Spatial Configuration of Japanese Elementary Schools: Analyses by the Space Syntax and Evaluation by School Teachers

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Abstract

In this paper, we analyzed the spatial configuration of Japanese elementary schools by using the space syntax theory. First, we selected the floor plans of 76 Japanese elementary schools from an architectural journal and educational government offices and analyzed them. They were classified into five types according to the spatial connection properties of mean integration, mean connectivity, and intelligibility. Second, they were classified into five types by the order of the integration of different functional spaces. Finally, four evaluations of the students’ activity and eight evaluations of educational performance were performed through a questionnaire survey of school teachers in each school. Through multivariate analysis of variance, the relation among the evaluations and the types of schools were estimated statistically. As a result, the merits and demerits of each type of elementary school were assessed.

Keywords: space syntax; elementary school; spatial configuration; post-occupancy evaluation; assessment

1. Introduction

As the birth rate declines in Japan, more elementary schools are closing or merging. Although their number is decreasing year by year, various types of school spatial planning have been developed considering openness to local community, flexible use of space, multidisciplinary education, etc. (Ueno 1999).

Studies on elementary school configuration have revealed the trends and background. Ueno (1994) analyzed the multipurpose spaces of public elementary schools subsidized by the government for advanced education, and classified them by their shape, size, location, etc. Yamaguchi (2009) investigated schools in Tokyo, Toyama, and Akita and classified classroom layouts into several types with respect to an open space around each classroom: open plan type, hall type, L-shape type, etc. He also discussed the floor plan changes in these regions. Otaki (2007) regarded the gaps in classroom layouts as a “manner” of design and investigated spatial configuration in terms of the classroom open space. He classified them into six types: L-shape, inner, cranked, etc. Nishikawa and Suzuki (2007) clarified the change in spatial configuration around classrooms and classified them into seven types: side corridor, center corridor, L-shape joint, etc. Hattori et al. (1976) classified the school plans into seven types: decentration, dumbbell, wing separation, etc., considering the location of classrooms for special uses such as music or science and ordinary classrooms. They used a questionnaire survey and demonstrated the relation with the use of the space.

As mentioned above, many researchers studied the space around classrooms; however, there are few studies on the entire space of elementary schools. Furthermore, there are few studies about the spatial connection of the local community at the school gate and building. The majority of studies are at the classification level. Miyamoto (1992) investigated how students build a mental cognitive map of the school building, and found that students tend to recognize the school not by the shape of the building but by the connection of spaces: classrooms connect with corridors; corridors connect with halls; halls connect with staff rooms; and so on.

On the other hand, space syntax can mathematically analyze the spatial connection in architectural and urban spaces. The method analyzes the relation of spatial configuration with human activities, spatial cognition, human communication, and so on. Hillier and Hanson (1986) presented a method for modeling and analyzing spatial connection, and presented an analysis of traditional settlement layouts, modern housing estates, and traditional and modern houses. They showed the relation among spatial configuration, social logic, and human activities. Hanson (1994,
In this study, we chose 76 elementary schools in Japan and used space syntax to analyze spatial configuration and its relation with the assessment of school teachers.

First, we modeled school plans using a space syntax convex space model, including both interior and exterior spaces, and calculated the space syntax indices: integration, connectivity, and intelligibility (IN). Then, we classified them into several different types (Typology 1).

Second, we performed a functional layout analysis of schools. We investigated the integration value of each function such as classrooms, circulation spaces, and teachers' room, and classified schools into several types (Typology 2).

Third, we investigated the assessment of each school by using questionnaire surveys. Students' activities, quality, and performance were assessed by teachers. Finally, we analyzed the relation between the spatial configuration type and assessment.

2. Spatial Configuration Analysis of Elementary Schools

2.1 76 Elementary School Cases in Japan

We chose representative elementary schools for analysis. The cases range from old-fashioned elementary schools of the early 20th century to contemporary schools with various open spaces. First, we chose 66 cases from the Japanese architectural journal Shin-Kenchiku, which is the most popular architectural journal in Japan. We selected schools built after 1980 for which all the floor and site plans were available. These cases include new elementary schools designed by famous architects. Second, we added five typical municipal schools in Yokohama city, which belonged to the side corridor type and two-row building type. Moreover, we added five "reconstructed elementary schools" built after the Great Kanto earthquake in 1923, considering their functionality, safety, and efficiency, and this type of school became the prototype of Japanese elementary schools.

2.2 Modeling of Spatial Configuration

We modeled the spatial configuration of all floors and site plans of each school, which included the school building, playground, court, gate, and so on, by constructing a convex map of the space syntax.

