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Development of web-based design management system through user participatory design and use-case modeling

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Abstract

The construction industry has several phases in which a variety of stakeholders are involved. As construction projects are becoming larger, more complex and more diverse, the design phase has become a more important factor for the success of projects than ever before. However, it is considered that most of the design work carried out in the actual design process is intangible. Such recognition assumes that the design phase is more unsystematic and arbitrary, which finally weakens the competitiveness of the whole project. In order to solve these problems, this study developed an integrated design management system (IDMS), which consists of 8 modules including the design document, schedule, quality, and building permit management. This study is also intended to validate the effectiveness of the newly developed system. Two characteristics have made this research significantly different from previous studies. Firstly, the users of the system including architects and other design professionals were continuously involved from the development phase to the validation phase. The other unique characteristic is that the actual design project was applied as a test bed in the final validation stage. The research team applied the actual data which had been generated during each business process, and the effectiveness of the system implementation was verified. The authors expect that such a user-centered approach enables the system to be more robust and effective.

Keywords: *Design management, Web-based system, Participatory design, Use-case modeling, Scenario-based method.*

1. Introduction

1.1. Backgrounds and objectives

As construction projects are becoming larger, more complex and more diverse, the design phase has become a more important factor for the success of projects than ever before. The need for efficient design management has further increased, and various studies have been conducted on related topics [1], [2], [3], [4]. Under these circumstances, the integrated project delivery (IPD) method, in which human resources, systems, and practices are integrated into a process that collaboratively harnesses all the knowledge and capability of all participants through all phases from design to construction, is recommended as an effective alternative by AIA (American Institute of Architects) [5]. As the decisions are properly determined at an earlier design phase, the project will be performed more effectively. It is clearly stated that making design decisions as early as possible is very important especially from the designer's point of view, which makes the project more effective and less costly [6].

Thus the importance of design and the need for efficient management of design-related work is increasing, much systematic approaches have been endeavored by researchers [7], [8], [9]. However, the thorough implementation of a systematic management system such as PMIS (Project Management Information System) is not being activated because of the intangible characteristics of design works. Although the course of design tasks is composed of intangible and qualitative aspects to a large proportion, the final products of building design should represent the specific characteristics required to construct a real building. For example, it is considered that the government's bureaucratic procedures such as a building permit are the most critical factors for the final outcome in the design process [10]. In other words, most of the actual outputs deduced in the design phase are not taken into consideration as elements of management. As a result, the design phase depends on the abilities and experiences of each architect rather than the organizational and cooperative system. Such practice makes the design management process

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somewhat arbitrary and less systematic, which weakens the competitiveness of the whole project [11], [12].

As a project becomes more complicated and various stakeholders become more involved, the documentation becomes more important as a means of design management and intercommunication [13], [14]. Although a systematic approach for the documentation is one of the most critical success factors, the majority of design companies have not been able to adopt such a system for economical reasons and some of large design firms have merely introduced a systematic approach for managing the design work [15], [16]. To solve the problems raised above, this study developed a web-based system for integrated design management (IDMS) considering the following factors which are differentiated from other existing systems: i) identification and integration of design management elements; ii) establishment of a cooperative environment among a variety of design professionals; iii) enhanced system flexibility to respond to the changes of the construction environment; iv) system development through intended user's participation from the beginning stage and v) system validation through use-cases modeling.

While many design support tools have been developed, the development of integrated design project management systems which recognize the design as a starting point of the entire project is rare. Also, in order to ensure the effectiveness of management tools for design, early involvement and system verification by intended users are efficient ways to reflect the uniqueness of the design works, which leads to the success of system development.

From this perspective, this study has recognized the importance of the design process during the system development, and has faithfully reflected the opinions of design experts ranging from the initial development to the verification stage. The web-based design management system is suggested in this research on the basis of a comprehensive understanding of the design process at each step and the intended user's continuous assessment.

1.2. Scope and methodology

Some researchers have intermittently showed their interest in design management and have endeavored to find ways to elevate the project quality through design improvements. Researchers have paid attention to information management [8], collaboration support [9], change management [10] and process improvements [11]. Most studies, however, have been individually progressed according to a topic. Thus, integrated design management tools are not frequently suggested.

Although the above studies are similar to this research in terms of the research objective in which an improvement in design performance is attempted, the scope and the target of the study are unable to provide a comprehensive analysis on design management. In addition, the above studies have not presented sufficient evidence of effectiveness and efficiency using actual project cases.

