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Research paper



A Study on the Usability of Agent Based Modeling from Space-Structural Perspectives by Comparison of Space Syntax with Pedestrian Simulation

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Abstract

Background/Objectives: It is very difficult to analyze space as a physical object. As an alternative, space syntax is a solution to codify space and analyze the topological relation between each spatial unit. In the architecture field, the study of space syntax has shown considerable progress. However, due to the value-neutral limitation, there has not been any progress toward an empirical study. This drove us to conduct a base study using an agent-based model to overcome some limitations of space syntax.

Methods/Statistical analysis: We prepared 12 sample models, which consist of spatial units with the same size and the same distance between them. We used convex map based space syntax and pedestrian-based discrete event simulation to compare indexes and analyze their relations. For 12 models, 3 characteristics (structural symmetry, depth, and structural form) were cross-applied and each was used to generate 4 alternatives. Based on this, we determined what kind of effects structural characteristics have and the relation between space syntax and the characteristics of each index.

Findings: After 1000 seconds of pedestrian-based discrete event simulation, it is found that global integration and local integration are very highly correlated to ABM density, whereas connectivity and control value have a relatively low relation with it. Therefore, the analysis range of each spatial unit has a high relation with density prediction. From the perspective of the structural symmetry of space, symmetry shows a higher relation than asymmetry. As for depth, a shallow structure is higher than a deep structure. From the perspective of form, a ring structure shows a higher relation with ABM density than a tree structure. This is considered to be related to the intelligibility of space syntax.

Improvements/Applications: It is difficult to come to any conclusion based only on the experiment of applying 12 simplified sample models. However, as long as space syntax shows a clear limitation in its use for empirical analysis of space, the Agent-Based Model, which can be expanded above this limitation has meaning as a base study for empirical research. Therefore, it is necessary to have subsequent studies, which can be expanded in terms of diversifying sample space, adding variables, etc.

Keywords: *Keywords: Agent based model, Space syntax, Convex map, Pedestrian Simulation, Density*

1. Introduction

It is practically impossible to mathematically define the form and the structure of space, which are complicated, for architecture. This means that analyzing architectural space from a physical perspective can be said to be extremely esoteric work. Space syntax theorists apply a topological method, which segments architecture space into certain units to determine the relation of connection between those spatial units. However, due to excessive codification, important variables that may substantially affect the evaluation are excluded. Since this is based on limitless free walking, variables have other limits, such as the purpose of space, visitors' moving range and moving distance, delay due to in-house support service, and others that are not considered.

To obtain empirical data for the social evaluation of space, correlations between more elements that constitute social space, such as user-space services, should be included in the analysis. An analysis taking these variables into account requires broader expansion. However, since space syntax is a value-neutral theory, this means that it has a fundamental limit. Furthermore, architectural space, in which shape itself gives enough complexity, should be considered with the relationships between countless users and services which are generated inside of the space. Realistically, this analysis is considered to be impossible. This study analyzes this physically with a socially hyper-complex relation of space from the viewpoint of a complex system. Therefore, we use the Agent-Based Model (hereinafter called, ABM), a complex system analysis theory, and among others, pedestrian-based discrete event simulation, which has a conceptually similar analysis structure to space syntax, to comprehend the relation with space structure theory.

This study builds the theoretical foundation of ABM as a space analysis tool by a comparison experiment with space syntax from the perspective that space syntax is a theory that has been used and proven in the architecture field. In other words, this study is intended to comprehend the relation between space syntax and ABM analysis in the same environment (space structure), to eventually determine whether ABM can be a substitute for space syntax. I believe that ABM can be expanded by adding empirical

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variables, such as acting party's nature and judgement, procedural purpose-driven walking, space service, and queue generated variables. These make comparison and verification meaningful.

Pedestrian simulation is bi-divided into a structure where an agent (service) block, defined in the workflow, and the measurement (purpose) area, installed in the space, match 1:1. Since this area is a passing stop for an agent (pedestrian) and at the same time, a place where the density is to be measured, it shares a common concept with the spatial unit of space syntax.

Based on this common concept, I compared space syntax with the analysis index of pedestrian-based simulation which was done in the same environment as that of space structure theory, to comprehend things in common, differences, and connectivities between them. For the experiment, I prepared 4 samples for each of 3 characteristics (space's structural symmetry (symmetry, asymmetry), space depth (deep, shallow), space structure shape ring, tree)) and suggested 12 sample models that cross-applied to them. For these sample spaces, an analysis of pedestrian-based event simulation and space syntax (convex map) was made, to collect raw data and comprehend each of their characteristics. The Pearson's product-moment correlation coefficient was used to compare 4 indices of space syntax (connectivity, control value, global integration, local integration) with the density of each measuring area (according to ABM), to analyze and comprehend their relations.

