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A Case Study on BIM-enabled Evaluation of Design Alternatives for an Actual Remodeling Project in Korea**

- Focusing on the Spatial Program Review in Early Phase of Design -

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Abstract

This paper depicts a case study of the BIM (Building Information Modeling)-enabled evaluation of design alternatives for an actual remodeling project in Yeongwol, Korea. The increase of urban population and income followed by the growth of economy has derived massive supply of grand scale housing project in Korea since 1970s. Consequently, building remodeling became one of the feasible resolutions for renovating such old housings in these days. This paper aims to introduce a technical approach to such remodeling projects based on BIM-enabled applications focusing on quantitative analysis of design alternatives. Among the technical issues of such building remodeling projects, this paper focuses on the BIM-enabled area analysis and comparison between design alternatives to support decision-making even in early phase of remodeling design process.

BIM and its variety of applications have broadly influenced the domain of AEC-FM (Architecture, Engineering, Construction, and Facility Management) within the lifecycle of buildings. As one of the applications facilitated by BIM, the automated area calculation and scenario-based comparison between alternatives can play an important role in the early phase of remodeling project. We modeled three design alternatives (buildings) and three housing modules (units) based on the actual case in Yeongwol city, Korea using a BIM design authoring tool. Nine combinatorial BIM models were demonstrated for the BIM-enabled review process described in this paper. To determine the most optimal design scenario among nine alternatives, this paper demonstrates a result of the conducted spatial program review. The main subject includes specific spatial program issues on; 1) the number of unit spaces; and 2) area of individual/grouped and private/shared spaces.

Keywords

건물정보모델링, 공간 프로그램 검토, 노후화 공동주택, 리모델링, 정량적 분석
BIM, Spatial Program Review, Old Apartment, Remodeling, Quantitative Analysis

1. Introduction

1.1. Research Background and Objectives

The massive increase of housing supply was one of main issues in past housing market in Korea. The housing supply ratio, however, exceeded 100% since 2000s demands for housing became diversified and segmentalized. It has been influenced by demographic change, changed household structure and increased income.[1] Old housing issues arose after a huge supply of housing since 1970s, as a result of deficient maintenance control.[2] For improving building performance, economic feasibility and aesthetic features etc., building remodeling was strongly suggested.[3] However, remodeling process has been quite inefficient because of the lack of information about existing buildings and the inadequate communication between various stakeholders,[4] as well as the distinct

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1) Jae-Pil Choi, Yoon-Jae Lee, Hyo-Jeong Kang , Na-Hyang Byun : Schematic Development on the Extension Remodeling Types of Public Rental Housing, Journal of Architectural Institute of Korea, Vol.25 No.3, 2009, pp.3-10
2) Mun-Sung Kim, Mun-Ki Kim : The Case study of Apartment Housing Remodeling Policy in Korea, Journal of Gyeongin of Public Administration, Vol.10 No.2, 2010, pp.1-27
3) Building Act article 2 clause 15
4) Eon-Yong Kim, Han-Jong Jun : A Study on Supporting Space

characteristics and uncertainty of given construction area.[5]

On the other hand, BIM (Building Information Modeling) supports efficient utilization of various information needed for construction industry.[6] It has positively influenced AEC-FM industry within the lifecycle of building,[7] and it has been studied how to use BIM pragmatically after the phase of introduction.[8]

As a result of combining remodeling issues and various applications of BIM in AEC-FM area through the entire lifecycle of building, BIM-enabled approaches began to be introduced in remodeling projects. Various BIM-enabled remodeling projects such as The National Museum of Korean Contemporary History and head office of Kyobo were conducted.[9]

BIM-enabled approach can be used to support objective and accurate processes such as design decision making, review of design quality, analysis of building performance,[10] circulation analysis, etc. using quantitative data.[11] This paper aims to discuss an automated design review with quantitative data regarding spatial program review, and consequently to demonstrate a design decision-making supportive result. We modeled three design alternatives (buildings) and three housing modules (units) based on the actual case in Yeongwol city, Korea using a BIM design authoring tool. To determine the most optimal design scenario among those nine alternatives, this paper demonstrates a result of the conducted spatial program review. The main subject includes specific spatial program issues on; 1) the number of unit spaces; and 2) area of individual/grouped and private/shared spaces.

1.2. Approach and Scope

This paper aims to demonstrate a BIM-enabled approach to the evaluation of design alternatives using an actual remodeling project in Yeongwol, Korea, mainly focusing on spatial program review. The main methods and scope of work can be summarized as follows. 1) Theoretical background and technical references associated with the difference between conventional 2D CAD - based approach and BIM-enabled approach have been reviewed, in order to obtain an appropriate BIM model based on existing 2D blueprints. 2) Multiple design alternatives can be generated with ease according to the requirements even in early phase of the project. 3) Design alternative models have been analyzed for selecting the best plan, using BIM-enabled comparison methods implemented in general BIM authoring tools. 4) The overall process conducted in the project and described in this paper have been visualized in a specific reporting chart to support decision-making tasks for the actual remodeling project.

