Parametric Design Model of Urban Collective Housing

Based on the Constructal Theory

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Most cities is becoming densely populated in unstable society. Demand for single-person households is increasing and also the demand for collective housing is increasing. In this situation, urban housing should be open and flexible and should move toward increasing opportunities for social exchange and satisfaction of resident. In this paper, development of new collective housing was explored to enable flexible and efficient communication and sharing by utilizing branch structure through Constructal theory on efficient flow in system. The methodology was proposed for future collective housing design through parametric design model with tree diagram that show the flow of shared spaces. This could be a solution to future social sustainability as a proposal to increase the shareability and respond to the demand for new building shapes.

Keywords: *Collective housing, Parametric design, Branch structure*

INTRODUCTION

Collective housing is the architecture in which the needs of many individual residents and the needs of the community are met. Recently, the unemployed and the elderly population have increased in the unstable society, and the concentration of the city is maximized because the populations are being rushed in the big cities. At the same time, the demand for single-person households is rapidly increasing. However, the focus is on the mass supply of housing, and most of the existing three to four family-oriented housing types. In the era of the fourth industrial revolution, the development of technology and the flow of society are rapidly changing, the importance of sharing economy is emerging, and many objects and information are being shared. Sharing offices that are sharing space with this trend of sharing economy are spreading to increase work flexibility and space efficiency. In case of residence, demand for shared housing mainly for one or two people is increasing, and more advanced model of shared housing are needed.

Jane Jacobs was argued that successful city spaces are activated through a mixture of people of different ages and backgrounds. A feeling for the public identity of people, a web of public respect and trust, and a resource in time of personal or neighborhood are needed in city. (Jacobs, J. 1992) Urban collective housing should move away from social control and isolation to openness and flexibility, to increase opportunities for social interaction and to increase the satisfaction of resident.

This paper explores a methodology of flexible collective housing design that could efficiently com-

municate and share the technology according to the social change trend in the urban area and could overcome the low growth of the economy with flexible design. The design method is based on the principle of the branch structure through the theory of constructal theory. Because the theory is about the ideal shape of the fluid flow system, this paper suggests the efficient flow of sharing and the opportunity of communication by using this theory in the design of the collective residence and suggests a new type of futuristic residential design.

CONSTRUCTAL THEORY

"For a finite-size flow system to persist in time to live its configuration must change in time so that it provides greater and greater access to its currents". This is the basis of constructal theory. (Bejan, A. 1997) Constructal Theory is the laws of physics that govern all flow systems. A flow system is an active or inactive system in which a movement is present. This principle also predicts all systems from traffic flow, sports, organization, and nature to birds in flight, swarming fish, and so on. This movement stops when it does not progress efficiently. A tree-like structure is an effective structure that allows it to flow easily from one part to another. So nature pursues these form rules and creates these shapes. This theory shows an example of vessel design in large and small scale and multi-purpose flow configurations.

The tree-shaped flow structure that extends over these branches appears hierarchically. It is found in everything that flows inside the human body, in motors that are the motive power of movement and locomotion. The core of this concept is 'hierarchical'. This structure consist of a large number of small things and a few large things flowing in one another. (Bejan,A., Lorente,S. 2013) In the collective house, if these things could assume as spaces and have natural flow positions like branches, the internal flow will be natural and efficient.

This principle is selected in two ways. The first is a way to predict and explain flow, composition, inanimate, and moving phenomena of nature with this principle. The second describes the principle of creating the flow structure first as a physics principle, and then aligning the surrounding solid body around the flow of mechanical stress. (Bejan, A. 2008) In this paper, using second principle of the constructal theory was used as development method to reflect active communication and efficient technology and resource flow.

'Branch structure' is a basic topological growth mechanism that maximizes the surface area of a tree limb, human lung or coral algae, and sends out resources and responds to structural forces. Branching in architecture is the most clearly described in structural systems that use it to meet design goal practically and associatively. Hierarchical branching can be used as an organizational tool for ordering information, space, resource flow, or even software logic. (Jabi, W. 2013)

In this study, the efficient energy flow of the whole system and the branching structure which is the natural form of supply are applied to the residential system. This paper proposes a methodology for developing a collective housing 3D parametric design model by creating a flow structure of a connection of an efficient shared space adapted to the purpose of living and the surrounding conditions and lifestyle of the resident.

