KIEAE Journal, Vol. 16, No. 1, Feb. 2016, pp.47-55

KIEAE Journal

Korea Institute of Ecological Architecture and Environment

77

Developing Technology Influence Matrix to Support Decision-making for Long-life Housing Planning

- Focused on Exclusive Housing Unit of Long-life Housing -

Song, Sanghoon* · Bang, Jong-Dae** · Park, Ji-Young**

* *Corresponding author, Land & Housing Institute, Korea Land and Housing Corporation, South Korea (ssong@lh.or.kr)*
** *Coauthor, Land & Housing Institute, Korea Land and Housing Corporation, South Korea*

ABSTRACT

Purpose: Long-life housing causes unavoidable cost increase while providing higher durability, flexibility, and repair easiness compare to those of normal apartment. The effectiveness should be evaluated considering the level of passing mandatory Long-life housing Certification System when supplying specific size of apartment complex. Thus, it is essential to identify the estimated costs and the obtainable grade by applying the optional element technologies selectively during the design phase. This study aimed to suggest the technology influence matrix(TIM) to support decision-making of element technologies in planning stage of long-life housing. **Method:** The technology influence matrix was established based on the property information about applicable element technologies for long-life housing such as construction methods, interface types, cost data, and certification-related characteristics. The usefulness of TIM was verified through case study, in which TIM was applied to the exclusive housing unit and the influences from four areas of quantity, cost, certification, and schedule were identified and calculated. **Result:** TIMs covering four areas representing the essential planning factors were developed, and are expected to contribute to sound decision-making in planning long-life housing.

KEYWORD

장수명주택
요소기술
영향 매트릭스
인필

Long-life Housing
Element Technologies
Influence Matrix
Infill

ACCEPTANCE INFO

Received January 14, 2016
Final revision received February 3, 2016
Accepted February 5, 2016

1. Introduction

1.1. Background and Purpose

Although studies on long-life housing have continued, long-life housing is not much popular in our country due to lack of the system PR and thus awareness, and low profitability as pointed in Kwon et al. (2014). To promote long-life housing, the government introduced long-life housing certification system in an effort to extend the service year of apartment housing in a long term and relieve public burdens on economic, social and environmental aspects.

Long-life housing inevitably involves cost increase by class of long-life housing certification while providing durability, variability, and ease of repair, which are equivalent to or above those of general apartment housing. Therefore, when housing planners supply long-life housing above a certain portion in a housing complex, they should consider cost effectiveness carefully while satisfying the mandatory requirements for long-life housing certification. That is, it is very important to know obtainable class of the certification and accompanying cost when applying the element technologies for long-life housing in the planning stage of long-life housing.

In this respect, the present study is aimed to propose element technologies influence matrix that can be used as basic data for making decision on element technologies to adopt in the planning stage of long-life housing. With this influence matrix, planner and business entity are expected to help make decision on technology or construction method in a fast and easy way because the matrix shows the changes in quantity, cost, certification class, and process by applied technology in the planning stage of long-life housing. Further, it is expected to contribute to developing tools related to long-life housing.

1.2. Contents and Method

This study attempts to find various and technologies applicable to long-life housing by its key attribute; connect the characteristics of construction technicology, certification system that implements by the objective of policy, and required cost; and thus propose a method to evaluate the change in design elements when element technology is replaced.

To make “long-life housing influence matrix” that schematizes the impact that the attributes of long-life technology has on quantity, cost, certification class, and process, this study conducted the followings as below.

① Examining the characteristics of long-life housing: definition,

pISSN 2288-968X, eISSN 2288-9698
http://dx.doi.org/10.12813/kieae.2016.16.1.047

core components, evaluation items of certification system, and performance class are studied.

② Reviewing the element technologies for long-life housing: element technologies applicable to long-life housing are listed by part.

③ Analysis of attributes by element technology: basic data (the characteristics of construction method in installation, dimensions in brief, evaluation items of certification related to applicable technology, obtainable performance class and score, cost per unit area) as well as connections (interface) that each element technology has are organized.

④ Drawing influence matrix: the matric is drawn in a way to include as many number of cases as possible to summarize the impacts of the changes in the element technologies upon technology itself and 4 areas (quantity, cost, certification class and process).

⑤ Verifying matrix applicability: the influence matrix prepared for unit household of long-life housing is verified for availability by applying it to calculate the changes in quantity, cost, certification, and process by applied technology and analyzing them.

⑥ Reviewing the possibility of developing a tool for automation: Tasks to which the matrix can be applied are reviewed and each function is reviewed for possibility of automation.