There are several aspects of design supposed to be reviewed in the remodeling project, such as energy conservation, circulation analysis, solar study, structural analysis, seismic design, etc. Spatial programming, however, has a critical role in early phase of design especially for the remodeling project that usually has specific requirements for existing occupants as well as very limited time frame. Thus, the focus of this paper is on the spatial program review as a BIM-enabled application to support such decision making tasks, e.g. selecting design alternatives, in early phase of the remodeling project.

2. BIM-enabled approach to remodeling projects

2.1. Current 2D-CAD based approach

Remodeling basically includes the activities to prevent deterioration of a building or repairing it for

Planning Based on Parameter Technology, Proceeding of 2007 Architectural Institute of Korea Annual Conference, Vol.27 No.1, 2007, pp.57-60

5) Jae-Kook Lee, Young-Gi Min : A Case study on the Remodeling Design through BIM(Building Information Modeling), Journal of Korean Digital Architecture Interior Association, Vol.12 No.4, 2012, pp.125-132

6) Chuck Eastman, Paul Teicholz, Rafael Sacks, Kathleen Liston: BIM HANDBOOK-A guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Constructors, John Wiley & Sons, Inc. New Jersy, 2007

7) Louise Sabol: Building Information Modeling & Facility Management, IFMA World Workplace, 2008

8) Jin-Kook Lee, Yeon-Seok Jung, Jae-Min Lee : A Case Study of the Building Information Modeling Enabled Universal Design Evaluation Methods and Applications, Journal of Society of Design Convergence, No.13, 2013, pp.17-29

9) Ho Kim, Jung-Dong Moon, Dae-Gyu Kim : The Construction of The National Museum of Korean Contemporary History, Journal of Architectural Institute of Korea, Vol.56 No.10, 2012, pp.96-98

10) Myung-Hwan Oh, Jong-Ho Yoon : A Study on the Evaluation of Daylighting Performance based on Weather Data Using The BIM Tools in Initial Design Step, Journal of Architectural Institute of Korea, Vol.27 No.6, 2011, pp.267-274

11) Lee Hyunsoo, Kim Jisoo, Shin Minkyu, Kim Inhan, Lee Jin-Kook: A Demonstration of BIM-enabled Quantitative Circulation Analysis using BERA Language, Isarc2014, 2014

improving its performance. Usually a part of existing building structures is the main subject of the remodeling project. Different from the new construction project, remodeling includes the activities of maintenance, extension and a broad range of repair.[12)]

Remodeling can make similar effects as new construction with 40-70% lower cost of new construction project. In addition, same effects can be achieved in 20 months in remodeling process while new construction process requires about 30 months. Accordingly remodeling is an effective solution for old buildings in terms of user's satisfaction and economical perspectives.[13)] It also has positive influence in the perspective of social cost. On the other hand, 2D-CAD-based approaches to remodeling projects have been performed manually[14)] and often dependant on experts' knowledge. Thus, they have been time consuming and somewhat ad-hoc. From early phase of design to completion of construction and maintenance, there have been problems such as 1) data loss and discordance caused by absence of standardized templates and databases, 2) miscommunication among participants of remodeling project resulted from uncertainty of scope in working process, and 3) difficultness to understand the existing building which has no plan drawings.[15)] Moreover, unpredictability of the construction cost has been another obstacle to successful projects.[16)]

2.2. BIM applications in remodeling projects

There have been various researches on how to apply BIM in various area after the stage of introduction and dispersion of BIM.[17)] BIM-enabled applications have become one of the promising directions replacing the conventional 2D-CAD-based process. Remodeling projects have been extended frequently over a long period of time because it is difficult to share information among experts and stakeholders within the project. On the other hand, BIM-enabled approach supports information delivery among experts of each area[18)] and catching errors in process. Consequently, useless and repetitive works and errors which have been difficult to be caught are reduced drastically.[19)]

<fig. 1> Example of early phase BIM model and its application

In addition, optimal and quantitative approach in design review phase supports design decision-making. Moreover, it can reduce construction cost results from design change which often entails drastic cost increase. Furthermore, it can influence on the phase of construction management and cost measurement from a quantitative perspective.[20)] And derivation of geometric data from BIM models, structure analysis and safety assessments are possible. In addition, It is also possible to analyze not only quantitative data related to spatial allocation issues such as circulation among units and the area according to different unit arrangement but also for whole building from an architectural view.[21)]