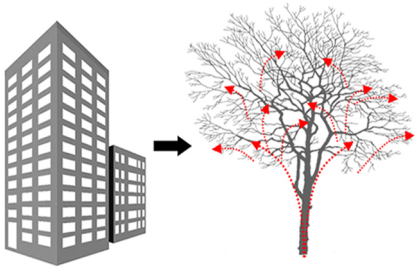
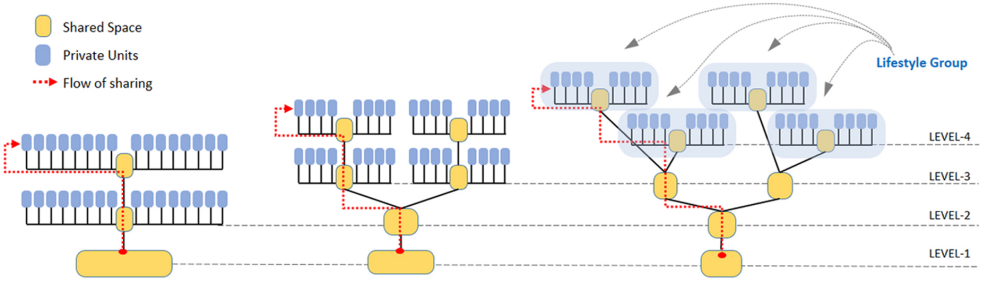


Figure 1
Building and Tree Branches

Figure 2
The idea of Branch Structure



PARAMETRIC MODEL

Parametric design as a design method based on intended algorithm is a process that grasps the relationship between the intent and the result, establishes the rules and then transforms the model through parameter adjustment. Beyond being another tool for model of complex shapes, this might be the unique design model.

The parametric approach is intended to represent change. It could be set up the relationships that each element is connected to, design using these relationships, then modify them through observation and selection, and the results are generated. This work enhances designers' ability to think and express ideas more. (Woodbury, 2010)

To conduct this parametric design, the main activities in the design principles should be characterized and identified and defined as the most consistent and distinctive elements. In addition, design creativity could be discovered as an evolutionary solution processing distinctive cognition by designer and it could be uniquely shown according to the technology type of media in strategy and solution method. (Oxman, R. 2017) We could generate instantly building model through the parametric design model using the branch structure system according to the change of the form and the element and could be a new solution for the generation of the future shared residential model.

In this study, the flow and network principle of branch structure was utilized as a solution to strengthen the flow of efficient sharing for collective housing. The study began with the question "What if the building becomes a tree?" It was thought if the building were embodied in the form of branches which is the most efficient flow of nutrients to feed the whole system, it would have a form of efficient spatial flow. Also, if each spaces are arranged in the shape of these trees, sharing spaces would have more opportunities for sharing, and at the same time, and the individual private units are spread out to be positioned according to the extended branches near the top area with less sharing. Also the space could be designed according to the social needs of the residents of the housing.

The process is enumerated the spaces of the collective housing, analyzed these spaces with commonality and showed the relationship of the spaces with the radial tree diagrams. The diagram is based on parametric modeling. Through this, a parametric design model will be implemented. In order to increase the space flow and the access rate of the shared spaces, we pursue the connectivity of the branches. Each shared space is recognized as a parametric element, and if there is a modification or transformation, it is immediately confirmed as a result model through the connection relationship. The flow of research is shown in next figure.

