Spatial Configuration Analysis on Three Korean Traditional Dwellings Using the Graph Theory

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Abstract
The study began with a survey on the similarity of spatial composition in traditional Korean dwellings and is an attempt to create a theoretical framework from the observation of that survey. There are various perspectives in analyzing traditional dwellings, which will result in diverse spatial interpretations depending on each perspective. This study demonstrates that traditional dwellings are not a spontaneous creation of architecture, but were established firmly through the filter of a long history.

In order to discuss the spatial configuration in detail, this study introduces the concept of threshold and expands it as a spatial interface. Furthermore, it proposes a new method of representing a residential space through nodes and edges in a graph by classifying domains and thresholds. It also considers the possibility that adjacent relationships between sub-spaces can be expressed as characteristics of spatial configuration. In the chapter regarding the graph analysis, an inter-related database is created through the C-language program. This suggests four types of analysis index regarding traditional Korean dwellings that provides a review of the similarities and differences of these relationships.

Keywords: spatial configuration; spatial description; graph theory; Korean traditional dwellings; threshold

1. Introduction
1.1 Background
In traditional dwellings, the logic of any spatial group is expressed as a physical space in any kind of form. This study attempts to explain that these spatial groups focus on the relationship between sub-spaces that configure a dwelling. Traditional dwellings are composed by various methods of spatial configuration based on ethnicity, culture, and natural environment, etc. These methods are developed by regional groups and if one can understand the pattern of spatial hierarchy, then one can discuss the similarity and differences between these groups.

1.2 Objective
The objective of the study is to understand the characteristics of spatial configuration in traditional Korean dwellings and the interrelationship of spatial elements. The main topics of study are as follows:
- To express the spatial configuration as a graph
- To develop an analysis index of inter-relationship
- To study three Korean traditional dwellings

1.3 Method
Physical space is diverse and complex, therefore, difficulties occur in realizing the concealed order of space; In order to objectively understand a space, it is significant to define a clear method. This study undertakes a quantitative approach by creating analysis indexes through the C-language program. Also, to discuss the interrelation of spaces in detail, the concept of threshold and partition of a dwelling in relation to each spatial element is introduced to rebuild it as a graph. Spatial configuration can be visualized by making a graph through quantitative data.

This study is configured into four processes. First, preceding studies of threshold and graph theory were reviewed. Second, the range of a dwelling and types of threshold were classified to visually represent it as a graph. Third, analysis indexes are defined to compare adjacent data in graphs. Fourth, field surveys of 3 traditional Korean dwellings were undertaken as case studies as a method of focusing on similarities and differences in spatial configuration (Fig.1.).

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2. Threshold

2.1 Concept

Threshold is defined by two different terms. One is an architectural term: The threshold of a building or room is the floor in the doorway, or the doorway itself. The other is in terms of psychology: a threshold is an amount, level, or limit on a scale. When the threshold is reached, something else happens or changes. This study's focus is closer to the latter. The concept of threshold is used to explain various phenomenon in the field of sociology and mathematics. For example, Claude Levi-Strauss said that communication does not stop at social boundaries. In this case, boundary means any kind of threshold represented when communication is weak, or shape of communication changes. Moreover, threshold does not disappear, but passes at the lowest level (Structural anthropology, 1974). Rene Thom defines as a catastrophe, such as rapid change from original state to the moment when anything happens at a fixed threshold, and develops the theory of threshold values (Structural Stability and Morphogenesis, 1994).

In short, if there are two different characteristics called A and B, then a threshold is located at the phase-changing boundary from A to B. If the threshold does not exist, one will not be able to distinguish the difference between A and B. On the other hand, if a threshold is in a homogeneous state, one state will be divided into two different states that will have an opposite structure to each other. Thus, a threshold exists between two different identities and creates a relationship.

2.2 Cases of Architecture Planning

In architectural terms, threshold is a relatively new spatial concept. However, examples can be found in a series of studies, such as in world traditional villages by Hara, H's laboratory of The University of Tokyo in the 1970s. He approached traditional villages as physical planning and introduced threshold concept to analyze the spatial interrelation. Threshold is a spatial device that corresponds to the changes in architectural space. A door is a typical threshold that is controlled by architecture. In the study of Iranian desert villages, he points out that integration and division of spaces occur simultaneously by thresholds. As a result, he classified this area's villages by buffer zone types ( Dwelling Group, Book 1 and Book 3, 1973 and 1976). In addition, Yamamoto, R. defined threshold as a spatial device to separate or connect two different characteristics of spaces and explained his work, such as apartment complex plan, based on the concept of threshold ( Housing Theory, 1993).