12) Dong-Gun Lee, Hee-Sung Cha : Development of BIM Standard Database System for an Approximate Estimate of Old-Aged Apartment Remodeling Project , Journal of Korea Institute of Construction Engineering and Management, Vol.11 No.5, 2010, pp.53-64

13) Jong-Gon Park, Jung-Young Jeong, Jeong-Gyu Kang, Chul-Min Kim : A Study on Residents' Perception of the Vertical Expansion Remodeling of Apartment Housing, Journal of Residential Environment Institute of Korea, Vol.12 No.4, 2014, pp.377-388

14) Jae-Dong Lee : Remodeling Process of the Residential Apartment using BIM, Seoul National University of Science and Technology Graduate Institute of Housing, 2012

15) Han-Jong Jun : Digital Design Technology for Design Environment in near Future, Journal of Architectural Institute of Korea, Vol.56 No.11, 2012, pp.34-36

16) S.Azhar: Building information modeling: Trends, benefits, risks and challenges for the AEC industy. 2011

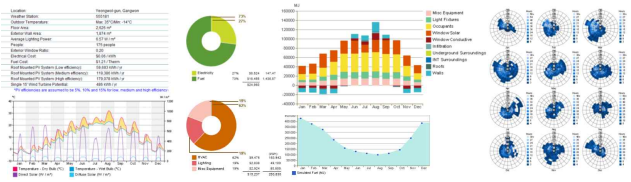
17) Jin-Kook Lee : Open BIM Standard, Journal of Architectural Institute of Korea, Vol.57 No.11, 2013, pp.42-45

18) Sang-Heon Lee, Byung-Jik Min, In-Ki Kim, Sang-Chul Nam, Sung-Duk Kang, Han-Jong Jun : A Study on BIM based Remodeling Architectural Design Process for Apartments, Journal of Society of CAD/CAM Engineers, Vol.15 No.4, 2010, pp.314-323

19) Chan Kang : A Study on the Improvement of a Building Remodeling Process Utilizing BIM, Kongju National University Graduate School the Department of Consruction Engineering major of Architectural planning and design, 2015

20) Tae-Ho Jung, Sang-Won Kim, Seung-Hwan Park, Sung-Wook Hong : The construction management of BIM-based small building remodeling, Proceeding of The Korea Institute of Building Construction Spring Annual Conference, Vol.12 No.1, 2012 , pp.191-192

21) HyunSoo Lee : BIM-enabled Modeling for the Efficiency and



<fig. 2> Result data of energy analysis with Yeongwol apartment

2.3. Building Performance Analysis Examples in Early Phase of remodeling project

With BIM authoring tools and BIM applications, variety of additional BIM-enabled approaches can be applied. For example, comparison among design alternatives in early phase of design can be made using energy data,[22] solar data automatically derived from BIM models[23] By designating actual location of building in BIM tool, temperature of dry bulb and wet bulb, electric cost, fuel cost, amount and direction of wind, etc. are analyzed. Fig. 2 shows variety of simple energy analysis derived from BIM model.

Solar analysis data derived in accordance with location, year, weather, time also able to be analyzed [24] and able to assist comparison among various design alternatives. Fig. 3 is result images when we did solar analysis with design alternatives of apartment building in Yeongwol, Korea.

3. Spatial program analysis in early phase of remodeling project

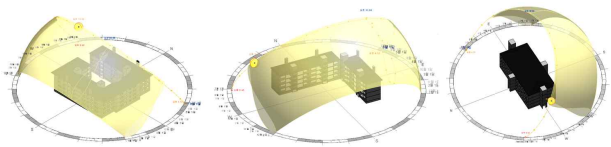
In the early phase of remodeling project, there are various considerations such as user's satisfaction, aesthetic improvement of building facade, understanding of system, regulation of building and construction cost.

Efficiency in construction cost is crucial issue because it is important to achieve maximum effects with minimum construction cost to fit project's purpose. One of the factors influencing efficiency in construction cost in remodeling project is area extension by enlarging a size of building. The other factor is modification of units which have different structural patterns. Furthermore, changing the arrangement of units also influences numerical values related to construction cost. In early phase of design, there are several issues diversified among design alternatives such as the building area, the total floor area, building-to-land ratio, etc. from the architectural perspective. From the spatial point of view, space-related issues including the number of units which are able to be arranged in building, types and sizes of units, the number of acceptable dwellers, etc. arise. From both perspectives, diverse types of building properties can be involved through remodeling construction process and furthermore, all of such issues will impact on efficiency of remodeling project.

3.1. Building extension scenario

Building extension is an action to expand building mass in the range of horizontal and vertical direction with keeping in existing condition of building partly. By extending confined area, more units are able to be arranged and each unit's area can be changed. Because areal factors would influence building user's satisfaction both directly and indirectly, they need to be checked from perspective of efficiency by investment.