Table 1. Evaluation Items and Points of Long-life Housing Certification System

Items			Points		
			Grade	Criteria	Point
(F) Structural System	Mandatory ❶	Length ratio of bearing walls and columns(%) = $\frac{\text{Length of Internal bearing walls and columns}}{\text{Length of all walls and columns}} \times 100$	1st	Less than 10%	15
			2nd	10% ~ 40%	13
			3rd	40% ~ 70%	10
			4th	70% ~ 90%	7
(F) Wall Materials and Construction Methods	Mandatory ❷	Ratio of Light-weight walls compared to all internal walls(%) = $\frac{\text{Length of Light-weight walls}}{\text{Length of all walls}} \times 100$	1st	More than 90%	5
			2nd	70% ~ 90%	4
			3rd	30% ~ 70%	3
			4th	10% ~ 30%	2
	Mandatory ❸	Flexibility Supporting Methods [3-1] Method not destroying process before final finishing of floor (for light-weight walls) [3-2] Method not destroying process before final finishing of wall [3-3] Method not destroying finishing of ceiling [3-4] Modularization(post-lintel, panel system, mixed system)	1st	More than three items among [3-1]~[3-3] or Satisfying [3-4]	8
			2nd	Two items	6
			3rd	One item	4
			4th	Other items (not [3-1]~[3-4])	1
(F) Plumbing	Optional ❶	Plumbing on same floor in bathroom/toilet - Plumbing on the wall(toilet bowl, washbasin) - Method without slab down - Method with slab down, et al.	1st	Plumbing on the wall + Dry finishing or Dry access floor without slab down	6
			2nd	Plumbing on the wall + Wet finishing or On-slab plumbing without slab down	5
			3rd	Slab down + Dry finishing	4
			4th	Slab down + Wet finishing	3
(F) Floor Height	Optional ❷	Additional points per 50mm increase of floor height		Over 3,150mm	4
				Over 3,100mm	3
				Over 3,050mm	2
				Over 3,000mm	1
(F) Space Flexibility	Optional ❸	Access floor fabricated without water		4 Points	
(F) Flexibility of Wet Zone	Optional ❹	Movement of bathroom(toilet)		More than two bathrooms	3
				One bathroom(toilet)	2
	Optional ❺	Movement of kitchen(dining room)		2 Points	
(F) Exterior Wall Method	Optional ❻	Manufactured product and replaceable method for exterior wall		3 Points	
(RE-e) Easiness for Repair and Inspection	Mandatory ❶	Providing independence for public plumbing and exclusive M&E space		5 Points	
	Mandatory ❷	Design easy for repair and replacement of plumbing and wiring		5 Points	
	Optional ❶	Prohibition of burying plumbing and wiring in structure		2 Points	
	Optional ❷	Dry floor heating panel		3 Points	
(RE-e) Horizontal Separation of Housing Unit	Optional ❸	Separation of plan for divided ownership by partitioning [3-1] Application of space planning		2 Points	
	Optional ❹	[3-2] Application of equipment planning		3 Points	

2. The Characteristics and Certification System of Long-Life Housing

2.1. Definition of Long-Life Housing

Long-life housing is defined as dwelling planned to cope with social change, technological change, household change, change in family composition and diversity by increasing the physical and functional lifespan of a house more than a general house (Ministry of Land, Infrastructure and Transport, 2014). Such long-life housing is a house based on long support of maintenance and with long-term durability and usability considering the change and replacement of infill (Kim and Park, 2014).

To make a house last long and maintain its functions and performance after long use, the structure itself should be durable enough and building components such as exterior and interior finishing materials and facilities should be designed and constructed to change and replaced in an easy manner to respond to changes (Jung and Lim, 2006).

2.2. Components of Long-Life Housing

Seeking one hundred-year service life, long-life housing is structured of highly durable column structure (support) and skin (cladding) designed to attach and detach PC or such, and the interior materials and house-specific facilities (in-fills) that should be designed to separate easily from the structure so they can shift and be re-installed (Lim and Lee, 2014). The structure support and infill for long-life housing equivalent to the skeleton and infill of Japanese SI housing can be defined as follows.

① Support: it is a structure, common facility and/or equipment that are decided for public interest. It has relatively long service life and is hard to change both physically and socially.

② Infill system: it is interior and/or house-specific facility that are decided for personal interest. It changes relatively more than a support physically and socially, having shorter service live. Especially, it is designed with lightweight nonbearing wall insead of existing bearing wall so that interior remodeling is easy to increase the life span of a house (Lee 2014). It requires high level of standardization and mass production (Hwang et al., 2014).

2.3. Outline of Certification System and Evaluation Items

Long-life housing certification system is to certify the performances of a house such as durability, variability, and ease of repair, which is finally approved by the head of certificate authority. Here, durability means resistance to heat and variability means spatial performance of accepting various demands while maintaining the structural stability of a building. It is materialized with visually variable structures and spatially variable structures. Ease of repair is high and easy level of repair and/or remodeling of common and exclusive parts of a building. It also means high responsiveness to change.

Certification class of durability is evaluated and decided with concrete quality (thickness of iron bar covering, design criterion strength, slump, unit volume of binding material, water-binding material ratio, air content, chloride amount, and such) in case of ferroconcrete apartment housing. As seen in Table 1 that shows evaluation items of variability and ease of repair for specific area, the evaluation items are divided into ‘mandatory items’ and ‘optional items’. Variability is evaluated with 3 mandatory items and 6 optional items. Mandatory items include length ratio of bearing walls and columns, ratio of light-weight walls compared to all internal walls, and flexibility supporting methods. Ease of repair is evaluated separately for common area and specific area. Specific area is evaluated with 2 mandatory items and 4 optional items. Mandatory evaluation items for specific area include ‘providing independence for public plumbing and exclusive M&E space’ and ‘design easy for repair and replacement of plumbing and wiring’.

