ARTIFICIAL LIFE-BASED HOUSING DESIGN ASSISTANT FOR NEW CONSTRUCTION PARADIGM USING SMART PARTS

Risa NISHIYAMA, Aoyama Gakuin University, lisa@esys.it.aoyama.ac.jp
Makoto EBISUI, Keio University, makoto-e@ta3.so-net.ne.jp
Ken TOMIYAMA, Aoyama Gakuin University, tomiyama@it.aoyama.ac.jp
Junichi YAGI, Shimizu Corporation, junichi.yagi@shimz.co.jp

Abstract: This paper proposes a life cycle oriented construction system that considers each construction parts; walls, bath units, kitchen utilities and other facilities as primitive artificial life (AL) forms consisting of a more complicated artificial life form, i.e. the house. As a start, we developed AL-based housing design assistant software that let AL-forms connect and construct house floor plans in 3-D virtual space, and AL-based remodeling design assistant software that wakes dormant AL forms up to re-generate new design plans. Those two of design assistant software are evaluated by questionnaires with mock customers.

Keywords: Artificial Life, Life cycle oriented construction system, smart parts, Movable Finite Automata, Housing design, Remodeling, Design preferences of customers, RFID

1. INTRODUCTION

We developed design assistant software using an AL theory. This study is a part of the Innovative and Intelligent Parts-Oriented Construction (IF7-II) project [1][2], sponsored by the Ministry of Economy, Trade and Industry, Japan. The aim of the project is to propose a new construction paradigm utilizing construction parts with ICs, called smart parts.

As a part of the new paradigm, a life cycle oriented construction assistant system was proposed and reported [3][4][5]. The life cycle of a building may consists of multiple phases as, design, construction, delivery, maintenance, remodel, reuse and waste (Fig. 1). The smart parts are capable of contributing to the health of the building throughout its life cycle with information that they contain.

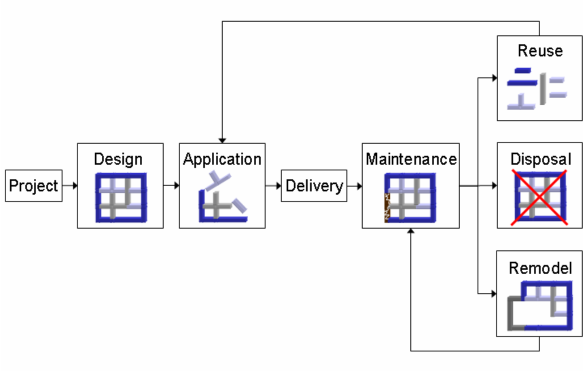

Figure 1: A life cycle of a building

The life cycle oriented construction assistant system takes advantage of this feature of the smart parts, noting that the smart parts can be considered as primitive artificial life-forms. For example, they can automatically construct the building in the application phase, and reconstruct another building with original design information and behavior in remodel phase. The system fully utilizing those AL-forms will increase efficiency of construction greatly.

As a start, we chose two phases of the life cycle: the design phase and the remodel phase. Information and behavior of artificial life forms are settled first in the design phase, and those are used again in the remodel phase. Since the latter is a re-design phase of a house, it is efficient to develop those two design assistant software packages together.

The software generates housing design plans using Movable Finite Automata (MFA), which is a branch of artificial life theories, to artificial life forms such as inside wall parts, bath units, kitchens, and other facilities. Those construction parts are important to characterize the generated design plans.

The design assistant software also can help customers to clarify their preferences. Most of them cannot express their preferences explicitly either in the design phase of in the remodel phase because of a lack of professional knowledge on construction. Instead, they show their preferences on room layouts in words like "3LDK" or "a large south side living room." It is also the case in the remodel phase that customers can only state their troubles in the houses they live in instead of telling how the house should be remodeled. The proposed design assistant software packages are able to process both of such vague requests and dissatisfaction of a customer and to generate various housing design plans that satisfy their requests or solve their problems.

They are also capable to show the plans not in 2-D diagrams but in 3-D graphics in order to enable customers to easily recognize characteristics of the design plans. From those design plans, customers can choose suitable ones according to their preferences. This can also help an architect to understand the customer's preference more specifically, which is a non-trivial job and time consuming. Thus the proposed system can contribute in reducing both the total construction time and money.

