DEVELOPMENT OF AN ADAPTABLE SYSTEM FOR EFFECTIVE UTILIZATION OF ARCHITECTURAL SPACE

Soungho Chae
Senior Research Engineer, Kajima Corporation
Visiting Associate Professor, Advanced Research Institute for Science and Engineering, Waseda University
2-19-1 Tobitakyu Chofu-shi, Tokyo, Japan

Naruo Kano
Professor, Dept. of Architecture, Waseda University
3-4-1 ookubo shinnjyuku-ku, Tokyo, Japan

Masayuki Kato
Director, KATO Institute of Structural engineering
Tokyo, Japan

Satoshi Kobayakawa
Visiting Researcher, Advanced Research Institute for Science and Engineering, Waseda University
Tokyo, Japan

Abstract: In this paper, the authors referred to the development of the suitable modification technology of architectural space in alignment with change in circumstance surrounding lifestyle of residents as necessary. A design method of architectural space and building elements, and a handling method of structural objects of having used robotic technology are proposed as a proposal of adaptability of building. The development and design of a Floor Adaptable System (FAS), which can modify architectural space by moving up and down of floor units, was performed. The Floor Adaptable System installation and test operation was done in WABOT-HOUSE, and showed the operation process. According to the result, the authors confirmed the possibility of the Floor Adaptable System with hydraulic jacks, and mentioned the factors necessary to develop for further practical use.

Keywords: WABOT-HOUSE, Adaptability, Space Modifying, Robotic Technology

1. INTRODUCTION

Recently, social recognition of the importance about decreasing resource, environment disruption, vanishing work force etc. is stimulating the demand for building stock maintenance in Japan. [1] In this atmosphere, the suitable modification technology of architectural space in alignment with change in circumstance surrounding lifestyle of residents is necessary. The modification means creating a new architectural space by movement, removal and addition of structures, such as a column, a beam and a slab. However, there are few development results of the modification technology compared with the new building construction technology. Most construction automation and robotics technologies were developed for the purpose of the improvement of working conditions. [2]

Modification of architectural space becomes more efficient by using and evaluating technologies developed for building construction. Moreover, in the plan of design and construction, the design specification with the entire element of adaptability such as an interchangeable component module, a reusable material and a detachable connection method is required.

The objective of this research is to develop a modification method of architectural space which can be adaptable to needs of user for greater sophistication and diversity.

This paper describes the basic concept of a building adaptable system, and explains the floor adaptable system built with hydraulic jacks.

2. ADAPTABILITY OF BUILDING

Building elements can be classified into two groups according to the actual service life. One group is structure object, such as a beam and a column, and other one of group is interior material, such as equipment and a partition. The structure object has about 30 years or more as an actual service life, and the interior material has about 10 years.

In general, the architectural space is decided with layout of structure objects, and interior material is arranged in the space. In order to change of existing architectural space, rearrangement of structure objects is needed. However, in many cases, the structure objects are created with heavy materials, such as concrete and steel frames, and each joint is rigid. Therefore, there are many difficulties in the disconnection and reassembly of structure objects, and buildings have been demolished to make architectural space for alternate demands.

Adaptability refers to the capacity of buildings to accommodate substantial change. The concept of adaptability is broken down into three parts: Flexibility, Convertibility, and Expandability. [3] The sustaining, inexpensive, and useful modification method of architectural space to user's needs is universalized by accomplishment of adaptability of building.

In this background, the authors proposed a design method of architectural space and building elements, and a handling method of structural objects of having used robotic technology as a proposal of adaptability of building.

3. DEVELOPMENT OF FLOOR ADAPTABLE SYSTEM

3.1 System Development and Design

The authors performed development and design of a Floor Adaptable System (FAS), which can modify architectural space by moving up and down of floor units.

The design requirements of the building with FAS system are described below.

a. Building use

The building which practical activity space is created for robots. The robots are developed by the WABOT-HOUSE LABORATORY of Waseda University, and have various kinds, such as a humanoid type robot, a communication robot, etc. [4]

b. Module specification

The module which the robots of various sizes can work in a building.

c. Building elements requirement

The building elements which handling and attachment for reassemble are easy.

d. Performance safety

The performance which control of movement objects is confirmed.