2.4. Analysis of Previous Studies

1) Studies on the element technologies for long-life housing

The studies regarding the element technologies for long-life housing include Hwang et al. (2014) that identified the elements to which infill system can be applied and discussed the introduction of certification system; Lee and Kim (2010), and Lee and Kim (2014) that examined the required performance and applicability of light-weight wall by construction method; and Lee et al. (2009) that classified the architectural element technologies of variability performance for apartment housing and suggested technological items to be evaluated for a structure and interior materials.

2) Studies on connections (interface)

Kim (2007) established interface composition system by applying modularization theory to long-life apartment housing system to save the cost of architectural production, increase constructability, and increase the service year of apartment housing. It mapped part classification spectrum, which is based on the perspective of ‘support/non-support’, ‘assembly priority (concave/convex)’ and ‘concealing/non-concealing, and repair cycle and service year specified in the current Building Act. Jung and Lim (2006) analyzed the current development status of long-life housing of which remodeling is easy, surveyed the construction status, and categorized barriers to remodeling long-life apartment housing in groups. They divided the types of interface into ‘support/non-support’, ‘concave/ convex’, and ‘concealing/non-concealing’. They pointed out the problem of grouping dry construction method, interface overlapping, and reclamation construction and suggested improvement for dry construction method, separation of component materials, and exposure of subsidiary materials. In the meantime, Japanese CHS (Century Housing System) set a standard of dimension, construction procedure, part replacement and such for interfaces to which components are bound, and establishes an improvement plan with interface map and details.

3) Other studies

Lee et al. (2014) analyzed the economic feasibility of wall-structured apartment housing and long-life housing from life cycle perspective. They designed life cycle for wall-structured apartment housing and long-life housing, respectively. They set renovation and remodeling in the 25th year and demolition in the 50th year from initial construction and compared the cost of life cycle by combining required cost of each year. The result shows that the initial construction cost of long-life housing is 18% higher than wall-structured apartment housing, but saved 7% of life cycle cost in the 50th year. Therefore, it turned out that long-life housing is more economical at discount rate of 6% or less.

3. Element Technologies For Long-Life Housing and Their Attributes

3.1. Types of the Element Technologies for Long-life Housing

The element technologies for long-life housing mainly concentrate on in-fills. They are concerned with not only application of variability and ease of repair to in-fills at the stage of use, but also further analyzing construction methods between in-fills and between in-fills and supports.

As seen in Table 2, element technologies can be applied to various areas of long-life housing such as confining wall between housing units, partition wall between housing units, ceiling, floor, bathroom and others. The areas to which the element technologies can be applied are classified as below.

① Wall: lightweight composite, extruding (lightweight), functional gypsum composite board, autoclaved lightweight can be supplied by many manufacturers. It can be used for partitioning wall or confining wall between housing units.

② Ceiling: light-weight ceiling system can be considered to apply inside a living unit instead of general gypsum board ceiling.

③ Floor: it is possibile to apply floor heating panel (dry system) and access floor system in place of current wet Ondol heating floor system.

Table 2. Properties of Element Technologies for Long-life Housing

Items	Symbol	Parts: Wall – Inside unit	Parts: Wall – Between units	Parts: Ceiling	Parts: Floor	Parts: Equip.	Installations: Interface Type*	Installations: Thickness/ Height (mm)	Related items to Long-life Housing Certification System: Category	Related items to Long-life Housing Certification System: Items
Lightweight composite concrete panel	W_{11}	○					S-S	100	Flexibility	• Length ratio of bearing walls and columns • Ratio of Light-weight walls • Flexibility Supporting Methods
	W_{12}		○				S-S	150		
Extruding (lightweight) concrete panel	W_{21}	○					S-S	100	Flexibility	
	W_{22}		○				S-S	200		
Gypsum board composite panel	W_{31}	○					S-C	100	Flexibility	
	W_{32}		○				S-C	200		
	W_{33}	○					F-C	125	Flexibility	
Autoclaved lightweight concrete Panel	W_{41}	○					S-S	100/150	Flexibility	
	W_{42}		○				S-S	220		
Extruding cement panel	W_{51}	○					S-S	100	Flexibility	
	W_{52}		○				S-S	150		
Light-weight ceiling system	C_1			○			-		Flexibility	Flexibility Supporting Methods
Floor heating panel (dry system)	F_1				○		-	110/ 125	Repair easiness	Access floor fabricated
Access floor system	F_2				○		-		Flexibility	Access floor
Wall plumbing method	P_1					○	-	-	Flexibility	Plumbing on same floor
Slab down method	P_2					○		-	Flexibility	Plumbing on same floor
※ Existing System – RC bearing wall	W_{01}	○					S-S	150	-	
	W_{02}		○				S-S	200	-	
※ Existing System – Masonry wall	W_{03}	○					S-S	120	-	
※ Existing System – Floor heating panel (wet ondol system)	F_0				○		-	110	-	

(Note) * Interface type in installation information is combined with top end type and bottom end. S= structural slab surface; F= floor finishing surface; C= ceiling surface

④ MEP: Considering independence, easy of repair, and flexibility in planning mechanical/electrical facility, wall plumbing method or slab down method can be applied to bathroom and showroom instead of existing floor plumbing method. Or non-plumbing a structure can be considered in mechanical/electrical work. It also involves planning of the size and location of facility space.

