DESIGN WITH SPACE SYNTAX ANALYSIS BASED ON BUILDING INFORMATION MODEL
Towards an interactive application of building information model in early design process

YONGZHI LI, JUMPHON LERTLAKKHANAKUL*, SEONGKI LEE**, JINWON CHOI
Dept. of Housing and Interior Design, Yonsei University, South Korea
*Institute of Millennium Environmental Design & Research, Yonsei University, South Korea; **Institute of Building Technology, Department of Architecture, Swiss Federal Institute of Technology (ETH) Zurich, Switzerland

ABSTRACT: This paper introduces a new framework to enable user-friendly space syntax analysis during the initial design stage. It assists designers, without in-depth knowledge on space syntax, to evaluate and compare design outcomes rapidly. The framework is realized by integration between space syntax and building information model in which space topology is autonomously retrieved. A BIM modeler so called ‘ArchiSpace’ has been developed to demonstrate the applicability of the framework to design practice. Our experiment shows that designers can use the modeler to analyze their design alternatives instantly at any moment during the initial design stage. Therefore, users can generate and evaluate their design alternatives simultaneously without distraction and tedious work on the space syntax analysis in detail.

KEYWORDS: Space syntax, building information modeling, evidence based design, space topology


MOTS-CLÉS : Syntaxe des espaces, modèle d’informations relatives au bâtiment, conception basée sur des preuves, topologie de l’espace

T. Tidafi and T. Dorta (eds)
Joining Languages, Cultures and Visions: CAADFutures 2009
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1. INTRODUCTION

In the design process, with interpretation of design constraints, architects bring two types of knowledge together to generate ideas and test them in a subjective way (Lawson 2004). The one is scientific or research based knowledge related with the human being, building, environment, etc. The others are intuitions and experiences, ideas, believes and values or guiding principles. Ziesel (1984) showed that design process involves three constituent activities such as imaging, presenting and testing. Testing in design process means comparing tentative presentations against an array of information like the designer’s and the client’s implicit images, explicit information about constraints or objectives, degrees of internal design consistency and performance criteria—economic, technical and sociological (Zeisel 1984). It is widely agreed that architects have to make the most important design decisions concerning design requirements in the early design stages. Especially to predict people’s movement and to distribute each functional space according to the space program for the design project are ones of designers’ most important abilities to solve the design problem.

In this context, space syntax provides a configurative description of both urban structure and architectural space and attempts to explain human behaviors and social activities from a spatial point of view. Most space syntax studies concern issues related to urban patterns, but the method is also relevant for studies on the scale of urban and architectural design. Space syntax can produce a kind of knowledge which supports architects to find out how well their designs might work; what kinds of properties their design solution has, and so on. In practice, urban planners and designers can predict pedestrians’ movement flows before the actual development of real urban systems and buildings by analyzing the morphological structure of the design plan using space syntax. It makes the deployment of non-discursive intuition more rational and therefore more discursive (Hillier and Hanson 1997).

With the aim of space syntax theory, a number of software packages such as Axman, Orangebox, Netbox, Pesh, Spacebox and Axwoman and so on (http://www.spacesyntax.org/software/index.asp) have been developed. To utilize these applications, we have to convert information modeled in a specific design media such as Autodesk DXF to one for these space syntax analysis tools, which means users must spend considerable time for this process and need special skill in order to manipulate it without errors. Various analysis to support design decision-making by space syntax analysis are only used for the few buildings in common architectural practice and if exists, those are conducted separately subsequent to the architects’ designing. Sometimes this process prevents designers from soaking themselves to the design task. Yet, their application and thus their influence on the design process have been rather limited. However, building information model that is served as an interdependent, multi-disciplinary
data repository can make new approaches on combining design analyses. Based on this component-based approach, building models with semantically-rich information including geometries and various attributes can be generated to extract information for diverse analysis such as energy, cost and space syntax.