As the basic unit of architectural space which the requirements of the WABOT-HOUSE design are satisfied, a cubic module was designed. And a system which the interior space of cubic module can be adjusted by addition, reduction and movement of floor units was developed.

The authors proposed a size of 12m by 12m by 12m cubic module with 6m by 6m floor unit (about 8 ton with live load) to verify that the architectural space is diversification. The cubic module is assembled using steel frame structure, and installed the floor units that divided cubic plane into four equally. Vertical position of the floor unit is adjusted per 10cm. The floor unit was designed by four-point bolted connection method in order to carry out removal for moving and attachment after positioning functionally. Brackets with bolt-holes of 10cm intervals were installed on the column, and the vertical position of a floor unit is adjusted using the bolt-holes. Guard plates for safety were installed in the lower position of each floor unit connection, and the accidentally fall of a floor is prevented in it. (Figure 1)

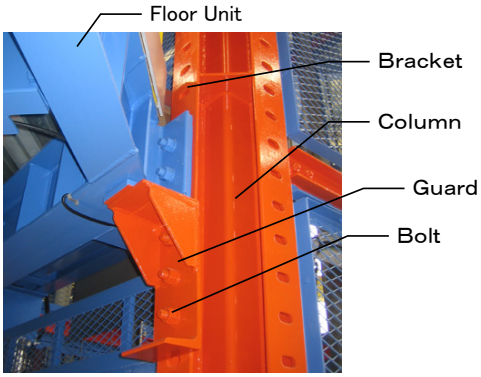


Figure 1. Picture of a floor unit connection

The authors performed arrangement simulation on the cubic module, and confirmed that the FAS sufficiently achieved the requirements for adjusting internal space according to a demand. (Figure 2)