3.2. Attributes of Element Technologies

1) Attributes to construction method

In-fill elements installed in a specific area vary in material property and price and the range of their impact is determined by the relationship between installation method and interfacing. Considering these points, upper/lower binding materials and thickness of each light-weight dry wall to be installed in a house unit, and dimensions of ceiling finish material and floor finish material are summarized in Table 2.

2) Connection to certification system

When applicable element technologies are confined to the specific area to housing unit, evaluation items for variability and ease of repair in specific area and the element technologies of long-life housing can be listed after excluding the common areas of a support for durability and ease of repair among the evaluation items of certification system.

4. Developing the Element Technology Influence Matrix for Long-Life Housing

4.1. Outline of Influence Matrix

As mentioned in Chapter 3, the element technology influence matrix is developed on the basis of the characteristics of construction method, cost information, and connection to evaluation items. It shows numbers of cases of quantity, cost, process, and certification class of concerned technology, interface, and other areas, which change when applied technology changes or replaced.

4.2. Drawing Matrix

Influence element matrix displays the impacts of change or replacement of applied technology. Since technological replacement takes place mainly locally (at a 'part'), the matrix is also prepared by area (part). Each cell in the matrix by area includes combined information of type and extent and level of impact. Level of influence is expressed in specific figures (numbers) or index. In the influence element matrix, the types of 'influence' are as below.

① Quantity(Q, Quantity) area: the element technologies for long-life housing are divided into many by area and construction type (e.g. wall, ceiling, floor, bathroom, facility and etc.). And for the same area, they are sub-divided by construction method and material to use. Change or replacement of applied technology brings direct change in the quantity of concerned item and indirect change in the quantity of interface item.

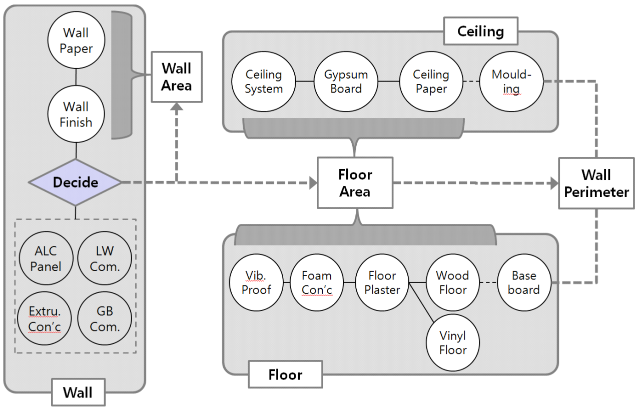

Fig. 1. Influences in Quantity according to Change of Technology

Figure 1 shows the case where the change of construction method for a specific area of housing unit has impact on the quantity of subsidiary material. As seen in the right bottom of Figure 1, decision on (or change to) light-weight wall type has effect on thickness and size of wall, size of ceiling and floor, and length of molding and base board.

These changes are included in Table 3 (Quantity-influencing Matrix). The impacts that the combinations of changes in 8 wall types inside a housing unit and 6 wall types between housing units have on quantity are categorized into 5 groups as below.

- Change in wall area (a): in case interface type is different
- Change in ceiling area (b): in case upper interface type is different. Or in case interface type is same but wall thickness is different
- Change in floor area (c): in case lower interface type is different. Or in case interface type is same but wall thickness is different.
- Changes in wall perimeter (d): in case wall thickness is different
- Addition or deletion of element (e): in case upper interface type is difference and it is specified in a drawing

Table 3. Method to Calculate Quantity Changes

$$a = \pm(l_W \times t_f) \text{ or } \pm(l_W \times h_c) \text{ or } \pm\{l_W \times t_f + h_c\}$$
$$b = \pm\{l_W \times (t_{W1} - t_{W2})\}$$
$$c = \pm\{l_W \times (t_{W1} - t_{W2})\}$$
$$d = \pm(t_{W1} - t_{W2})$$

(Note: l_W = wall length; t_f = floor thickness; h_c = height of ceiling lower framework finish; $t_{W1} - t_{W2}$ = difference in wall thickness)

As seen in Table 4, actual change of quantity is expressed in numbers by the formulas combining wall length(l_w), floor thickness(t_f), height of ceiling lower framework finish (h_c), and difference in wall thickness (t_{w1} - t_{w2}).

② Cost (C, Cost) area: it shows the level of change in cost by combined effect of increased or decreased quantity when technology is replaced or changes and sum of unit cost. Unit cost for a, b, c, and d is applied respectively and increased or decreased volume of cost from original cost (when housing unit was designed first) is calculated.

③ Process (S, Schedule) area: change in technology has impact on work process and schedule of concerned item. In addition, it causes addition or deletion of other construction work, creation of new work, and/or change of process. For example, binding materials for upper/lower light-weight wall can change (differ) by construction method. In case upper/lower area should be fixed to the slab of a structure (S-S type) construction progresses in the order of “wall→floor→ceiling”. However, when wall interfaces with ceiling and floor finish material (F-C type), construction should be carried out in this order: “floor→ceiling→wall”. When laying work of plumb pipes and electric wires in a structure is minimized, it reduces the required time for facility work in the current cycle of framework construction and thus changes the whole schedule of the facility construction.

However, process change in the initial planning stage is less important than change in areas related to cost or certification. And detailed information of construction method or work process is often insufficient. Therefore, the scope of its influence was analyzed only briefly. When overall construction methods are determined and detailed process information is obtained, this matrix can provide a variety of information on changes in process and estimate the reduction of construction period as mentioned in Hong et al. (2009).