There are various ways to extend a building. One of them is vertical extension. Vertical extension is



<fig. 3> Design comparison among alternatives with solar analysis

method to extend the top floor or the lowest floor in vertical direction by adding more floors just in case existing foundations and vertical members are in safe condition. There have been some concerns about

Comparative Evaluation of the Old-house Remodeling Design, Proceeding of The Korean Housing Association Annual Conference, No.2(Autumn), 2014, pp.277-281

22) Sang-Heon Lee, Byung-Jik Min, In-Ki Kim, Sang-Chul Nam, Sung-Duk Kang, Han-Jong Jun : A Study on BIM based Remodeling Architectural Design Process for Apartments, Proceeding of 2010 Society of CAM/CAM engineers Auunal Conference, 2010, pp.10-17

23) Yun-Jeong Lee, Ji-Hyo Seo, Seung-Yeon Choo : A Study on Improvement of Sunlight Evaluation Method in Apartment Housings and BIM-Based Verification Method - Focusing on G-SEED 1.2.1. Evaluation Items - / G-SEED 1.2.1., Proceeding of 2007 Architectural Institute of Korea Annual Conference, Vol.33 No.2, 2013, 2007, pp.63-64

24) Hyeun Jun Moon : Architectural Environmental Performance Analysis based on BIM , Journal of Architectural Institute of Korea, Vol.57 No.11 2010, pp.58-64

safety of vertical extension. Because plans have hardly existed in case of old buildings, it has been difficult to understand whole building and performance of existing structure. Regulation regarding extension, however, was revised to permit vertical extension only if existing foundation and vertical members are safe enough to perform extension. Consequently, vertical extension have been increasing its occupation in remodeling construction market.[25)]

3.2. Unit scenarios and its diverse arrangements

According to purpose of remodeling project, various kinds of units which are planned to be arranged and possible scenarios of their arrangement should be analyzed. Various scenarios can exist in early phase of design when minimum standard in housing is satisfied. In other words, the number of scenarios can be developed according to types and the number of units which are planned to be arranged inside the building. Furthermore, various arrangements of units according to purpose are supposed to be considered to develop scenarios in remodeling project.

In this paper, modules arranged in BIM models which used for implementation are designed with reference of the literature such as 1) minimum standard in housing of the Ministry of Construction and Transportation, 2) housing welfare standard of Seoul and 3) case study of public housing in UK, France, USA and Japan. Based on the modules, it is expected to derive areal data of residential space, common use space for one or more units, etc. from our implementation.

4. Yeongwol apartment spatial program analysis and applying design scenarios

4.1. Yeongwol apartment spatial program analysis

Yeongwol Apartment is a four-story building located in Deokpo-ri 594-7, Yeongwol-eup, Yeongwol-gun, Kang won-do, Korea. Its land area is 3,988 m^2 and there are sixteen households. It was once company housing for employees. Yeongwol Apartment is scheduled to be remodeled as one of the government projects in relate to housing environments and it is designed as housing for lower-income group. Yeongwol Apartment has no floor plans but blueprint images. We made BIM models with Revit2015 based on the blueprint images of Yeongwol Apartment to obtain simple quantitative data regarding architectural features and the spatial program.

<Table 1> Current state data of Yeongwol Apartment

Architectural & Spatial program data				
Entrance Floor	Public	Entrance1	17	15m^2
		⋮		
4th Floor	Public	Staircase8	26	12m^2
Grand total: 10	N/A	N/A	N/A	132m^2
1st Floor	Housing	101	101	88m^2
		⋮		
4th Floor	Housing	404	404	88m^2
Grand total: 16	N/A	N/A	N/A	1408m^2
Public area a unit	N/A	N/A	N/A	8.25m^2
Public area per a dweller	N/A	N/A	N/A	6m^2
Building area	N/A			392m^2
Building to land ratio(%)	N/A	N/A	N/A	9.82m^2
Total floor area	N/A	N/A	N/A	2024m^2
Floor space index	N/A	N/A	N/A	40.23m^2
The number of acceptable dwellers	N/A	N/A	N/A	64m^2

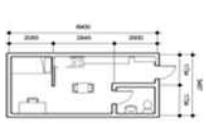
As shown in <Table 1>, fundamental architectural data and simple spatial program data were derived from the BIM model. Total floor area is 2024 m^2. The area of the entrance floor is 392 m^2 and each area of the floor where the four housing units are arranged is 392 m^2. The building area is 392 m^2, the building to land radio is 9.82% and the land area is 3,922 m^2. The floor space index is 40.23% except the roof floor and the water tank floor, which the dwellers are not allowed to access. The area of one housing unit is 88 m^2 and the total housing area is 1408 m^2. The total area of public space is 132 m^2. As shown in <Table 1>, various kinds of basic data can be derived automatically. Data that is derived beforehand and

25) Korea Remodeling Association : An introduction to Remodeling, Kimoondang, 2008

assists in the understanding of the current state will support comparison with other design alternatives.