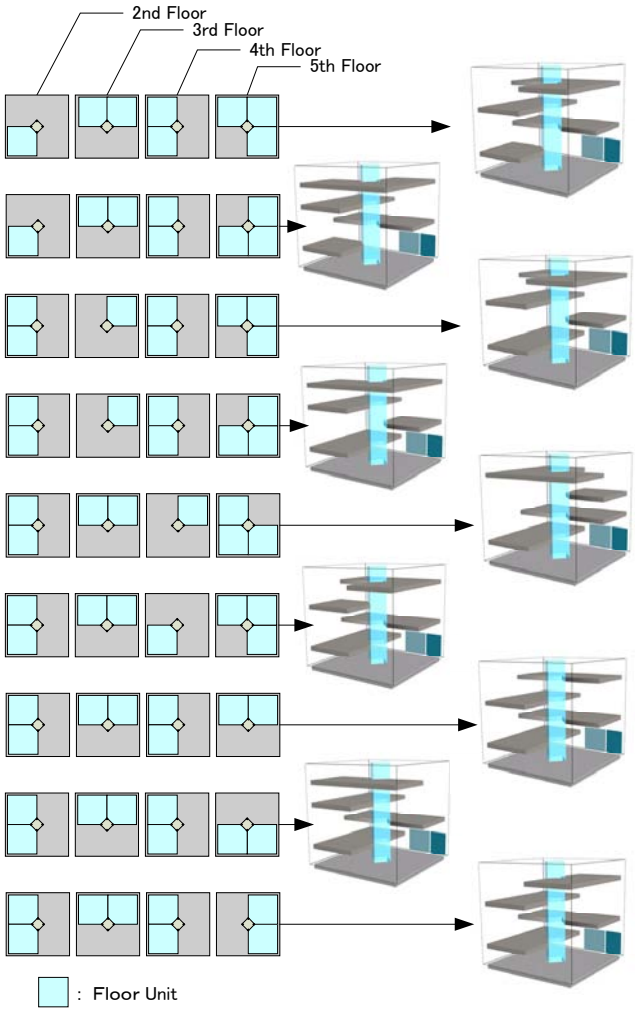


Figure 2. Diversification of architectural space by arrangement of floor units

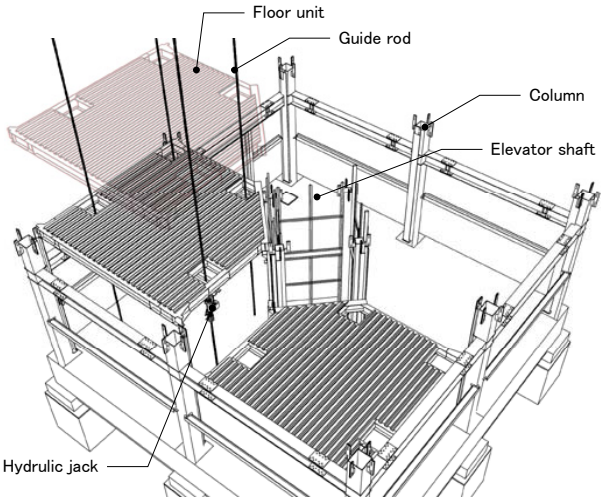


Figure 3. Structure of Floor Adaptable System

As the mechanism of a floor unit control, a method of using hydraulic jacks fixed in four corner places of a floor unit was developed. Figure 3 shows structure of Floor Adaptable System.

In construction work, the machine using hydraulic jack or electric motor power has been applied to a board range of handling of heavy weight structure. In this system, we decided to use a driving force of hydraulic jack in consideration of handling of a floor unit carried out in used building, because of the safety and workability of hydraulic is superior to motor power.

Figure 4 shows the hydraulic jack and other equipments designed for this system. Hydraulic jack is fixed under the floor beam by bolts, and moves a course along with a guide rod. The guide rod is hung from a thrust bearing installed on rod bracket of ceiling. The hydraulic jack which capacity is 129,242kg·m/s² has been used with the weight of a floor unit. (Table 1)

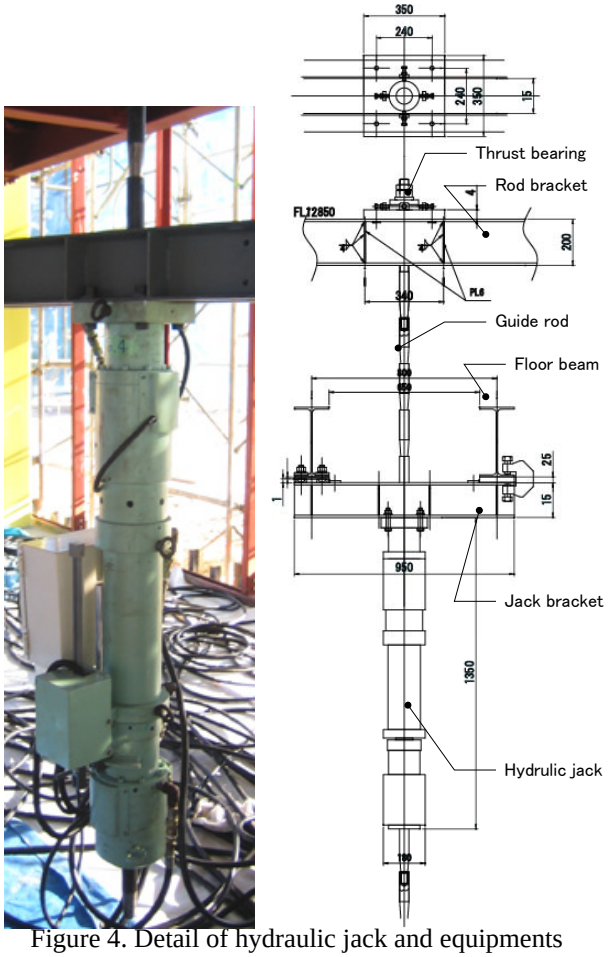


Figure 4. Detail of hydraulic jack and equipments

Table 1.Specification of hydraulic jack

Item	Contents
Capacity	129,242kg·m/s²
Stroke	Up:270mm Down:270mm
Weight	180Kg
Closed height	1,350mm
Required oil volume	1.696cm^3

In order to move a floor unit, it is necessary to separate assembled structures and equipments such as stairway, wiring, and piping from the floor unit.

Refrigerant pipe of air-conditioning, wiring of electric sockets, etc. are disconnected from the end of the floor unit, and after the floor unit fixed, disconnected parts are re-jointed in accordance with moving distance. We arranged Metallic piping for each floor unit, and connected each pipe with a union joint which is pipe fitting join two pipes without turning either pipe.