The authors have previously performed research in which the elements of design management were suggested based on a thorough understanding of the design process [12]. The IDMS consists of 8 major modules (project register, owner requirement management, design document management, human resource management, schedule management, quality management, building permit management, and community), which were selected based on the results of this previous study.

2. System development and structure

The IDMS was initiated with preliminary study such as extensive literature reviews and interview with the corresponding experts. Three stages of validation process were conducted through user participatory to improve the process implementation and usability of the IDMS. Fig.1 illustrates the development process of the IDMS.

2.1. System development through end-user participation

The design process, which is the baseline for IDMS, is established and suggested in this section. The significant feature which differs from the previous studies is that design professionals have participated from the early stage of the system development throughout the system implementation. The design process suggested in this study is intended to play a role as the basis for the system operation, and it faithfully reflects the opinions of the architects, the intended users of IDMS. The detailed design works, the related services of each phase, and a variety of information generated from individual tasks were established through participation from the Korea Association of Architects (KAA). The KAA formed a special committee and provided invaluable information which has been a basis for the study.

2.1.1. Definition of information-oriented design work process

This study established an information-oriented design work process through a collaboration of design experts and project management researchers. A design task process was devised to reflect the procedures of the actual design work, and it has been utilized as the preliminary information to develop the IDMS. The process consists of a three level structure as described in Fig. 2. Each respective work composing the design process includes both input information and output results. The design work breakdown structure applied in this study provides effectiveness and efficiency in classifying design and engineering documents generated by multiple professionals [17], and it enables the IDMS to be a more flexible and systematic system.

2.2. System configuration and its architecture

The IDMS consists of eight modules to provide a variety of functions for managing the design process more effectively and efficiently: i) project register; ii) owner requirements (OR) management; iii) design document management; iv) human resource (HR) management; v) schedule management; vi) quality management; vii) building permits management and viii) community. The functional composition of eight modules is illustrated in Fig. 3. The functions of individual modules and their relationships have been constantly configured and revised through several interviews with intended system users. These users are composed of the owner, the design manager,