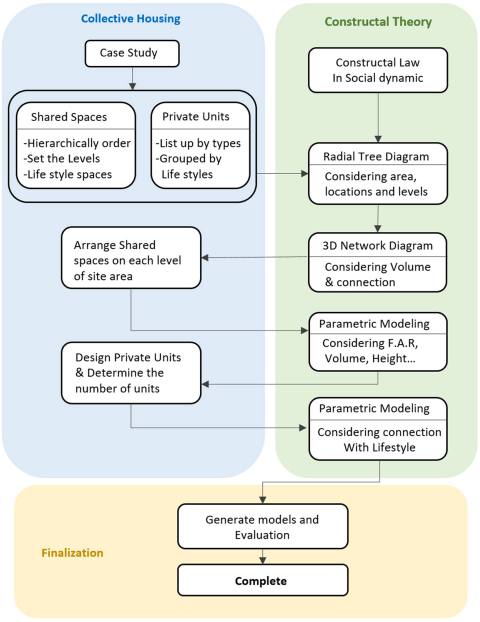


Figure 3
The Process of Parametric Design Model

ANALYSIS OF SPACES AND RADIAL TREE DIAGRAM

An existing case of share housing was selected to analyze the space of the residence for a research of design methodology and implement the design by substituting it into the process. Through this methodology, designer could set up the necessary shared space and area according to the requirements of architects and residents, create various community spaces through lifestyle analysis, and set up and design individual units.

The reference case is a social residence in Tokyo, Japan. In Japan, Tokyo is one of the crowded city with a large population and has been developed shared housing for a long time ago. Currently, there are many shared housing, of which a residence with about four levels with a hundred private units have been selected. The shared spaces in the residence lounge, kitchen, dining, study, theater, fitness, etc. Each space has its own area. Also, there are 110 units of individual units, and there are two types depending on the area.

The shared spaces were listed and sequenced. The hierarchical configuration of the space is assigned to each spaces by calculation of frequency and the number of users. The area of each space was set and then the occupancy rate was calculated. The occupancy rate was calculated by multiplying the number of users of space by the use time of the day. Finally, the area was multiplied by the estimated occupancy rate, and the final score was calculated. The core and entrance lobby showed the highest share, followed by Kitchen, Dinning, Study room, workshop, Sub lounge 1, 2, Fitness, Shower room and Theater. After that, the spaces was accorded the level considering the location in the building. These levels are reflected as the 'floor' of the building. As the tree branch, the main stem is the core space such as staircase and elevators with the highest degree of the shareablity, the lower part was arranged in the spaces with high shareability and gradually spreading in the form of branches, and with low sharing. Naturally, the lobby is located at level 1, Kitchen, dining, study room and workshop are located at level 2, and lounge, fitness, shower, theater at level 3.

Next, a lifestyle spaces were selected. This residence was divided into Study, Workshop, Fitness and Theater spaces, and grouped as the spaces according to the four lifestyles of work, study, exercise, and culture. When designing the building, it is possible to increase the efficiency of the communication by arranging lifestyle space and position close to each other. Considering the lifestyles of the residents, it is possible to place private units around the space of lifestyle according to the requirements of each space, to exchange people with similar lifestyle and, to increase satisfaction.

Finally, a Radial Tree Diagram was draw considering the LEVEL based on the list of analyzed spaces. The circular diagram can reflect the planar distribution of the space, and reflects each level. The highest shareability occupies the center of the hierarchy, and

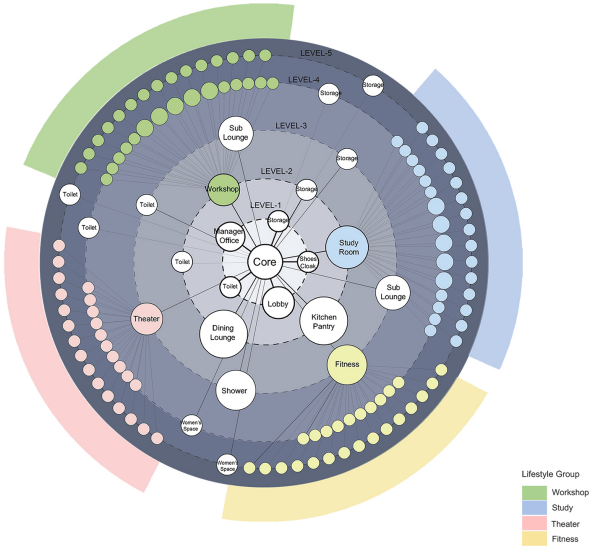
Figure 4
Space Analysis, Radial Tree Diagram, 3D Volume of Space networks