2. Theoretical background

2.1. *Space Syntax*

The theory that can analyze a spatial configuration from a social point of view to make an objectified quantitative index can be broadly divided into 2 streams[1]: visual access and exposure theory [2], which are based on Isovist theory [3], and space syntax theory [4].

Isovist and visual access and exposure (VAE) theories focus on visual structure, while index calculation according to space syntax is based on psychological depth, the number of spatial units that one should pass by when moving from one spatial unit to another.

Space syntax is a theory which was first frontiered by Bill Hillier and Julienne Hanson, Bartlett professors at the University of London, in the 1970's. Today, it is widely used by hundreds of universities and research centers as well as for commercial purposes in the world [5]. In addition, it has been applied to city research and analysis of complex architectures. For more than a decade, it has been improved by a variety of application theories and software development [6]. The primary objective of space syntax is to develop building's planes or fabric shapes of a city space, abstracted and re-configured space, typically and from a social viewpoint, to comprehend topological relations between spatial units [7]. This theory provides a method to quantitatively analyze any kind of building and any space on all scales, based on geospatial computer technology [8]. Space unitization methods for space syntax analysis include the axial map configuration method and the convex map configuration method. The axial map method is applied to spaces which are connected in fabric form like a city highway network. The convex map method is applied to spaces which can be defined on an area basis like an indoor architectural space.

The convex map configuration method segments the entire complex space into spatial units in convex form, indicating adjacency relations between spatial units using a network. Each spatial unit is in convex form, and its connected spatial unit has a depth of 1. The connected spatial unit and its connected one have a depth of 2, which is how the depth is traced. In other words, the depth between 2 spatial units is defined as the shortest syntactic steps or topological distance required to move from one space to another [9].

2.2. *Agent based Model and Discrete Event Simulation*

From symbolic interaction theory, it is assumed that every act made by a human is generated in a certain situation. Attention is paid to interactions between humans, which could happen in this situation, rather than a specific situation [10]. This interaction affects a pedestrian's moves and acts, and these acts come together to form a cluster of patterns.

Patterns generated in a space allow humans to discover how a space socially responds to humans, and what kinds of problems and improvements the space has had. Therefore, it is very important to predict a pedestrian's acts, which can be generated in a given space. Predicting a pedestrian's move is useful in many cases. An act is instructed by its own purpose and may look unreasonable. However, predicting pedestrians' acts based on normal situations can be used for construction, city planning, land use, marketing, etc. [11].

The concept of a complex system, which is a prediction system for multiple acting parties, was first suggested in the natural science field. This is a theory that is intended to discover self-organization phenomena by organic cooperation or intervention of the natural world components. The range of application can be expanded, not just to the entire natural world, but also to an artificial world, or a combination of an artificial world and the natural world. A realistic methodology to interpret a complex system, agent-based computing, is a research subject which has been addressed in the computer engineering field and includes agent-based modeling, design, and programming. This computer simulation is conceived as a sub-area of computer engineering, but its application range is wide enough that it is also applied to the social science field, to analyze interactions between social objects in social psychology, management, policy, etc., as well as physics, mechanical engineering, and biology fields. Interpretation of the acting party-based model can be done by a variety of computer simulation technologies, such as discrete event, object-oriented, and equation-based simulations [12].

A simulation model has its own rules, equations, flowcharts, state machines, and cellular automata with which a computer system can trace given environments or any future changes. A simulation is an "execution" process that uses discontinuous or continuous situation changes and takes their resulting models as time passes. Therefore, in general, simulation modeling can be a good solution to solve complicated problems and should address time dynamics with more care [13]

3. The Characteristics of Space Syntax Analysis and Sample Models

3.1. Sample Model Setting

To obtain more reliable experimental results, the space syntax concept is accepted without any alteration to create a simulation environment with the most identical conditions. To create an environment identical to that for space syntax analysis, all secondary variables were removed. The size and the distance of each spatial unit were identically set, to prepare 8 prototype sample models, which consist of 12 spatial units, as shown in Figure 1.