Eastman (1999) stated building information model (BIM) as “richer repository” than a set of drawings in that it has the ability to store different types of information. These types of information include geometric, semantic and topological information. Geometric information refers to the formal description of the building component. Semantic information concerns the properties of building components. Topological information describes the relations between building components. Even though most CAD software has been adopting building information model, its use is restricted to the final modeling of pre-decided architectural design for the remaining processes among the whole building life cycle. Moreover, there is no trial to combine this theory with building information model. Holistic space syntax analysis is not considered in any kind of computer aided architectural design tools that designers commonly use in practice. This lack of integration of space syntax in design process leads to an extensive modification afterwards in order to meet design criteria. More intelligent approach based on building information model must be sought to enhance the design process for various purposes.

The aim of this research is to suggest the methodology to use building information model from the early design stages considering the nature of the design process. As the goal of this approach is to realize real-time process of space syntax, the effort for input and editing of parameters must be kept as small as possible. This work concentrates on the integration of space syntax into the architectural design process. Therefore, the utilized space syntax calculation models are described briefly to display which parameters are implemented and calculated. This paper is structured as follows. Section 2 reviews and analyzes existing roles of space syntax in design and current indoor space syntax applications. Section 3 describes a new concept to combine building information model with space syntax in the design process. Section 4 and 5 demonstrate the usage of our framework by introducing a new BIM modeling so called ArchiSpace. Section 6 concludes this paper and gives directions for future research.

2. RELATED WORKS

2.1. Role of space syntax in design

Through the reviews of previous works, it is necessary to discuss roles of space syntax in design such as urban design, building design and design education. Dursun (2007) discussed the roles of space syntax in design through case studies in real design projects as follows. First, space syntax serves as a language
for thinking and talking about space in the dialogue between architect and
designed space. Second, it merges science-based knowledge into design process,
which constitutes the core of “evidence-based design” (Hanson 2001). Third,
space syntax provides tools for architects to explore their ideas, to understand
the possible effect of the design, and to let them evaluate their design before-
hand. Fourth, space syntax gives a chance to architects to evaluate the designs
as living organism experienced by inhabitants.

2.2. Indoor space syntax

Space syntax can be classified as indoor and outdoor analysis according to the
linearity of the space and we are interested in indoor one. Accordingly, space
syntax has three different visual representations (e.g. axial map, convex map
and Isovist map). Basically, the fundamental concept of the space syntax
analysis relies on an analysis of depth. A total depth in a spatial configuration
is the aggregate of all shortest distances from a node to all others. A node is
deep if there are many steps from the rest of the others. In contrast, a node is
shallow if there are a few steps away from others. Based on this, the distribution
of depth in the spatial configuration so called integration can be computed to
quantify the configuration properties of spatial or formal complexes. An inte-
gration value of a specific node indicates the extent to which the node is inte-
grated or separated from the whole system (Hillier 1999).

Intelligibility is another important spatial property. “An intelligible system
is one in which well-connected spaces also tend to be well-integrated spaces.”
(Hillier 1999) Intelligibility is defined by the coefficient of correlation between
local and global parameters such as connectivity and global integration (Jiang
2000). Either urban or internal space consists of two sections: free space and
spatial objects. The free space is broken into small pieces in terms of liberality
of the free space (Jiang 2000). In terms of linearity of free space, there are
three kinds of visual representation of space. The first visual representation is
the axial map that is usually applied to the environments with relatively
linear free spaces. An axial map is the least number of linked and the longest
straight lines. A good example of this kind of configuration is a city, a village
or a park as shown Figure 1(a). Axial analysis is the most common space
syntax analysis.

The second representation is more indoor oriented as shown in Figure 1
(b), where most rooms are extended in two dimensions. In the second presen-
tation, free spaces decomposed into a set of convex spaces. A convex space is
one in which a straight line can be drawn between any two points in the range
of that space. The main target of urban scale analysis is the continuous free
space while internal analysis focuses more on discontinuous labeled space such
as living room, dining room etc. However, by the nature of the discontinuous
of the interior spaces, experiences of inside building are formed rather conceptually than spatially as in outdoor spaces (Hillier and Hanson 1984).

Isovist Map is the third representation developed by Benedikt (1979). It is a map of properties of the vantage points in a floor plan generated by drawing contours of equal visual sections in the geometry map. It can give an insight into how human navigate the real buildings. Among all representation methods, the convex map is chosen as the visual presentation method for space syntax analysis in this paper because of the conceptual aspect of experience in the internal space which is relevant to the concept of building information model. In addition, compared with point based analysis- isovist analysis, convex analysis takes much less time than isovist analysis to generate the convex map which makes the method suitable for design process.