In this paper, we will give a summary of our two design assistant systems including rules and attributes given to AL forms so that they can adopt customer's preference in emergently creating design plans. Capabilities of the developed systems in reflecting customer's request is evaluated by running the system with requests of mock customers. Their responses to questionnaires on generated room layout plans are analyzed and results are presented.

2. ARTIFICIAL LIFE

2.1. Overview

In [6], it is stated that 'Artificial Life is the study of man-made systems that exhibit behaviors characteristic of natural living systems.' 'The behaviors characteristic of natural living systems' can be constructed by top-down approaches, as former theories in Biology did. However, AL theories generate them by bottom-up approaches. This feature of AL relates to 'emergent behavior,' which is a main feature of AL. Because of this feature, AL can provide variety of solutions for a problem it is applied to.

2.2. Movable Finite Automata (MFA)[7]

The proposed software generates multiple design plans using MFA, a technique of AL, where a floor plan is emergently generated by autonomous interaction among artificial life-forms, called automata and representing inner walls and room fixtures, in a virtual field, representing the construction space. In the behavior model of automata with MFA, each automaton has several bond sites on its body. If there is a complementary relationships between two bond sites of different automata, those bond sites form a bond and those automata connect to each other (Fig. 2). This 'complementary relationship' can be expressed as a relationship between a key and a keyhole. In this study, any bond site of automata is given either a key attribute or a keyhole attribute. A bond site on an immobile automaton is given a keyhole bond site and fixed in the virtual space. An automaton with key bond sites can move around and searches automata with a keyhole bond site to connect. Once connected, an automaton with the key bond site seizes to move and the pair of key and keyhole bond sites become dormant. Another keyhole bond site is generated on the 'edge' of the connected automata synchronously. The new keyhole bond site becomes ready to accept an automaton with the key bond site (Fig. 3).

Basically, this process is repeated until a new room plan is completed or pre-specified time duration is over. It is noted that, by the nature of AL technique, there is no global rule that governs how a new room plan is formed and that guarantees variation in generated room plans.

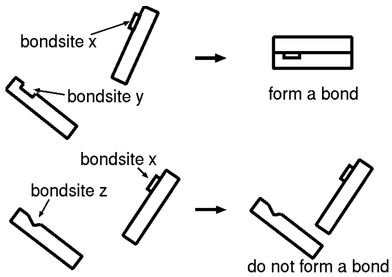

Figure 2: An example of relationships between bond sites: Shapes of bond sites express visualized complementary relationships.

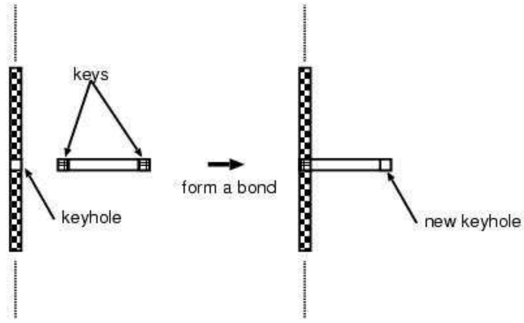

Figure 3: Induced keyhole on parts

3. DESIGN ASSISTANT SYSTEM

In this chapter, the design assistant system that generates floor designs according to customers' preferences is described.

The design assistant system for the design phase generates floor plans that are essential to housing design based on rough preference of customers. As discussed above, they show their preferences on floor plans in words like 'xLDK' where x denotes a number of rooms for individuals and "LDK" denotes a composition of a living room, a dining room, and a kitchen. Or they may say in words such as 'a large south side living room' that denotes ambiguous preference of rooms that have some important purpose.

Those words represent customers preferences or purposes of rooms such as: rooms for a family (e.g. living rooms or kitchens), rooms for individuals (e.g. bed rooms or study rooms), and rooms to connect each room and outside of the house (e.g. corridor or entrance). Also, in the case of average sized houses, most customers prefer rooms of the same purpose being nearby to each other. This observation leads us to divide the virtual space into three areas according to those three purposes of rooms: Family Zone, Private Zone, and Entrance & Corridor Zone. Thus, the rooms generated in the same zone have the same purpose as shown in Fig. 4.