To prevent any bias arising out of a space's structural characteristics, 3 structural characteristics of space were devised, and 4 sample spaces were allocated to each of them. We intentionally designed and shuffled, depending on space depth characteristics, 4 deep types with a maximum depth of 6, and 4

shallow types with a maximum depth of 4. Depending on the space symmetry, there were 4 symmetry types and 4 asymmetry types. Depending on the space structural form, there were 4 ring types and 4 tree types (see Figure 1).

These sample models were codified for their symmetry (S or A), maximum space depth (D or S), and structural characteristics (R or T). Therefore, "AST" means a sample model consisting of Asymmetry+Shallow+Tree types..

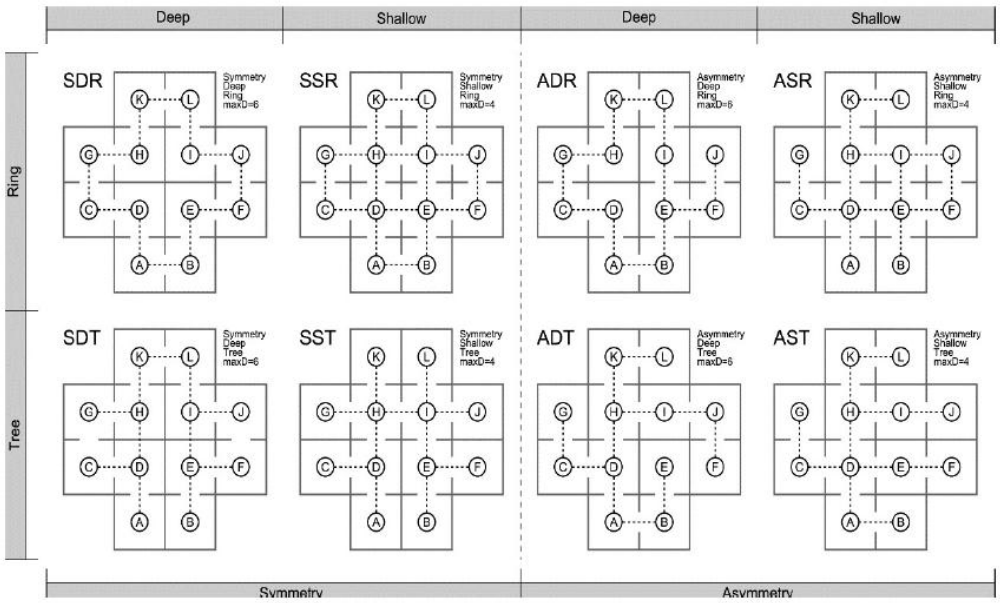


Figure 1: 8 Experimental models and network structure

3.2.*Convex Map Analysis*

For space syntax analysis, we used S3 Convex Analyzer (S3C) v2.1, which is a convex map based space syntax analysis tool developed by Seoul National University's Laboratory for Architecture & Urban Space (LAUS) [14,15].

The convex map based space syntax analysis, the maximum connectivity (Conn) of each spatial unit was 4, and all nodes were connected, which means every spatial unit had a minimum of 1 (mean=2.021). The Control Value (CV) was 0.250~2.583, and the global integration (Int*) was 0.423~1.741, with a mean value of 0.833. The local integration (Int3) was 0.333~1.741, with a mean value of 0.942 (Figure 2).

Intelligibility, which shows the correlation between local index and metro index (Pearson's product-moment correlation coefficient) shows a high value, over 0.9 (mean=0.944), which means that all sample spaces have simple structures. However, since the difference between the maximum space depth and the minimum space depth is 2, it is difficult to clearly explain the characteristics of this difference with a local integration of depth=3. The only thing that can be presumed is that SDT (symmetry+deep+tree) was relatively low at 0.768, while 4-deep type sample spaces had a mean value of 0.901, which was lower than that of shallow types, 0.987. Based on this, among the 3 elements (symmetry, depth, structural type), depth affects clarity (articulation).