In case of power equipment and network, for the purpose of reduction in danger of short circuit by cutting, a reserve cable set by moving distance limit of a floor unit is prepared for extension.

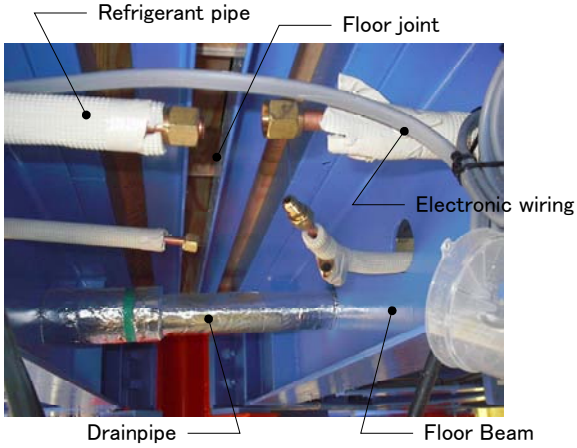


Figure 5. Connection of piping and wiring

Moreover, a combination method, which adjusts shape according to floor height, is necessary for internal structures, for example, partition, stairs, and so on. In this system, a stairway mechanism which arrangement is carried out using step units and a sliding plate was designed. A supporting point of stairway is derived with a sliding plate by move up and down the floor unit, and step units prepared for each height. The step units are inserted into the stairway when the floor unit is lifted, and the step units are removed when the floor is pulled down. Figure 6 shows an assembled stairway.

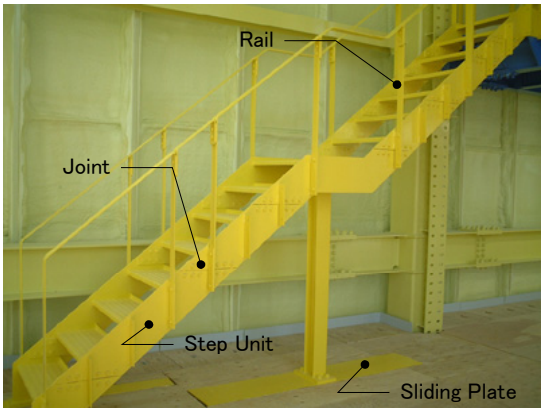


Figure 6. Stairway for Floor Adaptable System

3.2 Building Construction

The authors designed the robot research facility in the WABOT-HOUSE LABORATORY, Gifu Prefecture, Japan (Table 2), and performed the Floor Adaptable System installation and test operation.

Table 2.Outline of WABOT-HOUSE C building

Item	Contents
Location	Gifu Technoplaza, Japan
Building use	Robotic research facility
Total floor area	432m^2
Building area	150m^2
Structure	Steel structure