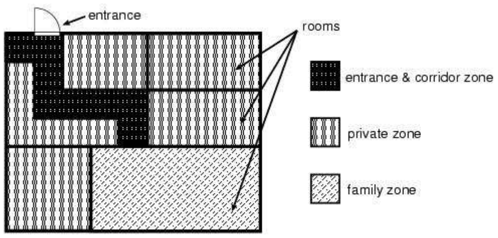

Figure 4: Relationships between zones and rooms

Customer's preferences on the floor plan are obtained according to the categorization of rooms.[4] The system takes preferences of

- numbers of big/medium/small rooms for the family and individuals
- location and general extent of an area for rooms for the family

as inputs from a customer. Customers can express the latter preference by drawing a circle to indicate the general location (Fig. 5).

The developed system takes the set of those preferences as an input to define the attribute of the artificial life-forms. Two methods are developed. Version 1 divides the interior of the house into two regions, excluding the corridor & entrance region, similarly as the partition of the outer walls. Then the floor plans are generated for two regions separately (Fig. 6).

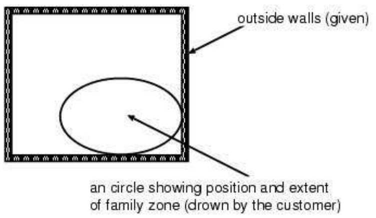

Figure 5: An example of drawings showing a preference of a customer for position and extent of Family Zone

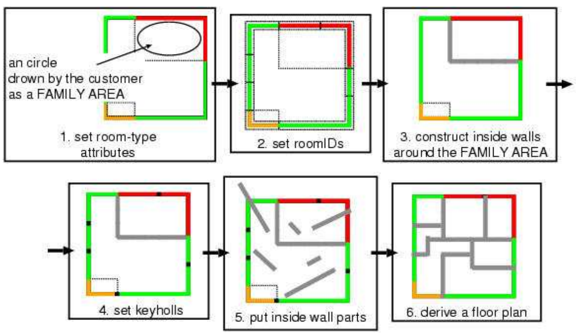

Figure 6: Process flow of Version 1

In Version 2, a corridor from the entrance to the area of rooms for the family is generated first before other rooms are formed (Fig. 7). The location of the entrance is chosen by the customer and is marked on the outer walls prior to this operation. The process of floor plan generation with MFA is shown in Fig. 8 for version 1.

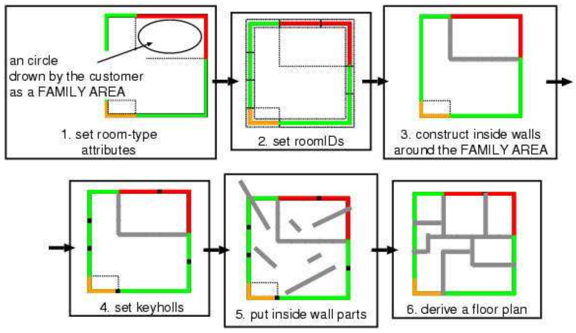

Figure 7: Process flow of Version 2

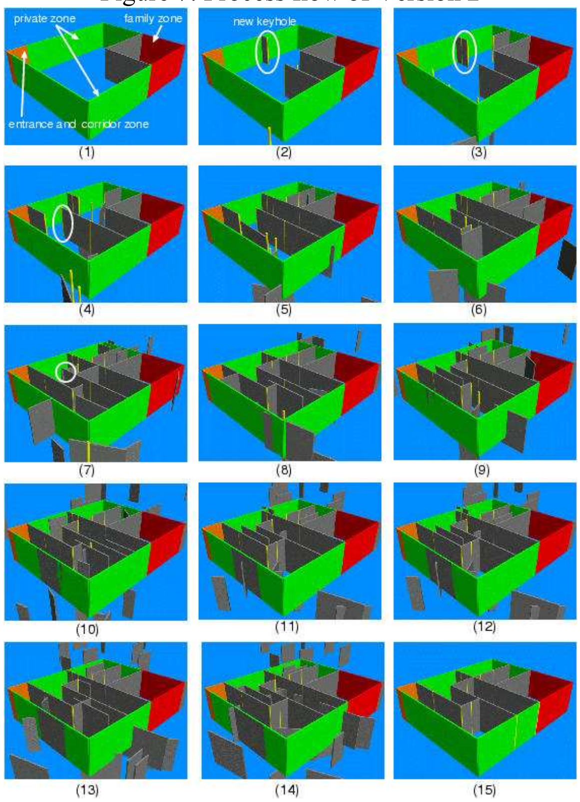

Figure 8: Process of floor plan generation by the developed system with Version 1

4. REMODELING DESIGN ASSISTANT SYSTEM

The design assistant system for the remodel phase considers expansions of the house and replacement of kitchen utilities, a bath unit and other facilities in addition to generating new floor plans. The processing flow of the developed assistant system is shown in Fig. 9.