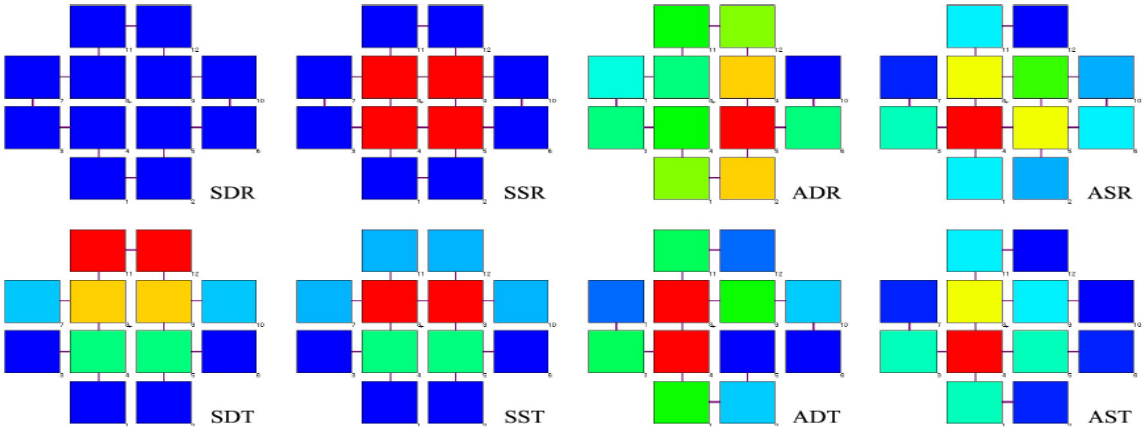


Figure 2: Result of space syntax analysis (convex map)

4. Pedestrian Based Simulation

4.1. Index Setting

In the pedestrian simulation, each pedestrian s is considered as an individual and each one's behavior is evaluated while interacting with space objects (e.g. wall, furniture, stair, opening). Agents should avoid each other or pass through each other to maintain their own speed, and each of them needs to change their speed and direction. Sometimes, to give others opportunities to move ahead of them, they have to stop and wait. These various kinds of interactions affect walking behavior. Macroscopically, results can be compiled from 3 perspectives: flow, speed, or density [16].

In this study, the core index of space syntax, integration, was interpreted from the perspective of density, and heat map analysis was used to intuitively comprehend the agents' flow. However, no variable was assigned for speed. A pedestrian's initial speed was 0.3~0.7 m/s. After that, there was a constant speed, 0.5~1.0 m/s,

meaning a general walking speed was applied. Since one trip-cycle distance, passing by the center spot of a spatial unit, is 72 m, agents walk a minimum of 7 cycles for 1000 sec.

Measurement of the number of agents depends on size, which means the number of agents remaining in every spatial unit at the moment of measurement. The density is the number of agents per spatial unit, and in this simulation, the size of every spatial unit is the same. The correlation coefficients for these 2 measurements are identical to each other. Therefore, only the density was used for analysis, to extract data every second for every spatial unit.

4.2. Work Flow Configuration

In the pedestrian-based discrete event simulation, an agent's moving range is determined with 2 elements. One is being controlled by a given workflow as in network-based discrete event simulation, and the other is by interruption between the agent and space object or agents' mutual interruption. However, once pedestrians collide with each other or avoid each other, the space structure theory and analysis concept change. Because of this, in the simulation of this study, the mutually permissible approach distance was set to 0, to allow the closest approach. Therefore, there is no interaction between agents, which only leaves the interaction between a space object and agent.

As for workflow, as shown in Figure 3, once an agent arrives at each spatial unit, the agent chooses the next destination from 11 other spatial units, except for the currently located one with the same probability. The destination spatial unit was set to be randomly chosen. This means that 12 space objects on the sample plane are variables, and the workflow diagram in Figure 3 is commonly applied to every plane. Therefore, agents have space objects (walls) to control their moving range. As their next destination, they choose the part of the moving range with the shortest distance and move.

As for agent generation, 10 agents were generated in the initial one second for each of the 12 spatial units, and then, without an additional agent generated, they were set to freely walk for 1000 seconds. The density was measured every 1 second from the first second to the 1000th second, totaling 999-second intervals, and its average (mean value) was taken to obtain the result. Besides, if there remained an excessive number of agents, this may generate traffic in the passage through which they pass to distort the data, which made us limit the maximum generation number for agents in the sample space to 120. For density data extraction, 1 rectangular measurement area was set for each spatial unit, and each measurement area was given a pedestrian area descriptor to read in the density variable in real time. This means that the spatial unit, which is the starting point as well as the passage point (rectangle area), is the measurement area.

For sample space modeling and agent coding, AnyLogic v8.2.3 [17] was used, and raw data was sent to Microsoft Excel for statistical analysis.