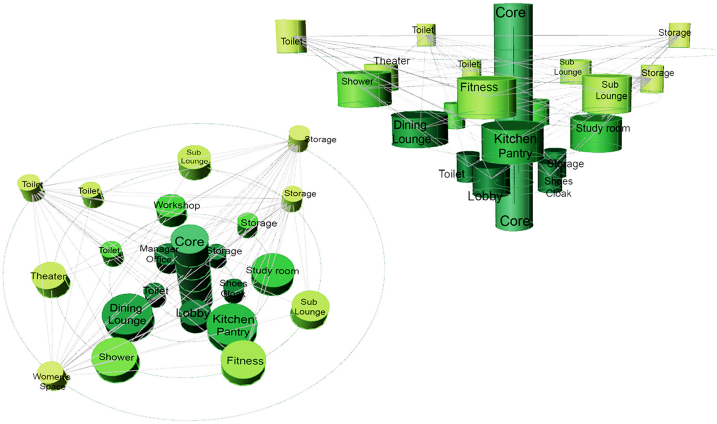
Space Analysis of Shared Spaces

NO	Room Name	Area (㎡)	Occupied		total score	Hierarchy	Level
1	Core (stair, elevator)	30	24/24x200	200	6000	1	L-0
2	Entrance Lobby	30	24/24x200	200	6000	1	L-1
3	Kitchen+Pantry	55	4/24x200	33.33	1833	2	L-2
4	Dining Lounge	50	4/24x200	33.33	1667	3	L-2
5	Study Room	40	10/24x50	20.83	833	4	L-2
6	Workshop	30	10/24x50	20.83	625	5	L-2
7	Sub Lounge-1	30	4/24x100	16.66	500	6	L-3
8	Sub Lounge-2	30	4/24x100	16.66	500	6	L-3
9	Fitness Room	40	4/24x50	8.33	333	7	L-3
10	Shower Room	40	1/24x200	8.33	333	7	L-3
11	Theater	30	4/24x50	8.33	250	8	L-3
12	Shoes Cloak	25	1/24x200	8.33	208	9	L-1
13	Toilet - 1	18	1/24x200	8.33	150	10	L-1
14	Toilet - 2	18	1/24x200	8.33	150	10	L-2
15	Toilet - 3	18	1/24x200	8.33	150	10	L-3
16	Toilet - 4	18	1/24x200	8.33	150	10	L-4
17	Toilet - 5	18	1/24x200	8.33	150	10	L-5
18	Women's Space-1	12	4/24x50	8.33	100	11	L-4
19	Women's Space-2	12	4/24x50	8.33	100	11	L-5
20	Manager's Office	45	1/24x50	2.08	94	12	L-1
21	Storage-1	20	1/24x100	4.16	83	13	L-1
22	Storage-2	20	1/24x100	4.16	83	13	L-2
23	Storage-3	20	1/24x100	4.16	83	13	L-3
24	Storage-4	20	1/24x100	4.16	83	13	L-4
25	Storage-5	20	1/24x100	4.16	83	13	L-5
26	Laundry - 1	20	1/24x50	2.08	42	14	L-4
27	Laundry - 2	18	1/24x50	2.08	37	14	L-5
29	Smoking Room	10	1/24x50	2.08	21	15	L-5

Space Analysis of Private Units

NO	Room	Area (㎡)	User	Lifestyle	Women
1	Private A - 01	15.6	2	Study	
2	Private A - 02	15.6	2	Study	
3	Private A - 03	15.6	2	Study	
4	Private A - 04	15.6	2	Study	
5	Private A - 05	15.6	2	Study	
6	Private A - 06	15.6	2	Workshop	
7	Private A - 07	15.6	2	Workshop	
8	Private A - 08	15.6	2	Workshop	
9	Private A - 09	15.6	2	Workshop	
10	Private A - 10	15.6	2	Workshop	
11	Private B - 01	11.5	1	Fitness	women
12	Private B - 02	11.5	1	Fitness	women
13	Private B - 03	11.5	1	Fitness	women
:	:	:	:	:	:
56	Private B - 46	11.5	1	theater	
57	Private B - 47	11.5	1	theater	
58	Private B - 48	11.5	1	theater	
59	Private B - 49	11.5	1	theater	
:	:	:	:	:	:
84	Private B - 74	11.5	1	study	
85	Private B - 75	11.5	1	study	
86	Private B - 76	11.5	1	workshop	women
87	Private B - 77	11.5	1	workshop	women
105	Private B - 95	11.5	1	workshop	women
106	Private B - 96	11.5	1	workshop	
107	Private B - 97	11.5	1	workshop	
108	Private B - 98	11.5	1	workshop	
109	Private B - 99	11.5	1	workshop	
110	Private B - 100	11.5	1	workshop	





as it spreads, the shareability decreases, the personality increases, and the structure of the tree spreads. Also it helps to design space efficiency by considering the distribution of individual space.