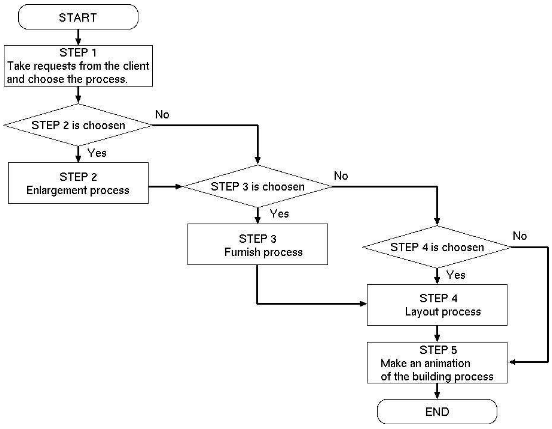

Figure 9: Processing flowchart of the system

The developed assistant system has a user friendly GUI for customer input session (STEP1). A customer can enter such items as:

- the number of bedrooms and type of combination of a living room, a dining room and a kitchen (Fig. 10)
- the area of the house that should not be remodeled (Fig. 11)
- general direction of water related rooms and facilities
- problems with his/her current house (Fig. 12)

It is noted that the system can consider complaints of customers who don't have enough professional construction knowledge to find out critical solutions for those complaints. According to problems chosen by them, the system chooses a set of solutions from expansion, refurnishing, and reconstruction of the floor plan (Table 1). Those pages of GUI are helpful for customers to express their preferences.

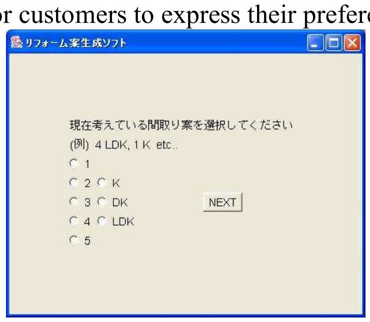

Figure 10: A GUI for client inputs on number of bedrooms and type of L, D & K

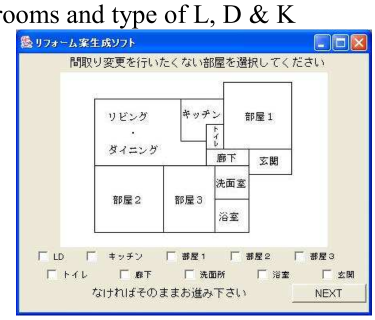

Figure 11: A GUI for determining exempted area from remodeling

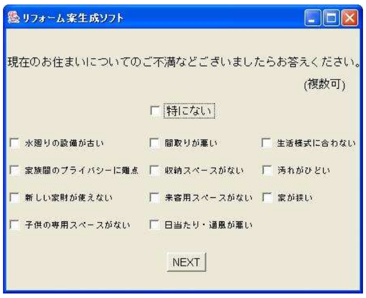

Figure 12: A GUI for acquiring complaints of the client on the present house

Table 1: Problems and corresponding solutions for remodeling

Problems	Solutions		
	Step2	Step3	Step4
Not enough living space	○		
Bad floor plan		○	○
Mismatch between floor plan and lifestyle		○	○
Lack of privacy		○	○
Cannot use new household articles		○	○
Need an exclusive space for children	○	○	○
Fixtures of bath room and toilet and kitchen are old			○
Bored with current house	○	○	○

The system takes the design of the current floor plan, which is generated by artificial life-forms in the design phase and is an aggregate of dormant artificial life-forms (e.g., inner walls, outer walls and household facilities), as the basic input. It not only selectively revives inner walls in the area chosen for remodeling but also selectively activates outer walls of the area chosen for extension and household facilities in the remodeling area.