Typically, the convex space is defined by its geometrical shape, but we did not divide the concave space if it was functionally continuous and the same, or similar to the study conducted by Funahiki (2009). Besides, serving spaces such as machinery rooms, storage, and kitchens, which are not visited by students and teachers, were ignored (Fig.1.). Special rooms in each school, which are uncommon, and swimming pools, which are used only in the summer, were not modeled. In addition, off-limit areas such as the court or roof terrace were excluded.

Each school was modeled as nodes and links, and the space syntax was analyzed.

2.3 Space Syntax Indices

In this study, we used three indices of space syntax for analysis: integration, connectivity, and IN. The meaning of these indices is given below.

Integration is the index for space centrality. It is also sometimes regarded as the index of accessibility. If its value is high, the space is located at the center of the system. If the mean value of the system is high, it means that the system is strongly connected and integrated. Thus, the system accessibility is high. This study uses the most common integration value defined by Hillier and Hanson (1984).

Connectivity is the number of links that connect to other spaces. A space with large connectivity has many connections to other spaces. A space of small connectivity is an independent space. If the mean connectivity (MC) of all spaces in a school is high, it means that there are more connections between spaces, loops, and more routes for moving.

Intelligibility is the coefficient of correlation between integration and connectivity. If spaces of
high integration and spaces of high connectivity are the same, the \( IN \) is high. Otherwise, it is low. In other words, this index represents the consistency of centrality and selectivity, and is related to the order of parts-to-whole relation. Hillier (1996) defined \( IN \) as "analyzing the relation between how a complex can be seen from its parts and what it is like in an overall pattern, i.e., as a distribution of integration."

3. Analysis by Space Syntax Indices (Typology 1)

First, we analyzed school plans by the connection of spaces only, disregarding the functional layout, and classified the schools (Typology 1). The mean integration (MI) and MC of the spaces in each school and the \( IN \) were used to classify 76 schools into five different groups by using hierarchical cluster analysis and examining the dendrogram (Ward’s method, SPSS 20).

The properties of the indices are summarized in Table 1. Type "a" has low MI and low MC, and rather high \( IN \). Type "b" has low \( IN \), low MC, and low IN. Type "c" has very high IN. Type "d" has very high MC. Type "e" has very high MI. These characteristics are graphically shown in Fig.2., where NC denotes "narrow center." The NC connects spaces such as corridors or open spaces. The NC space is a cluster core or a local center of spaces. Each type is named as a: intelligible and segregated type, b: all low type, c: very intelligible type, d: high connectivity type or loop type, and e: integrated type.

<table>
<thead>
<tr>
<th>Typology</th>
<th>MI</th>
<th>MC</th>
<th>( IN )</th>
<th>Type name</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Intelligible and segregated</td>
</tr>
<tr>
<td>b</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>All low</td>
</tr>
<tr>
<td>c</td>
<td>Low</td>
<td>Low</td>
<td>Very high</td>
<td>Very intelligible</td>
</tr>
<tr>
<td>d</td>
<td>Very high</td>
<td>Low</td>
<td>High connectivity</td>
<td>Loop</td>
</tr>
<tr>
<td>e</td>
<td>Very high</td>
<td></td>
<td>High</td>
<td>Integrated</td>
</tr>
</tbody>
</table>

Table 1. Five Types According to the Three Space Syntax Indices

Graphically and conceptually displayed by combining the three space syntax indices

Fig.2 Model of Each Type

Following are the explanations of these types according to the architectural plans.

a: Intelligible and Segregated-type (25 schools)
Integration is low but \( IN \) is high. There are many schools of this type. Because corridors are divided or sandwiched by courtyards, people have to pass many spaces while moving. The common characteristic is that NC spaces that connect spaces are continuously located. The NC spaces consist of corridors connecting classrooms, open spaces, and corridors connecting special classrooms. At the center, the NC spaces are continuous and connect each other in high density, but at the ends, spaces are connected in low density.

b: All Low-type (19 schools)
This type has low integration, low connectivity, and low \( IN \). Because the corridors are small, people need to pass many spaces while moving. The difference with type "a" is that the NC spaces are located at the ends. Many schools of this type comprise separate buildings, have independent classroom clusters of the same grade, and have bridges or connecting corridors.

c: Very Intelligible-type (5 schools)
This type has very high \( IN \), and spatial configuration has a consistent order of locality and totality. Their architectural plan has many NC spaces connecting at the center of the school; therefore, the school center is also a NC space. At the center, common corridors and halls are positioned and connected to many spaces, and therefore they work as the center where many students and teachers meet. Away from the center, the density becomes low, and it becomes isolated and independent.

d: Loop-type
This type has high connectivity and a large selectivity of routes. The courtyard merges with the building and connects many spaces. Therefore, people can move through corridors and courtyards. Each classroom or open space connects to the courtyard, and people can choose various routes for moving. Thus, the route selectivity is very high.
This type has a very large MI. The spaces are strongly connected and have high accessibility. Corridors and open spaces connect spaces such as common and special classrooms. This type has many NC spaces and spaces connecting the NC spaces too. Schools with long corridors are typical of this type.

