the planners, they can change the way of design. The ability to visualize potential modifications to the urban fabric and to experience these changes in their actual context allows planners and designers to evaluate alternatives more rapidly, with more details, and lower cost than through traditional analysis. The ability can also makes the results of planning process visible, allowing the public to view the proposed changes to their environment in a realistic fashion (Liggett et al., 1997). In the process of making the design from the abstract to the
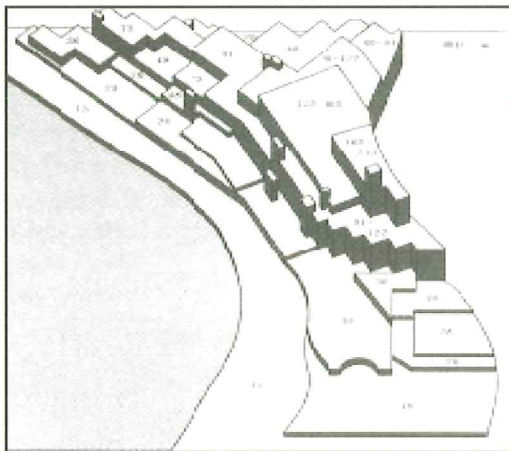
Figure 5. The concept map of height control of downtown in Seattle (Jin, 2001).

concrete, 3DCM application may provide planners and designers with tools to better consider the three dimensional space in the design process, as well as better control the form process of urban space by the urban governor and allow more people to participate in it. What we need is to build the urban space control system based on the 3DCM.

ACKNOWLEDGMENT

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