2.3 Role in the Architectural Space

(1) Signature

Architectural space consists of various elements, such as columns, walls, stairs and porch, etc. and these can be symbolic. Especially, in traditional dwellings, a simply-placed stone around a dwelling has a meaning to residents and neighbors. For example, at a dwelling in Jeju Island, Korea, three long logs instead of an entrance door are installed. The shape of the installation can inform the neighbors about the situation inside the dwelling. The size of the entrance gate indicates the social status of residents. Any room that has a door means that this room is private.

(2) Controllability

Because there is no completely closed architectural space, thresholds are installed and communicated with the outside spaces. Depending on the type of threshold, the strength of communication can be controlled and public or private space can be determined. Controllability of threshold has a deep relationship with spatial independence. A door in a room creates a highly independent space to separate spaces. On the other hand, if two spaces are separated by low steps, then they have a closer relationship to each other. The object that directly controls threshold is the activity of a human being. One is able to move from space to space through a threshold. The location and type of a threshold decides the circulation in a dwelling. More specifically, a type of door is highly functional as a spatial control device as it can control the circulation by being open or closed.

(3) Intermediation

Intermediation of thresholds creates a physical relationship between spaces. It is called 'adjacent' when any one domain is closely located to the other and connected by a threshold. If one can describe what kind of domains are adjacent to each other as well as the adjacent method for an entire dwelling space, then it is possible to visualize the spatial configuration of the dwelling. This study connects the character of intermediation in a threshold, as it is possible to discuss the similarities and differences of spatial configuration through a comparative analysis of adjacency between dwellings.

2.4 Definition of This Study

A threshold is defined in this study as a spatial device that has an interfacial function to intermediate domains, and is located on a boundary. Physical objects in this study are physical thresholds such as doors, stairs, etc. Also, it includes gate room, terrace, porch, etc. because they have a character of threshold and are transformed from boundary.

The study of spatial configuration by analyzing spatial interrelation allows us to predict and understand space by using the patterns of residents. Threshold is one of the factors to decide the order of architectural space and brings spatial character, as it is a superordinate spatial concept.

3. Graph Theory

3.1 Concept

Graph Theory is one field in mathematics that studies the geometric properties of graphs. A graph consists of nodes and lines, which are called edges that connect them, and transforms one into a relationship of nodes and edges.
Distance and direction in Graph Theory are omitted and remain as the topological relationship of objects.

3.2 Application

Topology and geometric properties of a graph have been studied in various fields, such as information science, chemistry, sociology, economics, engineering, etc. Therefore, the effectiveness of Graph Theory has been proven. For example, in computer science, a graph has been widely applied to computer data structure, algorithm, and configuration of a web page. In sociology, it has been applied to the communication network, hierarchy of groups, choice between members, and family tree. In the engineering field, it has been applied to process management, networks of roads, electric power grids, etc. In architectural planning, it has been applied to circulation distance, rectangular division, building layout, spatial configuration, and plane type classification, etc. March, L. and Steadman, P. (1971) presented that three residencies Frank Lloyd Wright worked on shared similar plan compositions by an adjacent graph. Hara, H. et al. (1981) classified traditional dwellings of the world using the maximum eigenvalue of adjacent matrix as an analysis index. Yoshida, K. (1980) studied plan partition, whereas Terada, H. (1990) studied the space partitioning method and quantified similarity. Kurosawa, K. (1987) carried out studies in respect to the regional characteristics of housing. In the case of Korea, there are lots of studies of traditional and current housing using Space Syntax, such as, Chang, D.K. (2002), who compared two region's traditional houses. Also Seo, K.W. and Kim, C.S. analyzed some existing house plans for flexible domestic life.

This study differs from previous studies in that thresholds were added to a graph, which was then analyzed. Thus, it can provide a more detailed analysis.

4. Spatial Description

4.1 Attributed Graph

From the preceding studies, a complex spatial interrelation can be expressed into a graph and a characteristic of graph geometry can be used by a quantitative index. However, the process of transforming a real physical space into a simple graph has to remove diverse spatial information. Therefore, it is necessary to review what kind of spatial information is presented in the graph, which then needs to develop into a method of spatial description and analysis index.

This study classifies types of spatial composition elements in dwellings and suggests the attributed graph. The node shows the type of domain and the function of a room, whereas the edge presents the type of adjacency between domains (Fig.2.).