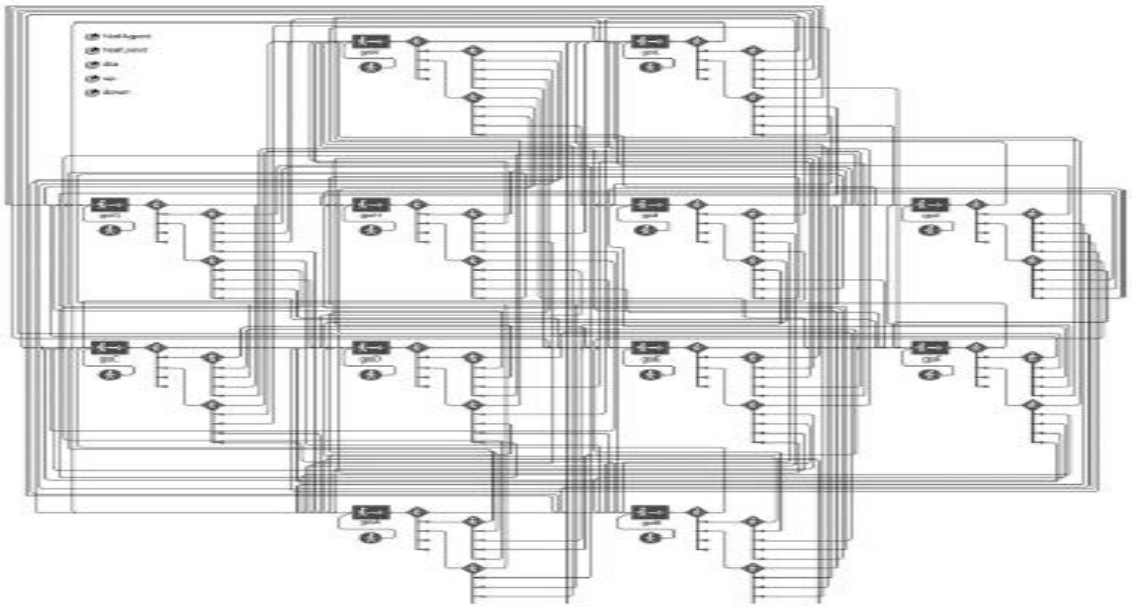


Figure 3: Work flow chart (diagram) used in the simulation

5. Correlation between Space Syntax and ABM

The density heat map, which appeared in ABM simulation, is shown in Figure 4, and the result of analysis on correlation with the space syntax index is shown in Table 1.

For a comparison index, we chose a representative space syntax analysis index, such as connectivity and control value, which are an adjacency index, to calculate the index based only upon the relation of connection to an adjacent spatial unit. Local integration and global integration are used to determine the relation of connection to the entire or a certain degree of depth, and their correlation was calculated using the Pearson's product-moment correlation coefficient.

Regardless of structural characteristics, for mean correlation coefficients of all sample models, the mean global integration was highest at 0.972. The next was mean local integration at 0.928. Then, the mean connectivity was 0.914. The mean control value was 0.756, relatively low.

For structural characteristics, in the case of connectivity, the mean correlation coefficient of an asymmetry structure was 0.939. and for a symmetry structure, the mean was 0.887. For control value, the mean asymmetry structure (CV=0.809) was higher than the mean asymmetry structure (CV=0.720). However, these adjacency indices have a low correlation in general. Among integration indices with high correlation, the mean global integration was higher in symmetry (Int*=0.981) than in asymmetry (Int*=0.966). On the contrary, mean local integration was higher in asymmetry (Int3=0.946) than in symmetry (Int3=0.906).

To sum up, it can be concluded that the integration index has an overall high correlation with ABM density, but a low correlation with connectivity and control value, which are adjacency index. Among integration indices, the global integration has a slightly

higher correlation with symmetry, and the local integration with asymmetry. In an actual architectural space, there partially exist some symmetry structures, but in general, mostly asymmetry structures, which means that the correlation of the asymmetry structure can be said to be more important.

The result of analysis with space depth characteristics was more consistent than that of symmetry. As for the deep structure, the result was as follows (mean values): connectivity (deep=0.856 < shallow=0.963), control value (deep=0.578 < shallow=0.893), global integration (deep=0.0.961 < shallow=0.981), local integration (deep=0.889 < shallow=0.959), showing that the deep structure has an overall higher correlation than the shallow structure. As for space clarity, the mean of the deep type was 0.821, while the shallow type was 0.949, which shows that there is also a relation with space clarity.

As for space depth characteristics, it was also found that an integration index has a higher correlation than an adjacency index, such as connectivity or control value.

The analysis of space shape characteristics shows that a ring structure has a higher correlation than a tree structure. As for connectivity, the mean ring structure was 0.949, which was higher than the mean tree structure, 0.893. For control value, the mean ring structure was 0.847, higher than the mean tree structure, 0.691. For local integration, again, the mean ring structure was 0.956, higher than the mean tree structure, 0.909. For global integration, the mean ring structure was 0.967, and the mean tree structure was 0.977, showing similar results.