4.2. Design scenario for remodeling project

<Table 2> Three types of housing module

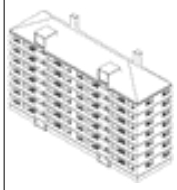
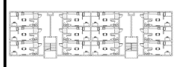
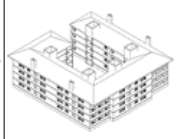
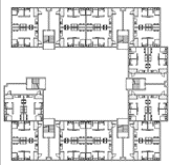
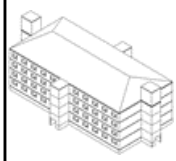
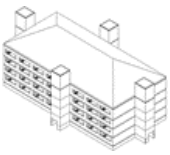
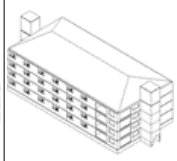
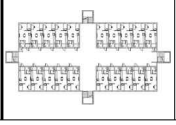
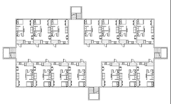
1 person housing	Newlyweds' housing	Shared housing
		
6,900 mm * 3,467 mm	7,000 mm * 5,200 mm	10,400 mm * 8,400 mm

BIM-enabled spatial program analysis is able to assist comparison and analysis among design alternatives in the early phase of design. For BIM-based spatial program analysis suggested as the main purpose of this paper, we made nine combinatorial BIM models and obtained quantitative data using Revit2015.

The virtual scenario includes three types of modules: 1) One- person housing, 2) newlyweds' housing, and 3) shared housing, in which three old men live together, sharing common space such as the living room and kitchen, while at the same time having private space such as bedrooms. Each type of housing unit is suitable for an individual, a couple and three people. The units were planned to be more spacious than 11.88 m^2, 20.13 m^2 and 29.04 m^2, respectively, which are the minimum standards for area in housing according to the number of dwellers.

The size of the one-person housing unit is 6,900mm * 3,467mm and it is composed of one Living Dining Kitchen(LDK), one bedroom, one bathroom and one entrance. The size of newlyweds' housing is 7,000mm * 5,200mm. It is intended for two dwellers and is composed of one LDK, one bedroom, one bathroom, one dress room and one entrance. At last, the size of the shared housing unit in which three old men live is 10,400mm * 52,000mm. It is planned suitable for three dwellers and composed of one dining kitchen(DK), one living room, three bedrooms, one bathroom and one entrance. Windows are not planned in the three types of units because their locations alter in accordance with the arrangement and direction of each unit.

<Table 3> Total of nine combinatorial BIM models

		1 person housing	Newlyweds' housing	shared housing
vertical extension	3D			
	Plan			
Horizontal extension	3D			
	Plan			
core extension	3D			
	Plan			

In addition, we applied three types of extension: 1) vertical extension, 2) horizontal extension, and 3) core extension as shown in <Table 3>. In the vertically-extended model, we added three floors in the vertical direction on the original top floor. In the horizontally-extended model, we extended existing the building in a horizontal direction, adding two corners architecturally within the existing site area. In the core extension model, we changed the locations and increased the number of staircase, adding two more staircases. In addition, we changed the type of corridor into a middle corridor type and extended it horizontally in this model. There are various structure and safety issues regarding extension. Since the main purpose of the paper is the automated design assessment in the early phase of building remodeling project among design alternatives, not on the structural safety of extension construction, the structureand safety issues were not configured in the BIM models in detail.