4. Analysis by Functional Layout (Typology 2)

Next, we analyzed spatial configuration with respect to the functional layout and classified them accordingly (Typology 2). We categorized the major functional spaces of the schools into eight categories: normal classroom, exterior of school premises, space for circulation including corridors and open spaces, special classrooms, arenas, entrance of buildings, teachers' rooms, courtyards, and playgrounds. Toilets, nursery rooms, presidents' rooms, and so on were omitted.

To investigate the functional layout, the functional integration ratio (FIR) of each category space was calculated. The FIR is defined as the MI value of specific functional spaces divided by the MI of all spaces in the school. It indicates the relative centrality of each function in the school plan. If its value is less than one, the function is located at a segregated position. If the value is greater than one, the function is relatively located at a more central position in the school.

Using the FIR, we constructed the genotype of each school. Genotype is the sequence of functions ordered by the integration value. The genotype has been used in the analysis of houses by Hillier, Hanson, and Graham H (1987), Hanson (1998), Major and Sarris (2001), Kigawa and Furuyama (2005), and Guney and Wineman (2008), etc.

This study derived the genotype by the FIR. By calculating the order of functions in a school, we analyzed the functional configuration. To clarify the functional configuration, we classified 76 schools into five types using cluster analysis by the FIR values of each functional space (Ward's method, SPSS 20).

Fig. 4 shows the characteristics of the FIR value of five types of groups. C denotes the classroom, X the exterior of school premises, M the circulation, S the special classrooms, A the arena, E the entrance, F the teachers' room, and Y the courtyard and the playground. We focused on the functions of high and low FIR in each type, and named them as follows: staff room center, circulation center, exterior center, exterior of school premises center, and teachers' room end.

A. Teachers' Room Center-type (20 schools)

This type is at the center of the school. Because the teachers' room is closer to the center than the classrooms, the teachers' room is spatially superior relative to the students' place. Besides, X and A are at a relatively subordinate position. A has the lowest FIR value among the five types. Because X is at a subordinate position, this type is isolated and segregated from the exterior local community. Many schools of this type independently have a separate arena at the periphery of the premises.

B. Circulation Center-type (27 schools)

The majority of the schools belong to this type. The FIR of M is the first or second largest; in 24 out of 27 schools, the FIR of M was the largest. In contrast, because the FIR of X was the smallest in 22 out of 27 schools, this type is considered to be closed to the local community.
Two out of three schools in the private sector are of this type. Four out of five reconstructed schools belong to this type. The reconstructed schools are designed for rapid evacuation of students because the FIR of M is relatively high. Besides, the playground is designed to be used by local residents in case of a natural disaster; the school building is designed such that it is difficult for the local residents to enter the building and therefore is closed (reports of reconstructed school in Yokohama, 1983).

C. Exterior Center-type (6 schools)

Y, A, and E are the most superior space of this type, whereas the most subordinate space of this type is C, X, and S. It is notable that the FIR of Y is the highest and S is the lowest in this type.

The playground and courtyard are at the center of the layout. Then, the FIR of E, which connects the playground and court with interior spaces, is also accordingly high. In contrast to the exterior space, special classrooms are isolated. All schools of this type have a courtyard and exterior spaces, including a playground, surrounded by school buildings. Several building blocks and outdoor corridors face exterior spaces. Classrooms face exterior spaces, but special classrooms are located at deep positions.

D. Exterior of School Premises Center-type (8 schools)

The FIR of X of this type is high and at a superior position, whereas it is low in the other types. Moreover, the FIR of Y is nearly above one and it is at a superior position. A and C are subordinate. The FIR of C is lower than the other types. Thus, the exterior of premises is superior, and the space of this type is open to the local community. On the other hand, normal student classrooms are isolated and independent. The school's design ensures safety even if the neighborhood people enter the premises. Seven out of eight schools do not have fences or barriers around the premises, and people in the neighborhood can enter and easily access the school facilities for community activities.