4.2 Spatial Description Model

This section contains steps to create physical architectural space in a graph and reviews the method of spatial description. The suggested model presents spatial configuration based on adjacency and the process simplifying physical spaces in domains and thresholds (Fig.3.). The summary is as follows:

- A dwelling is configured by one or more domains
- A domain has one or more thresholds
- A domain installed threshold is independent
- A unit of domain is not divided
- Intermediate domains, such as gate room, porch, etc. are thresholds, which become zoned like a domain
- A threshold forms adjacency between domains
- Domains and thresholds make adjacent networks
- A set of adjacencies make a spatial configuration

4.3 Graph of Spatial Configuration

(1) Significance and Objective

An order of configuration in architectural space which is created by connections of space and present spatial interrelations in a graph, which can be thought of as a quantitative method. The objective in a graph can be summarized into the following:

- To visualize the residential structure based on space model technology
- To create an adjacent database to compare the spatial configuration of each dwelling

(2) Subject and Range

From the resident's point of view, the range of a dwelling tends to expand because they consider a farm and any other empty space as residential space. On the other hand, an external observer will have difficulty in setting a dwelling range, because it is invisible. This study sets the residential boundaries of roads in consideration of former studies in creating a plan as well as for the convenience of future studies in
analyzing diverse dwellings. Thus, a road represents one of the nodes. This is the starting point of the graph.

(3) Process
In order to increase work efficiency, prevent work error, and provide efficient database management, a graph through a C-language computer program is created. The process of creating the graph is as follows (Fig.4.):

1) Consideration of the subject dwelling; review of spatial composition with drawings, photos, references etc. Main review items are type of domain and threshold, function of space, and location of space, etc.

2) Set up of dwelling zones; review adjacencies between outdoor and indoor spaces and decide the range of graph.

3) Domain partitioning; separate dwelling zone into small domains as much as possible.

4) Domain classification; classify in detail in regards to the functions of domain.

5) Threshold classification; classifying type of threshold located on the boundary and decide spatial interrelationship.

6) Convert attribution to symbol; symbolize domains and thresholds to decide spatial attribution, which is shown as nodes and edges in the graph.

7) Create a graph; connect nodes by edges depending on the existence of adjacency and complete the graph.

(4) Type of Domain and Threshold Classification
Spaces in a dwelling are classified into three types, which are functional space, intermediate space, and other spaces, such as a courtyard, empty area, etc. In addition, it is classified into 19 types of domain, where as threshold is classified into 9 types in a review of mediated subject (circulation and view), mediated method (vertical and horizontal). A graph is made of a combination of these attributions (Tables 1. and 2.).

(5) Domain Partitioning
Residential area is classified as shown in Tables 1. and 2. Domain partitioning is a process that decides a boundary and nodes in the graph. Through this process, one can understand the arrangement of a domain. It is possible to divide in detail according to the following rules:

- An area enclosed by boundaries is considered as one domain
- A boundary exists between adjacent domains
- If an area does not have a physical boundary, such as a wall, but has a function then it is a domain (a workspace, manure storage etc.)

Table 1. Symbolic of Nodes Attribution

| Classification | Attribution |
|----------------|-------------|
| Functional Space |             |
| Bedroom         | BR          |
| Living room     | LR          |
| Hall, Reception room | HA |
| Taechong<sup>1</sup> (wooden floor) | WF |
| Kitchen (cooking place) | KI |
| Storage, Jangdokdae<sup>2</sup> | ST |
| Bathroom (washing place) | WP |
| Barn (domestic animal) | DA |
| Work space      | WO          |
| Toilet          | TO          |

| Intermediate space |         |
| Gate room, Entrance | GR |
| Porch, Stylobate<sup>3</sup> | OS |
| Foyer, Bongdang<sup>4</sup> | FO |
| Passage, Corridor | PA |

| Other Space |         |
| Enclosed yard<sup>5</sup> | EY |
| Courtyard | CY |
| Front yard | FY |
| Backyard | BY |

| External Access |         |
| Main road | RD |

1) Main floor room. Most of the studies tend to analyze the reception room, family room, and social status. Thus, it is believed that Taechong is one of the spatial units.

2) Outside platform for crocks of sauces and condiments.

3) There is a case to install a stylobate as constructional method. This can be used as a passage and a terrace. Therefore, it is classified as an intermediate space as it has a function of threshold.