<Table 4> Quantitative data derived from vertical extension models

Vertical extension/1 person housing					Vertical extension/Newlyweds' housing					Vertical extension/Shared housing				
Entrance floor	Common space	Entrance1	85	15m²	Entrance floor	Common space	Entrance1	57	15m²	Entrance floor	Common space	Entrance1	29	15m²
Entrance floor	Common space	Entrance2	86	15m²	Entrance floor	Common space	Entrance2	58	15m²	Entrance floor	Common space	Entrance2	30	15m²
1st floor	Common space	Staircase1	87	12m²	1st floor	Common space	Staircase1	59	12m²	1st floor	Common space	Staircase1	31	12m²
1st floor	Common space	Staircase2	88	12m²	1st floor	Common space	Staircase2	60	12m²	1st floor	Common space	Staircase2	32	12m²
1st floor	Common space	Corridor1	89	21m²	1st floor	Common space	Corridor1	61	20m²	1st floor	Common space	Corridor1	33	15m²
1st floor	Common space	Corridor2	90	21m²	1st floor	Common space	Corridor2	62	20m²	1st floor	Common space	Corridor2	34	15m²
		⋮					⋮					⋮		
7th floor	Common space	Corridor14	114	21m²	7th floor	Common space	Corridor14	86	20m²	7th floor	Common space	Corridor14	56	15m²
Grand total: 30	N/A	N/A	N/A	504m²	Grand total: 30	N/A	N/A	N/A	478m²	Grand total: 30	N/A	N/A	N/A	408m²
1st floor	Residential	101	1	21m²	1st floor	Residential	101	1	32m²	1st floor	Residential	101	1	80m²
1st floor	Residential	102	2	21m²	1st floor	Residential	102	2	32m²	1st floor	Residential	102	2	80m²
		⋮					⋮					⋮		
7th floor	Residential	712	84	21m²	7th floor	Residential	708	56	32m²	7th floor	Residential	704	28	80m²
Grand total: 84	N/A	N/A	N/A	1764m²	Grand total: 56	N/A	N/A	N/A	1792m²	Grand total: 28	N/A	N/A	N/A	2240m²
Common space per unit	N/A	N/A	N/A	6m²	Common space per unit	N/A	N/A	N/A	8.53m²	Common space per unit	N/A	N/A	N/A	14.57m²
Common space per dweller	N/A	N/A	N/A	6	Common space per dweller	N/A	N/A	N/A	4.26m²	Common space per dweller	N/A	N/A	N/A	4.85m²
Building Area	N/A	N/A	N/A	406m²	Building Area	N/A	N/A	N/A	406m²	Building Area	N/A	N/A	N/A	406m²
Building-to-land ratio(%)	N/A	N/A	N/A	9.82%	Building-to-land ratio(%)	N/A	N/A	N/A	9.82%	Building-to-land ratio(%)	N/A	N/A	N/A	9.82%
Total area	N/A	N/A	N/A	2872m²	Total area	N/A	N/A	N/A	2872m²	Total area	N/A	N/A	N/A	2872m²
Floor space index	N/A	N/A	N/A	72.01%	Floor space index	N/A	N/A	N/A	72.01%	Floor space index	N/A	N/A	N/A	72.01%
Number of acceptable dwellers	N/A	N/A	N/A	84	Number of acceptable dwellers	N/A	N/A	N/A	112	Number of acceptable dwellers	N/A	N/A	N/A	84

5. Demonstration of comparisons among design alternatives using Yeongwol apartment case

5.1. BIM-enabled spatial program analysis of design alternatives in the Yoengwol apartment remodeling project

<Table 4> shows quantitative data derived from vertical extension scenario-based models. The three vertical extension models in <Table 4> contain one-person housing units, Newlyweds' housing units and shared housing units, respectively. From the architectural perspective, it is analyzed that the building area is 406 m², building-to-land ratio is 9.82%, total floor area is 2872 m² and floor space index is 72.01% which is higher than the current building condition. In the case of vertical extension/one-person housing unit model, the area of one entrance floor is 15 m², the area of one staircase is 12 m² and the area of one corridor is 21 m² as analyzed in <Table 4>. The area of common use space in the whole building is 504 m² as shown in the grand total value. The area of one housing unit is 21 m² and the number of units that can be arranged is 84. The total area for residential space is 1764 m². The acceptable number of dwellers in the extended building is 84. The area of common use space per unit and the area of common use space per dweller are both 6 m² (because unit is just for one dweller).

In the case of vertical extension/newlyweds' housing unit, the area of one entrance floor is 15 m², and the area of one staircase is 12 m², as in the previous model. However, the area of a corridor is 20 m² and the common use space area in the entire building is 478 m². The area of each housing unit is 32 m² and the number of possible units is 56. The entire area for residential space is 1792 m². The acceptable number of

dwellers in the building is 112 in total. Because the newlywed unit is for two dwellers, the area of common use space per unit is 8.53 m^2, in other words, the area of common use space per dweller is 4.26m^2.

In the case of vertical extension/shared housing unit, the area of one entrance floor is 15 m^2 and the area of one staircase is 12 m^2. The area of one corridor is 15 m^2 and the common use space area in the whole building is 408 m^2. The area of one housing unit is 80 m^2 and the number of possible unit is 28. The entire area for residential space is 2240 m^2. The acceptable number of dwellers is 84, the area of common use space per unit is 14.57 m^2 and the area of common use space per dweller is 4.85 m^2.