The volume of the building and the flow of the shared space could be verified well in the 3D diagram three dimensionally. This step allows designer to check and modify the volume and location of the spaces again. The 3D space network diagram naturally shows the shape of the tree branch with the highest sharing at the bottom and the lower shareability as it goes up and spreads. Upper levels 4 and 5 might have the most basic storages, showers, Women's rooms and 110 private rooms.

SIMULATION OF PARAMETRIC MODEL

On the process of developing the relation and arrangement of this space into actual building, the shape is based on a configuration in which simple geometry has various volumes and is stacked and deformed. The future brings new value with new technologies and new discoveries. New systematic logic with new technologies will create different types of 3d space and create new dynamic geometry shapes in the modeling system. Modularity has consistency and harmony, and it is organic system because it could be added or subtracted. The idea could be applied in a variety of ways to add a new link or module to the grid. (Burrows, R. 2018) A simple geometry design using a grid is proposed in this simulation for a new type of future.

First, the area of the building in which the residence will be located is set as a grid. This grid was considered as the site area, and the planar space was given on the grid based on the previously set area and radial tree diagram location. On Grasshopper, each level was set on curve component, adhered on a floor of building and elevated with a height in the form of building. The core was formed connected to the whole layer. Using the grid as the base the each layer having shared spaces accord their height and if the shared area is changed then the building model would change simultaneously because of the parametric structure. The volume, height, and arrangement on the floor of the building can be easily modified by adjusting the parameter value and the shape of the building can be adjusted.

In subsequent stage, the individual units are applied to the volume of the previously created shared spaces using customized generative process set up in Grasshopper. As shown in the diagram, individual units must be grouped according to their lifestyle and positioned close to shared space of the lifestyle. Also at level 4 and 5 the individual units are located intentionally.

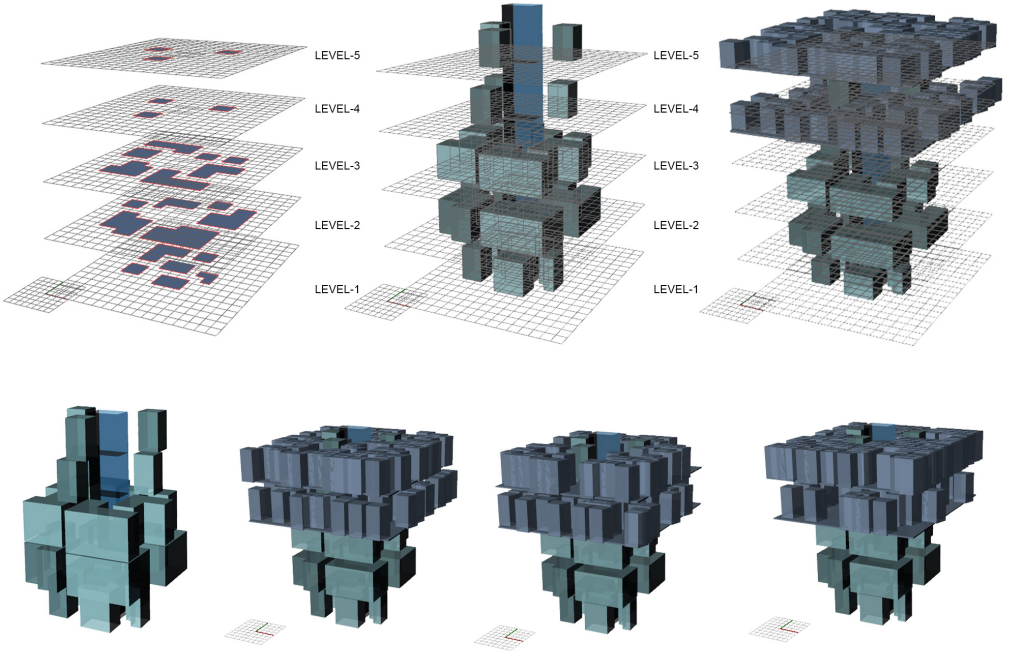
Firstly the modular form of the private unit was designed and the Grasshopper process is conducted that individual modular forms are generated at each level by the number of units avoiding shared spaces. The model could be generated variously depending on the designer's intentions and requirements and the design of individual module. The array of this model was fitted with total 110 units of four lifestyle groups.