4) Unfloored area between two rooms. It is usually located at the same place as Taechong.

5) Small dwelling has the spatial characteristic of a room, but is classified as outdoors surrounded by a wall and distinguished from a courtyard.

Table 2. Symbolic of Edges Attribution

| Classification | Attribution |
|----------------|-------------|
| Circulation |            |
| Horizontal |             |
| Door | do |
| Entrance (no door) | en |
| Edge<sup>5</sup> (eaves, stone) | ed |

| Vertical |            |
| Step | ra |
| Steppingstone | fo |
| Ladder | la |
| Stairs | st |

| View |            |
| Window | wi |
| Opening window | ow |

1) Although there is no physical boundary, this threshold separates domains from functional differences or relationship with the surroundings.

1) Review of Target Dwelling  2) Decision of Dwelling Zone  3) Domain Partitioning  4) & 5) Type Classification  6) Marking Symbol  7) Making a Graph

Fig.4. Process of Making a Graph
Dividing outdoor area, such as enclosed yard, courtyard, front yard, and backyard, are represented by approximate location in a dwelling, because boundaries are often unclear and difficult to separate in detail.

(6) Making a Graph

The means of creating a graph is by domains and thresholds converting into symbols and representing as nodes and edges in a graph with adjacency. In order to compare graphs, it is necessary to work in the same method. Rules of making a graph are as follows:

- Adjacent relationship is expressed by edges that connect node-to-node, whereas loop and multiple edges are expressed through a simple graph.
- A closed door makes an isolated node, but all kinds of doors are considered as open to complete the graph.
- If there is a plural adjacency between domains, for example, stairs and ladders, the easiest access route is selected.
- In order to improve visibility, crossing edges are prohibited in making a plane in the graph.
- An edge does not have a direction and makes an undirected graph.
- A view to the outside through a window and openings connects directly to outdoor domains, such as courtyard, backyard, etc.

5. Case Study of Graph Analysis

5.1 Three Traditional Dwellings

Three Korean traditional dwellings were surveyed in 2001. Jinbu is located in Gangwon province and was built during The Korean War (1950~1953). It was built on a steep slope. The layout is L-shaped and consists of two bedrooms, a kitchen, and a cowshed. The cowshed is connected to the kitchen. This type of layout is distributed widely in Gangwon province, North Korea, and Korean-Chinese villages. Muck piled out of the cowshed is used as manure (Table 3.a).

The other dwelling, Mino, in Gangwon province is estimated to have been built in 1935. There is an enclosed yard in the interior of the dwelling. This is a typical layout of -shape in this region. A plan composition of Sarangbang (a guest room for male visitors) and Anbang (a master bedroom, mainly a female's room) is placed around the Taechong (Main floor room). The gate room connects the inside to the outside of the dwelling and a rice mill, storage, and toilet are placed as auxiliary programs of the building. There are about 13 similar type dwellings in this village (Table 3.b).

Gwideok is located in the North West region of Jeju Island. The climate in this area has high temperature all year round. If building layout is compared to one of the Korean peninsula, it is similar to the surface in that each building is placed around a courtyard. However, one cannot distinguish Sarangchae (a men's building of a dwelling) and Anchae (a main building) for the buildings in this area. The main building is called Angeori. When the son gets married, then Backgeori, which is the couple's residence building, is built. Angeori and Backgeori are placed symmetrically on the courtyard. A fireplace was installed separately from cooking and heating to prepare for the summer heat. In large dwellings, Jeongjigeori, which is an attached building for a kitchen, is also built (Table 3.c).

5.2 Making and Use of Adjacent Database

Using the C-language program, an adjacent graph of a dwelling is made with the database that was used as the source of spatial configuration in comparing the dwellings (Fig.5.).

5.3 Four Analysis Indexes

(1) Diagram

The adjacent graph (Table 3.) of each housing has a different form, hence, it is difficult to compare the two. Therefore, the 19 nodes classified in Table 1. are fixed and relocated in a circular shape to easily understand the adjacent relationship. The thickness of the edge represents the frequency of adjacencies detected. Through this diagram, it is possible to compare the shape of the graph with the quantitative method (Table 4.a).

(2) Matrix

The numbers of all relationships in the adjacent graph are shown numerically. This index represents adjacencies through a matrix. If a value is '0', then adjacency does not occur, and if the number is 'one or more', then the number of adjacencies is detected (Table 4.b).