5.2. Comparison of data among design alternatives and visualization

<Table 5> Summarized data derived from vertical extension model

	Area of housing unit(m^2)	Area of common use space per unit(m^2)	Area of common use space per dweller (m^2)	Number of units(m^2)	Acceptable dwellers (m^2)	Acceptable dwellers per unit(m^2)	Area of common use space (m^2)	Area of residential space (m^2)
Vertical extension/1 person housing	21	6	6	84	84	1	504	1784
Vertical extension/Newlyweds' housing	32	8.53	4.26	56	112	2	478	1792
Vertical extension/Shared housing	80	14.57	4.85	28	84	3	408	2240

<Table 6> Percentage data derived from Table5

	Area of housing unit(%)	Area of common use space per unit(%)	Area of common use space per dweller (%)	Number of units(%)	Acceptable dwellers (%)	Acceptable dwellers per unit(%)	Area of common use space(%)	Area of residential space(%)
Vertical extension/1 person housing	15.78	20.61	39.7	50	30	16.66	36.25	30.67
Vertical extension/Newlyweds' housing	24.06	29.31	28.19	33.33	40	33.33	34.38	30.81
Vertical extension/Shared housing	60.16	50.06	32.09	16.66	30	50	29.35	38.61

Various kinds of data were derived from BIM models as shown in <Table 4>. We summarized numerical data into eight sorts of features. In the summarized data, there were area data such as 1) area of housing unit, 2) area of common use space per unit, 3) area of common use space per dweller, 4) area of common use space, 5) area residential space. The number of acceptable dwellers in the apartment, the number of acceptable dwellers per unit and the number of units were included as well.

As shown in Table 5, the area of common use space per unit is biggest in the vertical extension/shared housing model, and smallest in the vertical extension/one-person housing model. However, the area of common use space per dweller and entire common use space is biggest in the vertical extension/one-person housing model, smallest in the vertical extension/shared housing model. The number of units in the vertically extended building is highest in vertical extension/one-person housing model and lowest in the vertical extension/shared housing model. On the other hand, the number of acceptable dwellers is biggest in the vertical extension/newlyweds' housing model, and smallest in the vertical extension/shared housing model. In addition, the area of residential space is biggest in the vertical extension/shared housing model and smallest in vertical extension/one-person housing model. These findings show that ranking of the features differs between models even though they are related to the same area such as residential area or common use space.

<fig. 4> Visualization data with radiation graph

We grouped various types of data into the same unit and scale to compare each factors directly. The resulting values are visualized in an intuitive way as described in <Table 6> and fig. 4 using simple calculation. For example, to alter numerical values of housing unit area into percentage values, we divided each area of housing unit by the sum of them. Thus,

they could be replaced with percentage data to be compared directly with simple calculation. Fig. 4 is a radiation graph with percentage data equivalents of the as various types of numerical value in <Table 5>. By visualizing meaningful and summarized quantitative data of design alternatives, it is easier to compare and analyze the result intuitively. This also supports design decision-making among design alternatives.

5.3. Comparison of data and analysis among total nine combinatorial BIM models and visualization of data

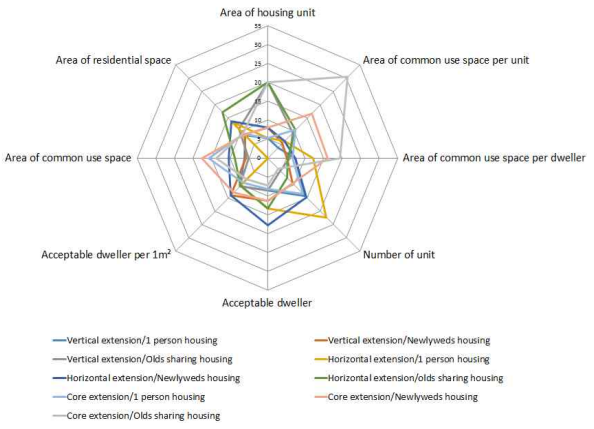
We derived spatial program data of nine combinatorial BIM models composed of one-person housing units, newlyweds' housing units and shared housing units as shown in <Table 7> Deriving spatial program data and changing them into percentage data was done using the same method applied in the <Table 6>.

As shown in <Table 7> and Fig 5, the area of each unit, which was applied to total nine combinatorial BIM models, is identical with its housing unit scenarios; 1) one-person housing, 2) newlyweds' housing and 3) shared housing. In the category of entire residential space area, the case of the horizontal extension/shared housing model is the highest followed by the horizontal extension/newlyweds housing model, with the vertical extension/one-person housing model being lowest. However, in the category of acceptable dwellers in the extended apartment, horizontal extension/newlyweds housing model is the highest and core extension/shared housing model is the lowest. On the other hand, numerical value of acceptable dwellers per $1m^2$ is highest in the vertical extension/newlyweds housing model and the horizontal extension/newlyweds housing model, and lowest in the horizontal extension/shared housing model. On the other hand, numerical value of common use space area is highest in the horizontal extension/shared housing model and lowest in the vertical extension/one-person housing model in accordance with extension plan and type of unit.