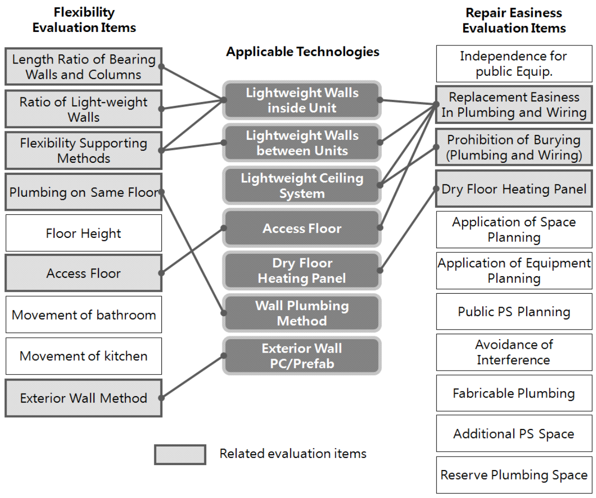

Fig. 2. Possible Influence Scope by Changing of Technologies

④ Certification (L, Long-life Housing Certification) area: the long-life technologies, mainly of in-fills, described in Table 2

Table 4. Quantity-influencing Matrix according to Changes of Internal Walls

Internal Lightweight Walls: Inside Unit

Wall Symbols			W_{01}					W_{03}					W_{11}					W_{21}				
Interface Types			Type Ⅰ / S-S					Type Ⅰ / S-S					Type Ⅰ / S-S					Type Ⅰ / S-S				
Thickness(mm)			150					120					100					100				
W_{01}	S-S	150							-	-	-			-	-	-			-	-	-	
W_{03}	S-S	120		+	+	+								-	-	-			-	-	-	
W_{11}	S-S	100		+	+	+			+	+	+											
W_{21}	S-S	100		+	+	+			+	+	+											
W_{31}	S-C	100	-	+	+	+	+	-	+	+	+	+	-	+			+	-	+			+
W_{33}	F-C	100	-	+	+	+	+	-	+	+	+	+	-	+	+		+	-	+	+		+
W_{41}	S-S	100		+	+	+			+	+	+											
W_{51}	S-S	100		+	+	+			+	+	+											

Wall Symbols			W_{31}					W_{33}					W_{41}					W_{51}				
Interface Types			Type Ⅱ / S-C					Type Ⅲ / F-C					Type Ⅰ / S-S					Type Ⅰ / S-S				
Thickness(mm)			100					100					100					100				
W_{01}	S-S	150	+	-	-	-	-	+	-	-	-	-		-	-	-			-	-	-	
W_{03}	S-S	120	+	-	-	-	-	+	-	-	-	-		-	-	-			-	-	-	
W_{11}	S-S	100	+	-			-	+	-	-		-										
W_{21}	S-S	100	+	-			-	+	-	-		-										
W_{31}	S-C	100						+		-		-	-	+			+	-	+			+
W_{33}	F-C	100	-		+		+						-	+	+		+	-	+	+		+
W_{41}	S-S	100	+	-			-	+	-	-		-										
W_{51}	S-S	100	+	-			-	+	-	-		-										

Internal Lightweight Walls: Between Units

Wall Symbols			W_{02}					W_{12}					W_{22}				
Interface Types			Type Ⅰ / S-S					Type Ⅰ / S-S					Type Ⅰ / S-S				
Thickness(mm)			220					150					200				
W_{02}	S-S	220							-	-	-			-	-	-	
W_{12}	S-S	150		+	+	+								+	+	+	
W_{22}	S-S	200		+	+	+			-	-	-						
W_{32}	S-C	200	-	+	+	+	+	-	-	-	-	+	-	+			+
W_{42}	S-S	220							-	-	-			-	-	-	
W_{52}	S-S	150		+	+	+								+	+	+	

Wall Symbols			W_{32}					W_{42}					W_{52}				
Interface Types			Type Ⅱ / S-C					Type Ⅰ / S-S					Type Ⅰ / S-S				
Thickness(mm)			200					220					150				
W_{02}	S-S	220	+	-	-	-	-							-	-	-	
W_{12}	S-S	150	+	+	+	+	-		+	+	+						
W_{22}	S-S	200	+	-			-		+	+	+			-	-	-	
W_{32}	S-C	200						-	+	+	+	+	-	-	-	-	+
W_{42}	S-S	220	+	-	-	-	-							-	-	-	
W_{52}	S-S	150	+	+	+	+	-		+	+	+						

a	*b*	*c*	*d*	*e*

* Classification of quantity influences
a: Changes in wall area
b: Changes in ceiling area
c: Changes in floor area
d: Changes in room perimeter
e: Addition or deletion
* (+) means "increase"
(-) means "reduction"

are related to certification evaluation items for variability and ease of repair areas. replacement or change of technology in those areas have influence over certification class and score by item and eventually can affect housing unit and its certification. In other words, connecting long-life technologies to current certification system evaluation items of long-life housing, as seen in Figure 2, can confirm the changes in certification score and class by change in design elements. Because the certification class of a housing complex is interlinked with various incentives, which effects the profitability of the complex itself. Therefore, it is very important information to housing planning manager.