E. Teachers' Room End-type (15 schools)

In this type, M, E, and Y are superior, and X and A are subordinate. Compared with the other types, F is at the subordinate position and its FIR is the lowest. The circulation, courtyard, and playground are at the center, but this type seems to be closed to the local community. Although the teachers' room is typically located at the center, it is located at a relatively deep and segregated position. Some schools have teachers' rooms in an isolated administrative block, whereas other schools have teachers' rooms at the end of the building. This type has a courtyard; some schools have courtyards with surrounding corridors, whereas others have many courtyards in the building block. There are many schools whose courtyards and buildings are merged and open to the exterior.

5. Assessment of the School Plan by Teachers

5.1 Questionnaire Survey

To determine the relation between spatial configuration and school performance, we conducted a questionnaire survey of assessment for school teachers. School teachers use the building daily; besides, they periodically move to different schools and consequently know many different school buildings. Therefore, we assumed that they could assess the building by comparing it with other buildings.

The questionnaire survey comprised two parts. The first part had questions about students' activities, which are as follows:

Q1-1 Exterior: do many students play in the outside playground?
Q1-2 Library: do many students use the library?
Q1-3 Teachers' room: do many students visit the teachers' room?
Q1-4 Concentration: can students gather during class?

The second part was about an assessment of performance in education and learning. According to the "merits and demerits by school size" by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT), small schools have an advantage in which teachers can be more attentive to each individual student, and the relation between students will become stronger and deeper. In contrast, in large schools, students have various learning methods, and can learn and develop their abilities in a better manner.

The same assumptions arise about the difference in spatial configuration. The questions to teachers are given below:

Q2-1 Attentive education: is it easier to attend the needs of and instruct each individual student?
Q2-2 Friendship: is it easier to build good relations with students?
Q2-3 Diversity: is it easier for students to accept various ways of thinking and develop their potential abilities?
Q2-4 Contact and interaction across grade divisions: are there more cross-grade contacts and interactions among students?
Q2-5 Communication between teachers: is it easier to communicate with other teachers?
Q2-6 Contact with the local community: is it easy to collaborate with local residents outside the school?
Q2-7 Flexible education: is it easy to conduct various types of learning and teaching such as group learning, competence-based learning, and professional teaching?
Q2-8 Operation and management: is it easy for teachers to operate and manage the school?

Teachers were requested to answer these questions by choosing among agree, somewhat true, neutral, somewhat disagree, or disagree. All teachers in 65 out of 76 schools, excluding the abolished schools, were targeted. A total of 44 schools kindly participated and a total of 586 teachers answered.

5.2 Spatial Configuration and Assessment

We calculated the rank correlation coefficient
between the space syntax indices: MI, MC, MI, and FIR, and answers to each question. The correlation coefficient of each question and school size was also calculated to see if the statements by MEXT are true. Table 3. shows the coefficient value of correlation.

Are there many students who play outside the building (1-1)

This has a weak negative relation with the FIR of A. If A is far from the school center and its accessibility is low, students tend to play outside the building. There are not any other relations with the space syntax indices.

Library, Teachers’ Room, and Mood (1-2, 1-3, 1-4)

There was no significant relation with any space syntax indices and FIR. The use of library, contact with teachers’ room, and concentration during class do not seem to have a relation with the space syntax of spatial configuration.

Attentive Education, Friendship (2-1, 2-2)

These assessment criteria have a negative relation with the number of classrooms; R = −0.364 and −0.417. If the number of classrooms is few and the school size is small, it becomes easier for teachers to guide and educate students, and students easily develop good relations with their friends.

Diversity (2-3)

MEXT (2008) stated that in large schools, students have more chances to encounter diverse ways of thinking and develop their abilities more easily. However, we could not see any relation with school size (number of classrooms) and a clear relation with the space syntax indices.

Contact and Interaction Across Grade Divisions (2-4)

This criterion has a positive correlation (R = 0.501) with IN and a strong negative correlation (R = −0.697) with the number of classes. Teachers assessed that when the IN is large or the school size is small, the interaction between different grades increases. Many cases of schools with low IN have divisions of grade clusters that are linked by bridging corridors. We assumed that such a layout strongly divides students' activity areas and decreases contact across grades.

Communication Between Teachers (2-5)

As for this criterion, there were no indices of space syntax or FIR with a significant relationship. We assumed that criteria other than spatial configuration are more important.

Contact and Interaction with the Local Community (2-6)

We saw a significant weak correlation between the FIR of F and this criterion. If the integration of the teachers' room is high, it becomes easier for the school to collaborate with the local community.