It can also utilize existing CAD data of facilities, from their manufacturers' catalogues to replace the ones in the current house plan. This function enables customers to evaluate both new floor plans and new facilities in a realistic setting. A set of a current floor plan and a remodel design plan based on the current floor plan is given in Figs. 13 and 14.

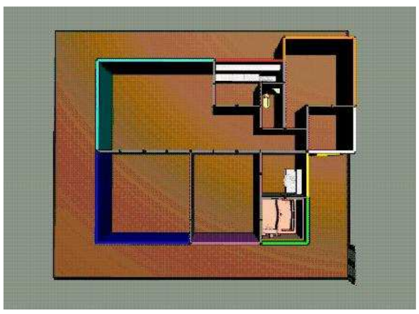

Figure 13: An example of a current floor plan

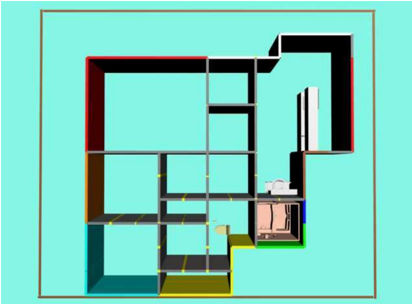

Figure 14: An example of a derived remodeling design plan from the plan in Fig. 13

5. Evaluation of Developed Assistant Systems

Capabilities of the developed systems in reflecting customers' requests are evaluated by running the both systems with requests of mock customers whose ages are over 20s to 60s.

5.1. Evaluation of Design Assistant System

We adopted two house shapes, House Shape A with rectangle shape and House Shape B with an indented corner, for evaluation experiments. Preferences listed in Chapter 3 are taken for the two house shapes from each of a set of 14 mock customers. An example of a set of customer responses is listed in Table 2. Floor plans are then generated and shown to the mock customer. Evaluation is done by asking the mock customer to answer a questionnaire on the four generated floor plans for each of two house shapes (Fig. 15).

Table 2: An example of a set of mock customer preferences (used for generating floor plans in Fig. 15)

	Family Zone			Private Zone		
sizes	L	M	S	L	M	S
number	1	1	0	1	1	1

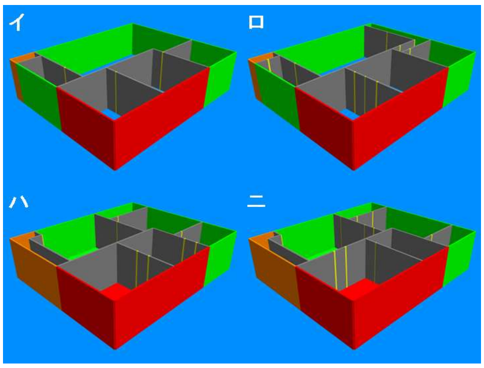

Figure 15: An example of a set of four generated floor plans for House Shape A

As the results of questionnaire in Tables 4 - 7 show, customer evaluations are satisfactory in most questions on how well the generated floor plans reflect the customers' preferences. Those results prove that preferences for Family Zone are well-reflected in floor plans. Preferences for Private Zone are, however, reflected not as well as the ones for Family Zone. We found, from the comments of customers, that scores for rooms in Private Zone can be improved by restricting room shapes to be rectangle and by avoiding too narrow or too wide rooms. Also, general acceptance of floor plans generated by two versions is about the same with a slight advantage in Version 2 with a corridor. This result suggests better prospect for Version 2.

Table 3: Scores for the location and extent of Family Zone

Score	Total Number of People	
	House Shape A	House Shape B
5	9	10
4	2	2
3	3	1
2	0	1
1	0	0

Table 4: Scores for the composition of big, medium, and small rooms in Family Zone

Score	Total Number of People	
	House Shape A	House Shape B
5	38	16
4	10	20
3	7	10
2	0	8
1	1	2

Table 5: Scores for the composition of big, medium, and small rooms in Private Zone

Score	Total Number of People			
	House Shape A		House Shape B	
	Ver. 1	Ver. 2	Ver. 1	Ver. 2
5	1	7	1	7
4	6	6	7	10
3	13	4	16	7
2	6	10	3	4
1	2	1	0	0

Table 6: Scores for the best room and the worst room in the four floor plans

House Shape	A		B	
Version	1	2	1	2
Number of the best room layout plans	4	10	8	6
Number of the worst room layout plans	6	8	9	5

5.2. Evaluation of Remodeling Design Assistant System

The same questionnaire is also used for evaluation of the remodeling design assistant system except that three remodel plans are shown for a mock customer. In this questionnaire, most customers state high scores for improvements of current problems (Fig. 17). Particularly high scores are obtained for a question on degree of variations in generated plans (Figs. 18 - 19).