4.3. Significance of Using the Matrix

The influence matrix for long-life technology is expected to provide such information as below based on the attributes listed by key technology.

① A supporting tool for decision making in the planning stage of long-life housing: design elements in the planning stage, required cost, and a tool to explore optimum point among certification classes.

② Providing coast calculation for long-life housing cost: as the basic data that can be applied to a tool to change design elements of a specific area of housing unit or to create and re-calculate new details of change in construction method history when construction method changes.

③ Providing incentive data of certification system: When changes in certification system class and cost are connected to each other, it can be used as data for estimating cost required to attain target performance by certification class.

④ Providing inside-unit remodeling data at stage of use: long-life housing has significance in that it can bring various changes in response to resident's needs at the stage of maintenance and provide data for plane adjustment of a specific area and cost estimation s at the stage of use.

5. Review of Influence Matrix Applicability

5.1. The Summary of Simulation

This study applied the influence matrix developed in Chapter 4 to decision making at the planning stage. Since this study focuses on the impacts that changes of technologies in a specific area of long-life housing have, it assumed that a housing unit is built in Rahmen structure with enough durability and applied with long-life technologies connected to variability. And it was also assumed that the reach of influence by change of technology is limited to concerned technology area itself and the interfaces.

5.2. Data for Basic Model of Housing Unit

1) The Outline of Initial Model

The basic model is a housing unit of 59㎡ (area of exclusive use) in a apartment housing block built in RC Rahmen (rigid frame). And the influence element matrix was applied. The basic model is, with 4-bay as base, composed with 3 bedrooms, 2 bathrooms, a living room, a dining/kitchen, a dress closet, a pantry, a porch, and 2 balconies.

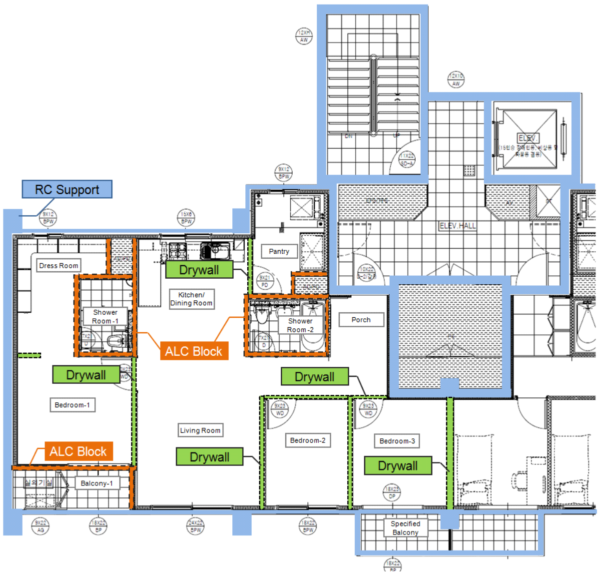

Fig. 3. Long-life Housing Unit and Types of Internal Walls

2) Applied Long-Life Technologies

The element technologies applied to the basic model are shown in Table 5. Industrialized outer wall method was excluded. Floor height was set at 3,000mm and open plumbing was employed.

① Wall: Outside and core parts, which belong to supports, are structured with ferroconcrete. Industrialized materials are not applied to outer wall. Of inner wall area, wet area or the wall areas bordering on the balcony are processed with high-strength waterproof autoclaved concrete and the rest partitioning walls are constructed with gypsum board composite panel. For interfacing, the construction method that can minimize the use of finishing materials is chosen for floor, wall, and ceiling.

② Ceiling, floor: light-weight ceiling is applied while existing dry construction method is appled to floor.

③ Facility: for the bathroom of a specific area, wall (above-floor) plumbing construction method is employed. Plumbing pipes and electric wire are not laid inside a structure to secure spatial independence of facility. Even in the common space, plumbing-exclusive space is prepared with an access hole for installation for easy repair and replacement. Some clearance is provided.

Table 5. List of Technologies for Unit Housing Model

Items	Symbol	Parts	Type	Thk./ Hgt.(mm)	Remarks
Gypsum board composite panel	W_{32}	Walls between units	SC	200	
	W_{33}	Walls inside unit housing	FC	100	
Autoclaved lightweight concrete Panel	W_{41}	Walls inside unit housing (wet zone)	SS	100	Water-repellent blocks
Light-weight ceiling system	C_1	Ceiling	-	300	
Floor heating panel (wet ondol system)	F_0	Floor	-	110	
Wall plumbing method	P_1	Bathroom plumbing	-	-	Dry finish

3) Quantity Calculation

The plane of housing unit applied with long-life technology was divided into frame (support) and finish area for separate calculation of quantity required. In addition, inner length, total perimeter (length), upper length, and lower length, area were calculated to estimate the basic quantity by room, which becomes the base for the calculation of finishing material quantity.

4) Cost estimation

To estimate cost, basic data was collected from the manufacturers (unit cost). But not all cost items were included in the calculation but only the items affected by change in technology to apply.

5) Long-Life Housing Certification Class

Long-life certification class of the basic model was first evaluated. It turned out that the durability, variability, ease of repair (specific area), ease of repair (common) in the housing unit (59㎡) were Class 2 (28 score), Class 1 with 40 (35), Class 2 with 14 (13), and Class 1 with 17 (15), respectively. And thus the total score was 91 and final class was "Best".