(3) Node Diagram

Node diagram is created to understand which individual node that forms the adjacent graph has a relationship with which types of nodes. This analysis is to determine the adjacent relationship of a specific node. The higher the degree of the nodes, the higher the frequency of usage within the housing and a node diagram is created depending on the number of nodes. In addition, Node Diagram is processed through a computer as a database to search for the common relationship between the 2 Adjacent Graphs (Table 4.c).

(4) Deep Graph

Similarity of spatial configuration in a dwelling cannot be understood through partial space but can be obtained from sequences of experiences by moving around the space. In the dwelling survey in Korea, two spatial approaches are considered similarly. One
Table 3. Three Traditional Dwellings

| Name  | (a) Jinbu | (b) Mino | (c) Gwideok |
|-------|-----------|----------|-------------|

| Isometric Plan |
|----------------|
| Jinbu          | Mino      | Gwideok   |

| Domain Partitioning |
|---------------------|
| Jinbu               | Mino      | Gwideok   |

| Adjacent Graph |
|----------------|
| Jinbu          | Mino      | Gwideok   |
is from the outside to the inside of a dwelling, and the other is from the courtyard to the interior space.

This study suggests the comparative method of the graph. It is expected to understand the similarity of sequential adjacency when it moves from the road to the inner dwelling. The road is the starting point in a deep graph (Table 4.d).

5.4 Spatial Configuration Analysis

(1) Adjacency of Three Traditional Dwellings

The node 'OS' appeared relatively often in the three dwellings. The three dwellings have an adjacency of 'BR-OS' in common.

From the thickness of the edge, Mino has several similar adjacencies. It can be seen that similar adjacency happened repeatedly in contrast to the complex shape of the adjacent graph. This affects all of the spatial configurations.

Gwideok has a relatively thin edge with even distribution. It is composed of two buildings of similar appearance, but the pattern of adjacency is different (Table 4.a, 5.a, and 5.b).
(2) Common Adjacency

Table 5.c is the aggregate of all adjacencies of the three dwellings. This method verifies the possibility of classifying dwellings in groups and comparing the adjacency between groups.

The most common adjacency in the three dwellings is 'BR-OS' which was detected 8 times. It is followed by 'OS-OS' 7 times and 'ST-OS' 6 times, respectively. In the review including thresholds, the results are 'BR-OS/do', 'BR-BY/wi', and 'FY-RD/ed'.

(3) Searching Common Part in a Graph

Two dwellings were compared using an index of the node diagram. There are three matching cases such as, 'Jinbu-Mino', 'Jinbu-Gwideok' and 'Mino-Gwideok'. If the same relationship exists within the adjacent graph, then these nodes will be marked. Table 6.a shows the result of comparison in the node diagram. The matching of 'Jinbu-Mino' was detected the most. It can be seen in a similar layout around the front yard. The matching of 'Jinbu-Gwideok' was detected the least. Although 'Jinbu-Gwideok' has a common adjacency of 'RD-FY', a common part was not detected in the inner dwelling of the graph. It shows that a significant difference of the spatial configuration exists.

Table 6.b is a result of the comparison in the deep graph. 'Mino-Gwideok' has three common adjacencies, such as 'RD-FY', 'OS-OS', and 'OS-BR'. In addition, it shows the regularity of spatial arrangement, such as 'OS-OS-BR'.

Fig.6. shows the common arrangement of Mino and Gwideok.

6. Conclusion

This study is an attempt to define the threshold and develop theoretically. Additionally, it suggests methods of graph analysis, which is obtained by adding the intermediation concept of threshold in the existing method. In this study, the achievements and tasks are as follows:

(1) In the spatial analysis, concept of threshold is expanded and defined as a spatial device, which has an interpersonal function for mediating spaces located on a boundary. It is possible to discuss in detail the architectural space as a continuous interrelationship of physical architectural elements. (2) It suggests the method of visualizing spatial configuration through representing the characteristics of domains and thresholds in a graph. Through this method, it is possible to maintain architectural spatial information in an adjacent subject way. (3) It suggests a method to find a commonality of adjacency. To make an adjacent database, it used C-language programming and as a result, it used adjacencies of dwellings as objective data. (4) In the arrangement of nodes, it suggests comparison indexes in searching for a common part in a graph. Node diagram is adjacent to individual nodes and deep graph is an arrangement of nodes.

This study discusses the similarities and differences of three Korean traditional dwellings through the verified analysis method. Further in-depth studies will verify the validity of the theory and analysis method.

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