As for shape characteristics, the higher the clarity, the higher the correlation every index has with density.

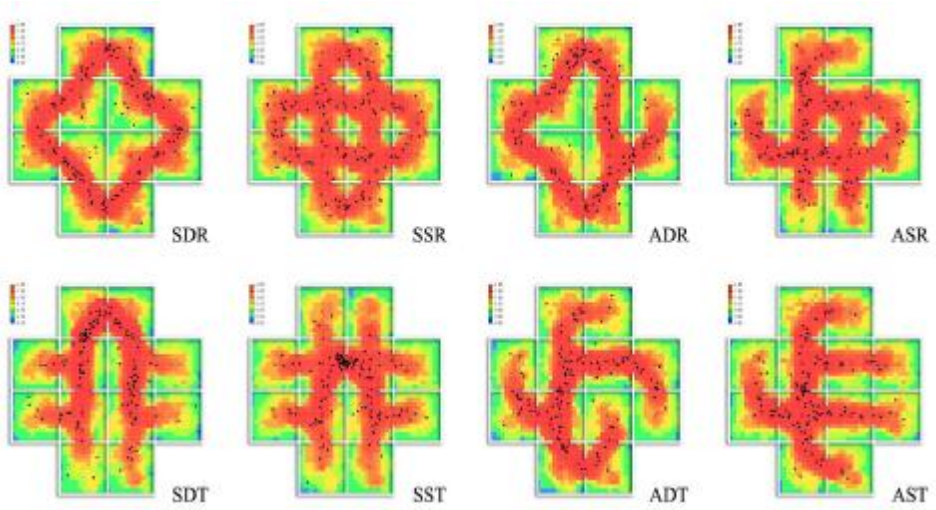


Figure 4:.Pedestriandensityheat map

Table 1: Correlation between space syntax and ABM for space characteristic

		Global Index									Local Index		
		Adjacency index						Integration index					
		Connectivity [conn]			Control Value [CV]			Global Integration [Int*]			Local Integration(r=3) [Int3]		
		min	max	mean	min	max	mean	min	max	mean	min	max	mean
Symmetry	Symmetry	0.722	0.993	0.887	0.540	0.993	0.809	0.968	0.993	0.981	0.768	0.993	0.906
	Asymmetry	0.921	0.978	0.939	0.515	0.871	0.720	0.934	0.991	0.966	0.923	0.964	0.946
Depth	Deep	0.722	0.924	0.856	0.515	0.677	0.578	0.934	0.982	0.961	0.768	0.953	0.889
	Shallow	0.933	0.993	0.963	0.816	0.993	0.893	0.968	0.993	0.981	0.923	0.993	0.959
Structure	Ring	0.921	0.993	0.949	0.677	0.993	0.847	0.934	0.993	0.967	0.923	0.993	0.956
	Tree	0.722	0.978	0.893	0.515	0.894	0.691	0.968	0.991	0.977	0.768	0.964	0.909
Overall		0.824	0.976	0.914	0.596	0.903	0.756	0.951	0.990	0.972	0.845	0.976	0.928

6. Conclusion

While applying space structure theory and pedestrian simulation to 8 prototype sample spaces with 12 spatial units in identical conditions and conducting an experiment and analysis, we obtained the following conclusion.

The correlation coefficient between the ABM density and an integration index was over 0.9, showing a very high relation. This means that integration, which is an abstract index of space syntax, can be considered as the pedestrian density or traffic amount. However, since passing is different from staying, supplementary simulation may be required. On the contrary, an adjacency index, such as connectivity or control value, has a very low correlation. This means that the analysis range of a spatial unit has a relation with ABM density.

From the perspectives of structural characteristics, in general, the following have a higher correlation with ABM: symmetry over asymmetry, shallow structure over deep structure with deep depth, and ring structure over tree structure. This is presumed to have a relation with the intelligibility of space syntax.

In this study, space syntax is used with analysis as much as possible. The size of spatial units and the distance between them was set to be the same. If excessively complex actual spaces are applied, their structural characteristics make it difficult to determine the results, which is why 8 sample models with 12 spatial units were used for our experiment. By cross-applying these characteristics, for each of 3 characteristics, 4 cases were prepared. However, to presume our conclusion, it is true that those cases are not sufficient. Therefore, it is necessary that there should be subsequent verification studies with expanded ideas, for more progress.

Acknowledgment

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