**FIGURE 1.** (A) URBAN SCALE (HILLIER 1996, P. 117); (B) INTERNAL STRUCTURE (BELLAL 2007).

### 2.3. Indoor space syntax applications

Since this paper deals with indoor building design issues, we restricted the scope of our study to indoor space syntax application. Axwoman and DepthMap are well-known space syntax applications among existing ones. Axwoman was initially developed as an extension to ArcView 3.x for urban morphological analysis, based on space syntax theory at the Bartlet School of University College London. The main idea is to incorporate space syntax into GIS to promote both GIS and urban morphology research. Depthmap was developed based on the Isovist analysis (Benedikt 1979), and the other space syntax theory (Hillier and Hanson 1984). Both Axwoman and Depthmap support axial map analysis and convex map analysis used for spatial analysis of indoor structure. Users need to draw convex spaces polygons by hand on top of an underlay sitemap or a floor plan for space syntax analysis. In summary, current space syntax applications are not able to automate generating convex map.

On reviewing the current indoor space syntax application, we believe that an integrated solution to combine functions of architectural design and space syntax analysis seamlessly together is required to minimize tedious, time-consuming transformation of the data format for the space syntax analysis after architects’ designing work.
3. BIM BASED SPACE SYNTAX

Building Information Modeling (BIM) is a process of establishing manageable and sharable representations of physical and functional data that define buildings throughout their life cycle. It allows an architect to perform a continuous update and sharing of critical design information among various disciplinary areas in the building industry (Park 2008). The key advantage of BIM relies on the ease of managing digital building documents. Generally, it is found that application used within BIM framework tend to be used to resolve structural and civil engineering coordination (Hamza and Horne 2007). However, an attempt to apply BIM outside construction domain has been found recently. Researchers such as Hamza and Horne (2007) have been trying to integrate BIM and Building Performance Modeling (BPM) to create building performance analysis tools to predict daylight, thermal comfort, natural ventilation and acoustic performance.

Regardless of BIM definition which aim to cover the whole building life cycle, several scholars (Park 2008; Hannu 2007) have approved that current BIM applications provide very limited degree of design freedom, and rather difficult to learn as they seem to require very detailed component based building modeling, methods commonly available only in the later design phases. However, early stage of design is the stage where the architect can increase the impact of functional capabilities with low cost of design changes, and can have a high degree of design freedom that supports creativity in design (Park 2008). In fact, it is generally observed that the uptake of BIM systems has been slower in practice and indeed in educating future design and construction specialists (Hamza and Horne 2007). This is concurrent with the adoption of space syntax in design practice mentioned previously which is hard to apply and requires in-depth knowledge, thus, is always avoided during the design process. As BIM offers a great advantage to manage digital building information based on object-oriented CAD which can be utilized in space syntax analysis process, our paper sets forth to find out a new method of generative space syntax analysis during the initial design stage by means of building information modeling.

3.1. Generating space topology with indoor building information model

The building information model applied in this study is developed based on 'Structured Floor Plan' (Choi et al. 2007). As shown in Figure 2, it described a building composed of several floor plans in which their components are hierarchical constructed and thus effectively expresses its architecturally meaningful structure. The fundamental spatial entity for each floor is defined as a ‘space’ equivalent to a typical room. Thus a space is always enclosed by walls and connected to other spaces through doors (horizontally), stairs and elevators (ver-
Once a building model has been created, it is possible to query quantity, location and content of spaces on each floor.