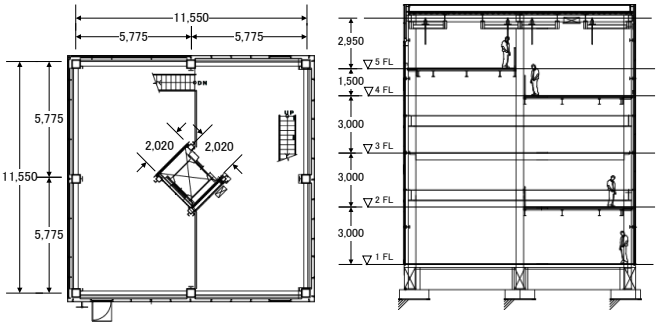


Figure 7. Plan（2nd floor）and Elevation

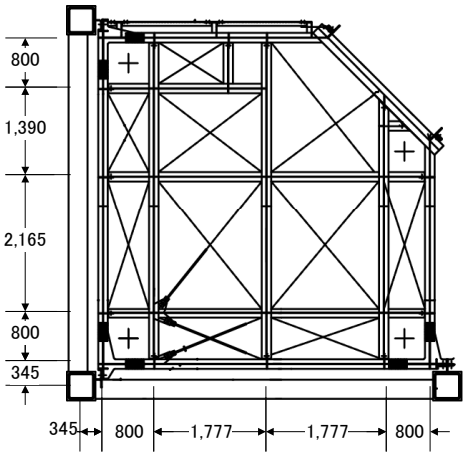


Figure 8. Detail of a floor unit

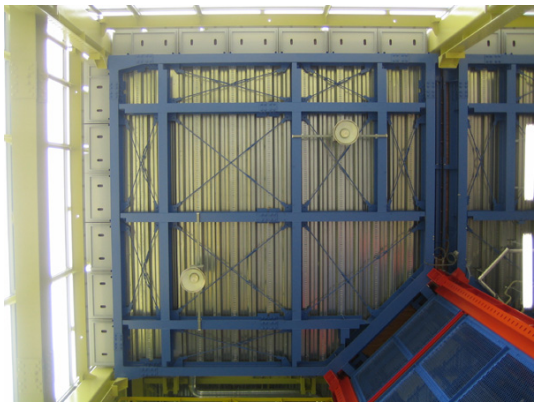


Figure 9. Picture of a floor unit (worm's-eye view)

Figure 10. Picture of elevator shaft

3.3 System Operation

The method about operation of FAS in a constructed building is described below.

a. Carrying in equipments

Equipments used for FAS are removed in order to make a living space comfortable in everyday life, and when doing out a floor up and down, equipments are carried into a building.

b. Arrangement of connection joints

Pipes and structures which are connected to a floor unit to operate are removed, and it is arranged so that the moving course of a floor unit may not be obstructed.

c. Attachment of thrust bearings

A thrust bearing for perpendicular adjustment and fixation of a guide rod is installed on the beam located under a roof structure.

d. Attachment of guide rods

A guide lot is connected downward from the position of a trust bearing to the first floor using the screw carved at the tip. A guide rod is 120cm long and 12kg.

e. Attachment of hydraulic jacks

A hydraulic jack is set on the tip of connected guide rods in the first floor using a guide rod inserted into a hydraulic jack hole.

f. Hydraulic piping

Hydraulic pipes from a pump unit and the cables from an operating panel are linked to hydraulic jacks for moving control.

g. Moving up hydraulic jacks

Hydraulic jacks goes up to the bottom of the target floor unit without a weight load. The hydraulic jacks adjusted to the accurate position are pressurized, and the load of floor is put on the brackets of hydraulic jacks.

h. Disconnection of floor joints

It is confirmed that the load of floor unit supports with the hydraulic jacks and the joints of floor unit with the bracket of a column are removed.

i. Positioning of floor unit

The floor unit is shifted to the assigned position by movement of hydraulic jacks up and down.

j. Connection of floor joints

The floor unit is fixed to the bracket of columns after confirming the leveling. Finally, piping and structures are resettled, and equipments are taken out.

1. Carrying in equipments

2. Arrangement of connection joints

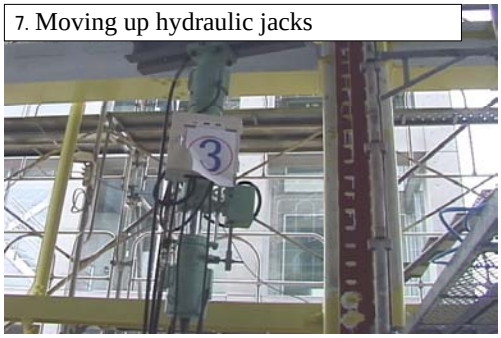
3. Attachment of thrust bearings

4. Attachment of guide rods

5. Attachment of hydraulic jacks

6. Hydraulic piping

7. Moving up hydraulic jacks



8. Disconnection of floor joints

9. Positioning of floor unit

10. Connection of floor joints

Figure 11. Picture of experiment process

3.4 Experiment Result

The authors conducted the operation experiment of FAS and confirmed that the modification of indoor space was practicable.