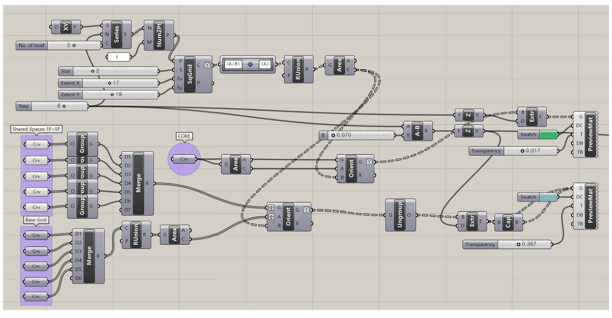
The final model of collective housing is shown in Figure. Final Models are able to generate according to the design of modules differently and it is possible to create depending on the quantity and the area randomly or regularly. This could be finalized by designer judgement and the building condition and requirements.

CONCLUSION AND FUTURE WORKS

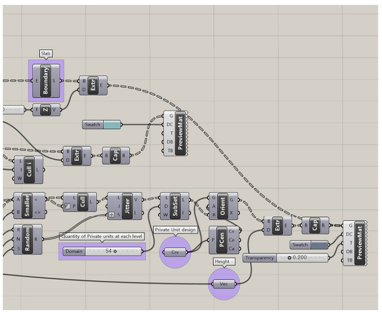
The design methodology derived in this study has kept as generation process linearly and simply, to increase frequency of communication and relationship with future residents through arrangement of shared spaces efficiently. The actual components and the flow of spaces and the structure for the building are not considered yet and it is a proposed methodology about the arrangement of the shared space and the arrangement of the individual units. The process proposed here is based on some subjective judgments and is lacked of evidence and conviction about behavior and interest of future residents. It was the design creation of the future collective housing

Figure 5
Simulation of Parametric model and Grasshopper Script





Grasshopper Script for Shared Spaces



Private Units

which started with the assumption that the branching structure discussed in the constructal theory is a natural and efficient flow dominating the world. However, it is necessary to evaluate whether the flow of circulation in the proposed building is actually efficient in relation to the judgment of whether the shape of the building can be realized and the efficiency of circulation.

It is a design process that could place the shared space considering the proper layout and efficiency considering the frequency of use of the space and the number of users. Designing through this methodology would increase the opportunity for sharing, and the unit layout would enable to design a collective housing considering lifestyle and interests of resident with higher satisfaction. Furthermore, we would suggest a design to increase the shareability, which can be a solution to future social sustainability and it is considered that there is enough future research in response to the demand for a new building shape.

REFERENCES

Bejan, A 1997, 'Constructal-theory network of conducting paths for cooling a heat generating volume', *International Journal of Heat and Mass Transfer*, 40(4), pp. 799-816

Bejan, A 2008 'Design with Constructal Theory', *Shape and Thermodynamics, International Workshop Florence 2008*

Bejan, A and Lorente, S 2013, 'Constructal law of design and evolution: Physics, biology, technology, and society', *Journal of Applied Physics*, 113(15), p. 6

Burch, M 2011, 'Evaluation of traditional, orthogonal, and radial tree diagrams by an eye tracking study', *IEEE Transactions on Visualization and Computer Graphics*, 17(12), pp. 2440-2448

Burrows, R 2018, *3D Thinking in Design and Architecture: From Antiquity to the Future*, Thames & Hudson

Jabi, W 2013, *Parametric design for architecture*, Laurence King Publshing

Jacobs, J 1961, *The death and life of great American cities*, New York: Vintage

Oxman, R 2017, 'Thinking difference: Theories and models of parametric design thinking', *Design Studies*, 52, pp. 4-39

Woodbury, R 2010, *Elements of parametric design*, Routledge, New York