The key advantage of BIM is an ability to generate space topology dynamically based on building components and space attributes. In this paper, we defined space topology as semantic relationship among spaces which can be described using a node graph. The graph is basically constructed based on two elements; topology node and topology link. A node is an abstraction of a building component such as space, door, window and column whereas a link is a connection between two related spaces. As they are countless numbers to create this kind of relationship among spaces in a building, the question is how to generate this topology graph automatically based on some kind of rules. Figure 3 depicts various possibilities to generate topology graphs autonomously for a building floor plan depending on given rules. For instance, (1) main circulation of a building can be generated by linking all space nodes to door nodes. (2) Adjacency connection among spaces can be created if any space shares the same wall. (3) Ventilation path can be derived from the connection between spaces through any openings. (4) It is possible to trace a circulation for disabled by linking spaces with the same elevation height unless ramps or elevators are provided.
As our research goal is to construct the topology graph for indoor space syntax analysis, further criteria must be specified. In accordance with Hillier and Hanson (2001), continuous permeability is the main information required to perform indoor space syntax analysis and described as every part of the building accessible to every other part without going outside the boundary. Accordingly, we can deduce that main building circulation is required to generate the indoor space topology for general space syntax analysis. In a public building, this refers to all public spaces where visitor can access without permission.

4. ARCHISPACE: THE BIM MODELER

To apply our main idea, ArchiSpace, a CAD modeling system, has been developed based on Building Information Model (BIM) approach. Its output digital model consists of not only 3D geometry but also additional spatial information to describe semantic relationship among building components. Objects created by ArchiSpace are treated as components based on structured-floor plan model. To create a building, one has to begin with insertions of walls and openings to define a space or a room. Constraints are integrated in the design. For example, openings such as doors and windows can be only inserted on a wall to make connection between spaces. This set of connections then forms a building story. In the same manner, stories are connected and become a building. Thus, each building component can be created and connected with other components to generate a bigger and more complicated set of building data. Further, these components contain parametric attributes in which once changed can automatically update other related components. Connections between stories are maintained by vertical connector classes such as stairs. By means of these connectors, it is able to trace the circulation among floors which is critical for spatial query; a searching algorithm that connects two entities located in different locations. Based on this, it is possible to generate space topology and calculate space syntax variables automatically.

4.1. Space syntax analyzing module

Interaction in ArchiSpace is divided into three modes; Sketch, Space and 3D modes. Basically, building components such as walls and doors are drawn and inserted in Sketch mode. Then, users can freely switch into Space and 3D modes. Spatial information such as space and topology is generated automatically whenever switched to Space mode. Three-dimensional model, likewise, is autonomously constructed and displayed in 3D mode. In Space mode, users can perform space syntax analysis instantly to predict how current design outcome may influence future inhabitants. Analysis options are provided to enable a selection of the analysis boundary between a floor level and the whole building level. The results as space syntax variables stored inside each space are represented as space
colors on the plan. When clicking on each space, users can retrieve space syntax information including connectivity, global depth and global integration. More detail results are displayed in tables and graphs. Figure 4 describes the process to use ArchiSpace for space syntax analysis and visualization.

**FIGURE 3. VARIOUS TYPES OF INDOOR SPACE TOPOLOGY.**

**FIGURE 4. SPACE SYNTAX ANALYSIS AND VISUALIZATION IN ARCHISPACE.**
4.2. Validation Analysis

For the sake of the validation of our solution, comparison of space syntax analysis among ArchiSpace, DepthMap and Axwoman is conducted using the same input floor plan of ‘Gallery.DXF’ downloaded from ‘DepthMap’ official website (http://www.vr.ucl.ac.uk/depthmap/tutorials/). The file contains 61 spaces, and 77 links. The two most common space syntax parameters - connectivity and integration are chosen for validation. Validation analysis was conducted under Windows XP with 3.0GHz CPU and 1 GHz memory. The process of validation includes following steps; in ArchiSpace: (1) Launch ArchiSpace application; (2) Import ‘gallery.dxf’ file for underlay; (3) Model floor plan by drawing walls and openings above the underlay; (4) Generate the topology for the layout; (5) Calculate the space syntax parameters. For Axwoman and Depthmap: (1) Launch the application; (2) Draw the convex map; (3) Calculate space syntax parameters. As shown in Table 1, almost the same result was produced proving that Space Syntax Analyzing Module in ArchiSpace is reliable and effective. Besides, ArchiSpace runs much faster than Axwoman. Unlike drawing every polygon in Axwoman and Depthmap on top of a given floor plan, designers are required to create a minimum set of building components and let ArchiSpace generates the spatial topology and analyze space syntax.
5. EXPERIMENT

In order to demonstrate how to apply ArchiSpace for autonomous space syntax analysis during initial design stage, a design project with an objective to renovate an existing faculty building (Figure 5—the existing floor plan) was assigned to a user. The building contains a 400-seat auditorium and its facility on the east wing as well as groups of faculty offices on the west wing. All rooms are connected to a main corridor stretched along the building layout. Existing entrances are located in the central hall providing accesses from the main corridor to the North and the South. Existing problems were the bottle-neck of circulation from the main entrance hall (room 39) to the auditorium (room 22) during class hours and lack of security in financial offices (room 31 and 32) at the west corridor.