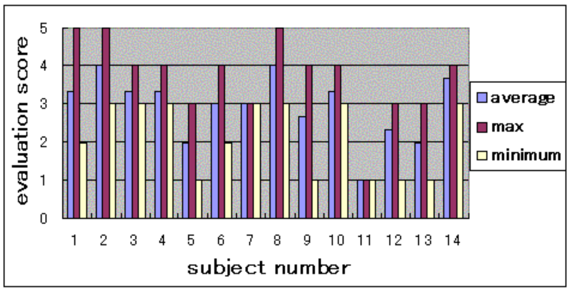

Figure 17: Improvements on current problems

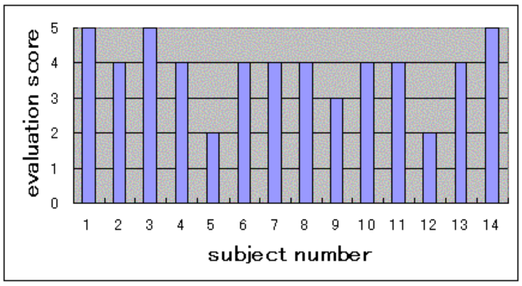

Figure 18: Diversification in room sizes

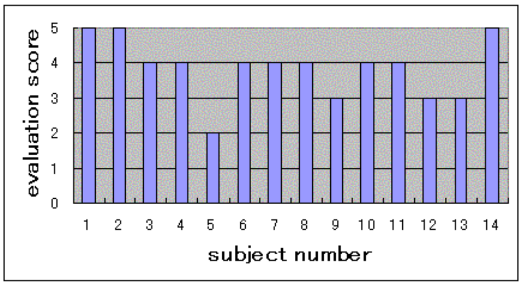

Figure 19: Diversification in room positions

5.3. Discussions on Evaluation of Both Design Assistant Systems

The results of questionnaires for both systems imply that the both systems can generate variety of floor plans. This endorses the intended capability of the floor plan generation engine that is common to both systems. It is also found, as expected, that the variation in floor plans is more limited when the set of preferences of the customer is more specific. It is also observed that rooms with irregular shapes are not popular among the mock customers. This gives rise to a need for a scheme to restrict chances of generating odd shaped rooms.

6. CONCLUTIONS

We developed two design assistant software packages, the design assistant system for floor design generation and the remodel design assistant system for remodeling design generation. Together, they can help both customers and designers in the initial design phase and the remodel phase. Those systems take customers preferences and complaints into consideration and use them in generating various design plans with an artificial life theory called MFA. The developed systems are tested with a set of mock customers and the derived design plans are evaluated by a questionnaire. The results of questionnaire endorsed the validity and the prospects of the developed software.

Acknowledgments

The authors thank other members of IF7-II for their valuable advices as construction professionals on our study.

REFERENCES

[1] Manufacturing Science and Technology Center (MSTC), IMS Promotion Center, *Innovative and Intelligent Parts-oriented Construction (IF7-II)*, 2002.

[2] Manufacturing Science and Technology Center (MSTC), IMS Promotion Center, *Innovative and Intelligent Parts-oriented Construction (IF7-II)*, 2003.

[3] Arima, S., "AL-Based Design Assistant System," *ROBOMECH2003 (CD-ROM)*, No. 1A1-2F-A4, 2003 (In Japanese).

[4] Nishiyama, R., "AL-Based Design Assistant System III," *ROBOMECH2004 (CD-ROM)*, No. , 2004 (In Japanese).

[5] Ebisui, M., "Housing Design Assistant for Remodeling Based on AL Approach," *ROBO-MECH2004 (CD-ROM)*, No. , 2004 (In Japanese).

[6] Langton, C. G. , "Artificial Life," *In C. G. Langton (ed.): Artificial Life*, pp. 1-47, 1989.

[7] Goel N. *et. al.,* "Movable Finite Automata (MFA): A new tool for computer modeling of living systems," *ibid*, pp. 317-340, 1989.