An operator who handles hydraulic jacks, and five workers who perform installation of equipments and handling of the floor unit took part in the experiment. The floor unit of second floor, the third floor, and the fourth floor were moved up and down, and the maximum moving range was from 1.2 meter to 3.6 meter. (Table 3) Figure 11 shows the process of experiment

Table 3. Experiment conditions

Item	Contents
Manpower	Operator: one person
	Steel worker: five persons
Moving Range	Second floor: 1.2m
	Third floor: 3.6m
	Forth floor: 1.5m

Table 4. Time required for each task of the Floor Adaptable System

Work	Activity	Time
Preparation	Carry equipments	75.00 (min./set)
	Place hydrulic jacks	15.00 (min./set)
	Attach guide rods	8.00 (min./place)
	Deliver hydrulic jacks	20.00 (min./set)
	Attach a hydrulic jack	5.00 (min./place)
	Attach a jack braket	4.17 (min./place)
	Connect hydrulic piping	62.50 (min./Times)
	Check a system	10.00 (min./Times)
	Rasise hydrulic jacks	13.64 (min./meter)
	Increase a pressure	12.25 (min./Times)
Disconnection	Remove a floor guide	3.27 (min./place)
	Remove stairway	6.00 (min./place)
	Remove a floor unit	25.00 (min./unit)
Processing	Lower a floor unit	17.38 (min./meter)
	Raise a floor unit	13.65 (min./meter)
Attachment	Attach stairway	10.00 (min./place)
	Attach a floor guide	4.33 (min./place)
	Attach a floor unit	26.25 (min./unit)
	Attach a thrust bearing	9.69 (min./place)
Romoval	Lower hydrulic jacks	11.15 (min./meter)
	Remove a jack braket	3.00 (min./place)
	Remove a hydrulic jack	10.00 (min./place)
	Remove guide rods	11.25 (min./place)

The process of FAS is divided into task breakdowns and measured time each part. (Table 4)

At first, the system process is broken into five parts: Preparation, Disconnection, Processing, Attachment, Removal, and amount of time required is measured for each breakdown of tasks. Time need for all process was about 20 hours. Preparation and Disconnection was done to set the equipments used for modification of the floors, and took total of about 11 hours.

The lifting velocity of the floor unit was about 73mm per minute, and the lowering was about 57mm per minute. Because there was a different of setting pressure by the moving direction of hydraulic jacks, the lowering required more processing time as compared with the lifting. Attachment and Removal are performed to restore the indoor space, and spent about 7 hours.

The structures of WABOT-HOUSE have been manufactured with dimensional accuracy of 3mm and the 1cm interspaces between floor unit and bracket for the prevention of damages by collision. In the experiment, the authors confirmed that the manufacture specification has sufficient operation safety of FAS.

Moreover, the disconnection and attachment of stairway, wiring, and piping from the floor unit were conducted. WABOT-HOUSE has used equipment parts manufactured by the purpose used for the fixed structure, and the handling process was inadequate from a functional standpoint. In order to change layout of equipment parts, development of the parts for the adaptability is necessary.

4. CONCLUSION

The authors developed and designed the Floor Adaptable System which can modify architectural space by moving up and down of floor units. The Floor Adaptable System installation and test operation was done in WABOT-HOUSE, and showed the operation process. After the research, we found that reduction in size and weight of mechanics of manipulation, development of flexible joint method and equipment parts may accelerate the creation of widespread modification of architectural space.

WABOT-HOUSE BUILDING C was planned and constructed as a living space for the robots. However, the modification method of floor units is expected to be a realization approach of adaptability of building, by using the robotic technology to control heavy structures and design method to change space planning.

ACKNOWLEDGEMENTS

This project has been completed without the cooperation of Gifu prefecture and a lot of people in the research institutes in WABOT-HOUSE. Here, it is our pleasure to express our profound appreciation for their good wishes and co-working.

REFERENCES

[1] Ministry of Land Infrastructure and Transport Government of Japan, White paper on Land Infrastructure and Transport in Japan 2001,
http:// www.mlit.go.jp/english/white-paper/mlit01.html

[2] Yukio Hasegawa, A new wave of construction automation and robotics in japan, 17th ISARC, ppK15-K19, sep. 2000

[3] Assessing the Adaptability of Buildings. International Energy Agency. Annex 31. Energy-Related Environmental Impact of Buildings. Nov. 2001

[4] WABOT-HOUSE LABORATORY homepage
http://www.wabot-house.waseda.ac.jp/html/e-top.htm