5.1. Design Alternatives

The user was requested to solve existing problems using ArchiSpace as the design tool. Current building floor plan and space syntax analysis results are given as the starting materials. The designer came up with ideas of articulating the long corridor to solve the security problem as well as changing the building entrances. Based on this, the user designed three alternatives by adding, editing and removing spatial components including building entrances and partitioning walls which lead to changes in circulation flow. (1) For the first alternative, the south entrance was removed and the west corridor was partitioned into three sections to enhance the security of the financial offices. The east entrance was inserted to avoid bottle-neck circulation at the main entrance. (2) In the second alternative, there were the existing north and the new east entrances. The west corridor was dead-end and separated from the main entrance hall. (3) Only the north entrance was kept in the third alternative, and the west corridor was modified with the similar way to the first alternative. While using ArchiSpace to create the three alternatives in sketch mode, the analysis of space syntax for each case was performed instantly and the results were illustrated in Figure 5 and Table 2.
5.2. Experiment results

In overall, the average global integration (GI) and the intelligibility values of new floor plans are relatively less than the original ones. In general, low intelligibility is unfavorable in public building as it refers to difficulty in orientation. High integration on auditorium must be achieved to enhance accessibility to the seminar space but the value must be kept as minimize at the financial offices for the sake of security. The analysis result of the first alternative yields the lowest values of intelligibility (0.644) and the global integration of the auditorium (1.055). Insertion of the east entrance could not reveal remarkable impact on the auditorium. Thus, it has been excluded from the consideration. The analysis with Alternative II results in fair condition for all variables with relatively low integration value of the financial offices (1.009). Nonetheless, the third alternative was chosen as the final design solution since the design yields the greatest intelligibility (R = 0.739) and GI values for auditorium (1.36432) among those of new alternatives. Besides, the financial offices are just a little more integrated (1.167) than those of Alternative II.
6. CONCLUSION AND FUTURE WORKS

This paper introduces a new framework to enable user-friendly space syntax analysis during the initial design stage where Building Information Model and Space Syntax have been found to be rarely applied. This assists designers without in-depth knowledge on space syntax to evaluate and compare design outcomes rapidly. The framework is proposed and realized by means of BIM in which spatial information is constructed along with geometry information through relationship among building component classes. Thus, it is capable of retrieving space topology based on given rules such as connectivity among spaces as the input data for space syntax analysis. A BIM modeler so called ‘ArchiSpace’ has been developed to demonstrate the applicability of the framework to design practice. Our experiment shows that designers can use the modeler to analyze their designs instantly at any moment during the initial design stage. Therefore, users can develop their design alternatives and evaluate them simultaneously without distraction and tedious work on the space syntax analysis in details.

Nonetheless, various research issues have been left for further study as the project is still in its initial stage. Those issues are (1) space definition, (2) topology rule, (3) design alternative comparison, (4) 3D topology and (5) interoperability with IFC data. At the moment, both concave and convex spaces are treated as the same. Depending on rules, space topology can be generated diversely. Current development applies general rule to include all spaces during analysis. However, it is possible to expand the rule for more specific situation with the current framework. The next important issue is 3D topology based on stair and elevation circulation among floors which create more dynamic method to generate the topology. Lastly, our modeler can now import geometry floor plan in DXF format. More research and development must be further explored to incorporate IFC data in the modeler.

ACKNOWLEDGEMENTS

This research was supported by a grant (07KLSGC04) from Cutting-edge Urban Development - Korean Land Spatialization Research Project funded by Ministry of Land, Transport and Maritime Affairs.

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