However, numerical value of common use space area per unit is highest in the core extension/shared housing model, second highest in the core extension/newlyweds' housing model is one, and lowest in the vertical extension/one-person housing model. The ranking regarding common use space per dweller is different. The most spacious model and the second most spacious model are the same in category of which is the most spacious and the second most spacious common use space area per unit. However, as shown in Fig. 5, rankings from the third most spacious model to the smallest models are different from those of common use space per unit. The area of common use space is smallest in the horizontal extension/newlyweds housing model and second smallest in the horizontal extension/shared housing model is next.

<Table 7> Spatial program percentage data from the nine combinatorial BIM models

	Area of housing unit (%)	Area of common use space per unit (%)	Area common use space per dweller (%)	Number of units (%)	Acceptable dwellers (%)	Acceptable dweller per $1m^2$ (%)	Area of common use space (%)	Area of residential space (%)
Vertical extension/ One-person housing	5.26	3.9	7.5	14.18	8.53	10.61	6.19	8.61
Vertical extension/ Newlyweds housing	8.02	5.54	5.33	9.45	11.38	13.97	5.87	8.75
Vertical extension/ shared housing	20.05	9.47	6.06	4.72	8.53	10.61	5.01	10.93
Horizontal extension/ one-person housing	5.26	6.41	12.33	22.29	13.41	10.29	15.99	13.53
Horizontal extension/ Newlyweds housing	8.02	6.51	7.39	14.86	17.88	13.97	10.38	13.75
Horizontal extension/ shared housing	20.05	10.54	5.4	7.43	13.41	10.29	8.77	17.19
Core extension/ one-person housing	5.26	10.47	6.75	13.51	8.13	9.19	15.82	9.08
Core extension/ Newlyweds housing	8.02	16.72	16.08	9.45	11.38	12.86	17.69	8.75
Core extension/ shared housing	20.05	30.4	19.49	4.05	7.31	8.08	13.78	9.37



<fig. 5> Visualization of the total nine combinatorial models

In addition, ranking of scenarios in terms of common use space area is different from that of former categories. The core extension/newlyweds model housing is the highest followed by the horizontal extension/one person housing next as shown in Fig. 5. As these comparisons and analyses show, extension plan, arrangement of housing unit, type of unit and so on are able to influence numerical issues including housing satisfaction, construction cost and purpose of remodeling project in the building.

With the BIM-enabled approach to the remodeling project, derived quantitative, meaningful data and visualization using graphs are expected to support experts who conduct design review or design decision-making. As in the actual case of Yeongwol Apartment, there will be various criteria corresponding to a given remodeling project's purpose. If the purpose of a remodeling project is maximizing the number of possible dwellers in the building, it necessary to check acceptable dwellers in one unit, acceptable dwellers in 1 m^2 and arrangement of units; each can be changed depending on other factors. In other case, if remodeling project focuses on the area of common use space, comparison and analysis regarding the area of common use space, common use space area per unit, common use space area per dweller, and so on should be checked mainly including other factors.

5. Conclusion

Current remodeling process has been quite laborious and fairly cost-inefficient because they have often dependent on expert's subjective and arbitrary knowledge. Thus, it tends to be quite expensive and time consuming. However, BIM-enabled approach of remodeling process can assist increase of productivity and efficiency by using quantitative data. Especially well-modeled BIM-models are able to assist overall process of remodeling project or even through whole life-cycle of building from the perspective of interoperability.

In this paper, we mainly focused on an approach to the analysis and comparison among design alternatives using quantitative data from BIM models, and this approach may be supportive of decision-making in review process. We demonstrated a BIM-enabled spatial program review in the early phase of remodeling project using an actual old apartment case in Yeongwol, Korea. We analyzed the efficiency of three separate plans of extension; 1) horizontal extension model, 2) vertical extension model, and 3) core extension model. In addition, we applied three types of housing module; 1) one-person housing, 2) newlyweds' housing, and 3) shared housing. This paper analyzed basic architectural program and spatial program by extracting quantitative data using nine types of design alternatives in accordance with several categories. Each BIM-model has different characteristics in the perspective of spatial programming. For example, a BIM-model which has the biggest common space is not sure to have most spacious common use space per a unit or a dweller. The suggested approach can be a supportive indicator for decision-making and design review between design alternatives especially in early phase of design. We expect to develop suggested work considering comparisons among more diverse arrangement of various unit types with more automated framework. Furthermore, we hope that suggested work could be developed reflecting more critical and specific issues in actual remodeling project.

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