5.3. Application of Influence Matrix

1) Limit of Change Scope and Influence Scope

Changes were given to long-life technology applicable to the basic model and the results were evaluated. Since housing unit as the subject for simulation, the common areas for durability and ease of repair were not given any change. As seen in Table 6, the changes given to the element technologies were divided into 3 categories and the impacts were analyzed. But it is noteworthy here that construction method for inside-unit wall was changed to give impact on variability areas, but a different method was adopted for bathroom/toilet from existing one.

Of the evaluation items, those items that require floor planning such as shift of bathroom and kitchen and partially rentable items were excluded from influence element. In addition, among inside-unit walls, the bathroom and the area bordering on the balcony, where high-strength waterproofing blocks can be replaced with extruded concrete panel or extruded cement panel (evaluated to have water-resisting quality high enough to satisfy required performance in Lee and Kim (2010), and Lee and Kim (2014) and masonry wall can be in wet zone.

Table 6. List of Changes in Technologies

Parts		Changes: Before		Changes: After		Code
Internal Walls	Normal Area	W_{33}	Gypsum board composite panel (Type: F-C)	W_{31}	Gypsum board composite panel (Type: S-C)	①
	Wet Zone	W_{41}	Autoclaved lightweight concrete Panel	W_{03}	Masonry Wall	②
Plumbing		P_1	Plumbing on the wall + Dry finishing	P_2	Slab down + Wet finishing	③

2) Analysis of the influence of technology change

As seen in Table 7 that summarizes the influences by change of applied technology, changes in 4 areasby 3 element technologies were analyzed. The yellow-colored cells in the previous influence matrix (Table 3) are quantity changed. When expanding calculation into cost and certification area, it was known that

Table 7. Influence Evaluation Results for Each Area

Changes: Code	Changes: Contents	Quantity Influence: Category	Quantity Influence: Quantity	Cost Influence: Unit Cost	Cost Influence: Cost Variation	Cost Influence: Total Variation	Certification Influence: Items		Changes in Grade and Points: Item	Changes in Grade and Points: Category	Changes in Grade and Points: Overall	Schedule Influence
①	$W_{33} \rightarrow W_{31}$	Itself	34.135	- 6,395	- 218,293	- 209,194 (⇩)	Flexibility supporting methods	before	1st grade (8 points)	1st grade	Best	Work order changes (F→C→W ⇨ C→W→F)
		a	+ 1.49	46,397	+ 69,131							
		c	- 1.35	34,623	- 46741			after	4th grade (1 points)	2nd grade	Excellent	
		e	- 4.26	3,120	- 13,291							
②	$W_{41} \rightarrow W_{03}$	Itself	55.5	+ 103	+ 5,716	- 6,679 (⇩)	Ratio of light-weight walls	before	1st grade (5 points)	1st grade	Best	Dry execution ⇨ Wet execution
		b	- 0.1948	27,792	- 5,413							
		c	- 0.1948	34,623	- 6,744			after	3rd grade (3 points)	2nd grade	Excellent	
		d	- 0.08	1,830	- 146							
			- 0.04	2,318	- 92							
③	$P_1 \rightarrow P_2$	Itself	2 areas (1 set)	+ 47,000	+ 94,000	+ 94,000 (⇧)	Plumbing on same floor (bathroom)	before	1st grade (6 points)	1st grade	Best	On-wall plumbing ⇨ on-slab plumbing
								after	4th grade (3 points)	2nd grade	Excellent	

change in light-weight wall in a general area reduced cost, though slight, while it lowered certification class one step down. Changing to mansionry wall for ALC block did not barely have impact on cost. However, when wall plumbing method was replaced with slab down method, it increased cost marginally. In both cases, certification class was demoted from “Best” to “Excellent”.

6. Conclusion

With a target to a optimum point among key elements (input cost, certification class, process and such) in the planning stage of long-life housing, the present study proposed the basic data helpful in making decision on the selection of element Technologies for long-life housing. Key findings are as follows.

① The element technologies applicable to long-life housing were classified by area (wall, ceiling, floor, and facility) and the characteristics of construction method, cost and certification system were associatively examined.

② The impacts of changes or replacement of the element technology change or replacement upon 4 areas (quantity, cost, process, and certification class) were analyzed and influence matrix was drawn by area. Quantity area was designed to expand to cost area and certification class area while changes in process area were briefly examined considering the insufficient information at planning stage.

③ The influence matrixes were applied to long-life housing unit (the basic model) in Rahmen structure to test the applicability of the matrix. It turned out that it is possible to quantify the changes in quantity, cost, certification areas with the matrix.

④ The significance of using the matrix was discussed as supporting tool for decision making in the planning stage of long-life housing, providing cost calculation for long-life housing, providing incentive planning data of certification system, and providing remodeling data at O&M stage.

This study did not intend to quantify construction cost at the sub-level of evaluation items, but with rough unit costs. Therefore, there can be tolerance in calculation and output. It is expected that following research will focus on the application of the influence matrix to housing unit or long-life housing complex at the cost level of overall construction.