Flexible Education (2-7)

The easiness of various learning and teaching styles has a strong correlation with the space syntax indices and FIR. We could see a strong negative correlation with the FIR of M and C, and with MI, i.e., as the centrality of the circulation space and classroom and the integration of the school are low, more teachers evaluated that it is easier to follow various educational styles. Isolated and independent classrooms and weak circulation systems tend to afford flexible education. Schools with open spaces have low MI and are less integrated than others. In contrast, schools with a linear layout of classrooms and a side corridor have high MI and are more integrated. Thus, we assume that schools with open spaces promote a more flexible education style.

Operation and Management (2-8)

Easiness of operation and management is weakly correlated with the MC and FIR of E and F. If the school has a high selectivity for route choice and movement, and if the entrance and teachers' room are at an integrated position, the operation of the school becomes easier. We assume that teachers can monitor the movement of students or guests and can choose the better route according to the situation; this has led to high evaluation.

5.3 Teachers' Evaluation and Type of groups

We performed multiple comparisons of each assessment criterion of different types using multivariate analysis of variance. Because the answers to questions were obtained by an ordinal scale, we converted them to quantitative values of the interval scale for analysis. The averages of each assessment are compared to the types of spatial configuration, which we discussed in sections 2 and 3. From the result of multiple comparisons of averages, significant differences in the evaluation in types: higher or lower than others are shown in Tables 4. and 5., where criteria with no significant differences (below 5%) are omitted. Types with significantly higher or lower assessment are marked as "*". Types without any mark do not have significant differences with others in terms of the assessment.

From Table 4., we can recognize that there are several significant differences in the assessment criteria among the types of Typology 1.

The intelligible and segregated type is the highest regarding flexible education (2-7). In addition, the interaction between different grades and good human relationships among students (2-4) is higher than the other type. In contrast, assessments concerning the various ways of thinking and developing students' abilities (2-3) and the easy operation of schools (2-8) were relatively lower than the other types.

The assessment of all the low types regarding the communication among teachers (2-5) is the lowest
among the five types. In addition, generally, the assessment of this type is lower than others, and schools of this type are negatively assessed in every criterion.

The very intelligible type is positively assessed in many aspects. Teachers can lead students more carefully and more attentively; students can develop good relations; students can learn many ways of thinking and developing their abilities; there are good interactions across grades; and teachers can communicate well with each other.

The loop type is the most positive in the assessment of school operation and management (2-8). The assessment of the contact across grade divisions (2-4) is low, but careful and attentive leading (2-1) and communication among teachers are higher than others.

The assessment of the integrated type is significantly lower than others for all performance criteria.

From Table 5., we can recognize that there are some significant differences in the assessment criteria between the types in typology 2.

The teachers' room center type has the highest assessment for flexible education. Usage of library and students' visits to the teachers' room are also very high.

On the other hand, the criterion regarding the various ways of thinking and students' ability is lower than the other types.

The circulation center type received positive assessment for outdoor and library activities, and human relations between students and others.

The exterior center type received the lowest assessment for various ways of thinking and students' ability. The assessments of human relations, various ways of thinking, and flexible education were also lower.

The exterior of the school premises center type generally received better assessment than the other types. More students play outside to develop their ability to deepen their relationships, and also to develop various ways of thinking than the other types.

The teachers' room end type has the lowest criterion and received many negative assessments except for the students' outdoor activities.
6. Conclusion

This study focused on the spatial configuration of elementary school buildings in Japan, and analyzed 76 school plans by using the space syntax indices. We classified them according to two ways of analysis. First, we classified them by the spatial connection, without functional meaning, into five different types. Second, we classified them by the functional order of the configuration.

As mentioned above, combining the assessment with a questionnaire survey, we found and statistically revealed that the assessment varies in spatial configuration and functional order. We could see the differences in educational performance and students' activity by using the spatial configuration.

For example, comparing the teachers' response, the very intelligible-type and loop-type were generally assessed as better than the low- and integrated-type. The intelligible- and segregated-type received both good and bad ratings.

Based on the functional layout for the center-type, the assessment results for the teachers' room and exterior of the school premises was better than the circulation and exterior.

For better schools, we should be more critical of the relation between spatial configuration and performance. We hope that we have contributed to this end.

Acknowledgements

We deeply appreciate the teachers who kindly answered the questionnaires. Especially, we thank the school presidents for permitting a survey of the assessments. As the teachers requested, we did not name the schools or the floor plans by which the schools could be identified. We would appreciate it if readers could allow for this inconvenience.

References