Acknowledgements

This research was supported by a grant(15RERP-B082171- 02-00 0000) from Residential Environment Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

References

[1] 국토교통부, 장수명주택 건설.인증기준(국토교통부고시 제2014-847호), 국토교통부, 2014 // (Ministry of Land, Infrastructure and Transport (MOLIT), “The Standard for Construction and Certification of Long-life Housing”, MOLIT, 2014)

[2] 권대근 등, “사례 분석을 통한 국내 장수명 주택 활성화 방안에 관한 연구: 저해요인 분석 중심으로”, 대한건축학회연합논문집, 16권4호, 2014 // (Kwon, Dae-Keun, et al., “A Study on the Plans for Encouraging Domestic Long-Life Housing through Case Analysis - Concentrated on an Analysis of Impediment Factors”, Journal of the Regional Association of Architectural Institute of Korea, Vol.16, No.4, 2014)

[3] 김수암, 박진아, “국내 장수명 공동주택의 흐름과 과제”, 한국주거학회 2014 추계학술발표대회 논문집 제26권 제2호, 2014 // (Kim, Soo-Am, Park, Jin-A, “Flow and Challenges of long-life Housing in Korea”, Proceedings of The Korean Housing Association 2014 Fall-Conference, Vol.26, No.2, 2014)

[4] 김홍용, 장수명 공동주택의 내장부품 접합부 구성체계에 관한 연구, 연세대학교 박사학위논문, 2007 // (Kim, Hong-Yong, A Study on the Categorization System of the Interface among Infill Components of the Long Life Housing”, Doctoral Dissertation, Yonsei University)

[5] 이재현, 김용로, “건식벽체 시스템의 현황과 발전방향”, 대림기술정보, 2014 // (Lee, Jae-Hyun, Kim, Yong-Ro, “Status and Development Direction of Drywall System”, Daelim Technical Review, 2014)

[6] 이정석 등, “차세대 장수명 공동주택의 가변성능향상을 위한 건축요소기술 우선순위결정에 관한 연구”, 한국건설관리학회논문집, 제10권 제2호, 2009 // (Lee, Jeong-Seok, Cho, Gun-Hee, Sohn, Jeong-Rak, Kim, Jae-Jun, “Selection on the Order of Priority Factor of Construction Key Technology for Improving the Flexibility for a Long Life Apartment Housing at the Next Generation”, Korea Journal of Construction Engineering and Management , Vol.10, No.2, 2009)

[7] 이지희 등, “생애주기비용 분석을 통한 벽식 구조 공동주택과 장수명 공동주택의 경제성 비교 연구”, 한국건설관리학회 논문집, 제15권 제6호, 2014 // (Lee, Jeehee, Kim, Kyuree, Son, JeongWook, Yi, June-Seong, “A Comparative Study on the Life Cycle Cost of Wall Type Apartment and Beam-Column Structural Apartment”, Korea Journal of Construction Engineering and Management , Vol.15, No.6, 2014)

[8] 이학주, “설문조사를 통한 장수명주택의 경량벽체 시공성 사후평가”, 2014년 춘계학술발표대회 논문집, 제14권 제1호, 2014 // (Lee, Hak-Ju, “Post Evaluation on the Constructibility of the Lightweight Wall in Long Life Housing through Interview Survey”, Proceedings of The Korea Institute of Building Construction 2014 Spring-Conference, Vol.14, No.1, 2014)

[9] 이학주, 김형근, “장수명주택을 위한 경량벽체 시스템 연구: 성능기준 및 가이드라인을 중심으로”, SH공사 도시연구소, 2010 // (Lee, Hak-Ju, Kim, Hyung-Keun, “A Study on Light-weight Wall System for Long-life Housing”, SHURI, 2010)

[10] 임석호, 이창재, “비용절감형 장수명 주택의 인필시스템을 위한 설계 표준화 개발 연구”, 한국주거학회 2014 추계학술발표대회 논문집 제26권 제2호, 2014 // (Lim, Seok-Ho, Lee, Chang-Jae, “A study of developing the design standards for infill systems of Cost effective long life housing”, Proceedings of The Korean Housing Association 2014 Fall-Conference, Vol.26, No.2, 2014)

[11] 정우진, 임석호, “장수명 공동주택의 리모델링을 위한 구성재 접합부 실태조사 연구: 주호 내부 구성재의 시공 실태조사를 중심으로”, 대한건축학회논문집, 제22권 5호, 2006 // (Jung, Woo-Jin, Lim, Seok-Ho, “A Study on the Component Joint of Long Life Span Multifamily Housing for Remodeling”, Journal of the Architectural Institute of Korea, Vol.22, No.5, 2006)

[12] 홍성욱 등, “장수명 공동주택 시공지침 개발을 위한 Infill-system 공기예측에 관한 연구”, 대한건축학회연합논문집, 제11권 4호, 2009 // (Hong, Sung-Wook, et al., “A Study on Infill-system Construction Planning and Scheduling Prediction for Long Life Housing Construction Guideline Development”, Journal of the Regional Association of Architectural Institute of Korea, Vol.11, No.4, 2009)

[13] 황은경, 박수로, 김수암, “인필 인증제도 도입을 위한 기초 연구”, 한국주거학회 2014 추계학술발표대회 논문집 제26권 제2호, 2014 // (Hwang, Eun-Kyoung, Park, Su-Ro, Kim, Soo-Am, “The Basic Study of Introduction for the Certification System of Infill”, Proceedings of The Korean Housing Association 2014 Fall-Conference, Vol.26, No.2, 2014)