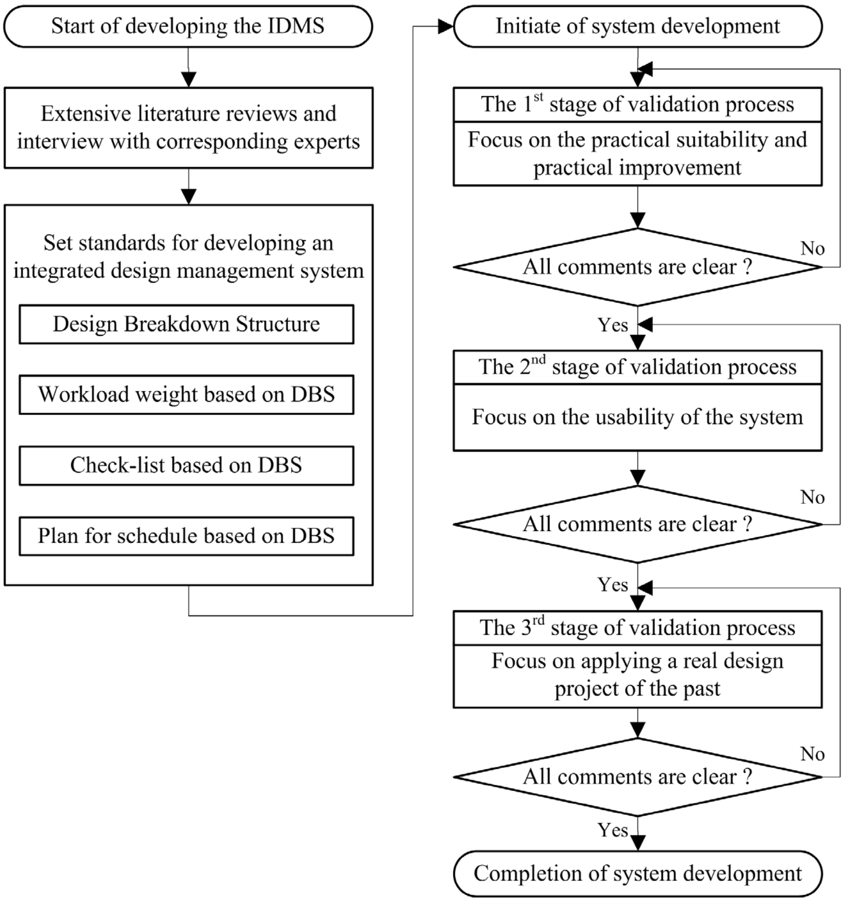

Fig. 1 The development process of the IDMS through user participatory design

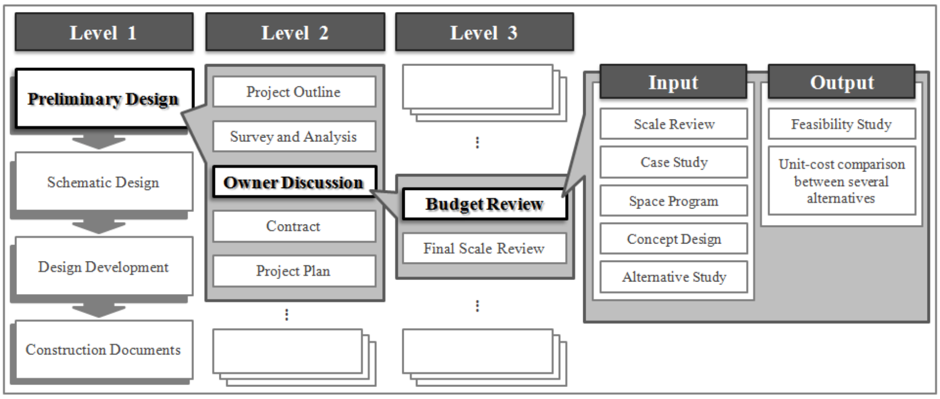

Fig. 2 Design work breakdown structure

architectural designers and a variety of engineers (structural designer, mechanical engineer, electrical engineer, etc), who would be authorized to access the IDMS and utilize the system. The system architecture and relationship of the IDMS is presented in Fig. 4. More detailed descriptions on the relationship between project register and design document management are explained as follows:

As shown in project register module (the left part of Fig. 4), design breakdown structure (DBS) could be established based on the project characteristics, design firms and design teams. The DBS consists of design work (DBS-①), permit work (DBS-②), and engineering work (DBS-③). Design document (PD-①), attached document for permit work (PD-②), and engineering work (PD-③) could be individually redefined according to the DBS. And the other setting elements, which mean responsible person (PR-①), workload weight (PR-②), check-list (PR-③), and plan for the schedule (PR-④) could be also redefined. These setting information would be intimately connected to design management indices of the IDMS, which includes (1) design document management, (2) schedule management, (3) HR management, (4) quality management and (5) permit management as shown in Fig. 5.

Fig. 5 explains the system architecture and relationship of the IDMS, especially on the relationship between design document module and the other design management indices module.

• Module (1): This module mainly manages the design documents, which could be redefined according to the project characteristics.

• Module (2): This module manages the design schedule. As design documents are uploaded to designated databases in module (1), the IDMS creates monitoring indices such as master schedules, design schedules and permit schedules. Such indices are generated depending to the standard defined in the PR-②: ‘workload weight’ and the PR-④: ‘plan for the schedule’.

• Module (3): This module manages the human resource (HR), i.e., the time commitments of each person responsible for the corresponding work. While design documents are uploaded to designated databases in module (1), the due times for each task should be assigned according to PR-①: ‘responsible person’.

• Module (4): This module manages the design quality. As design documents are uploaded to the designated databases in module (1), the IDMS creates the monitoring indices on the

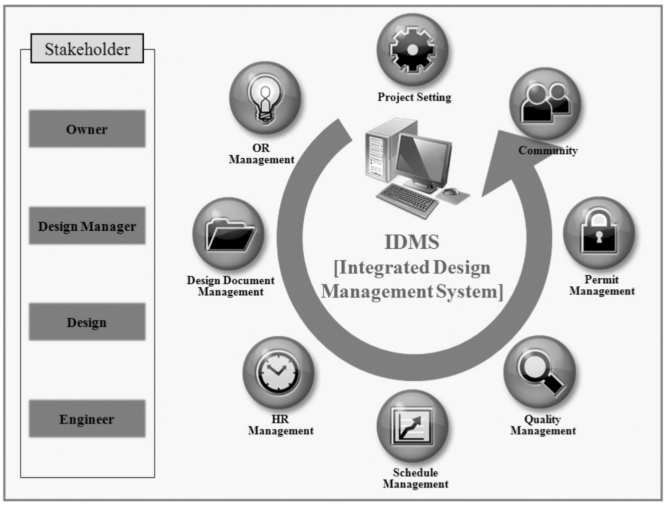

Fig. 3 A functional composition of the IDMS

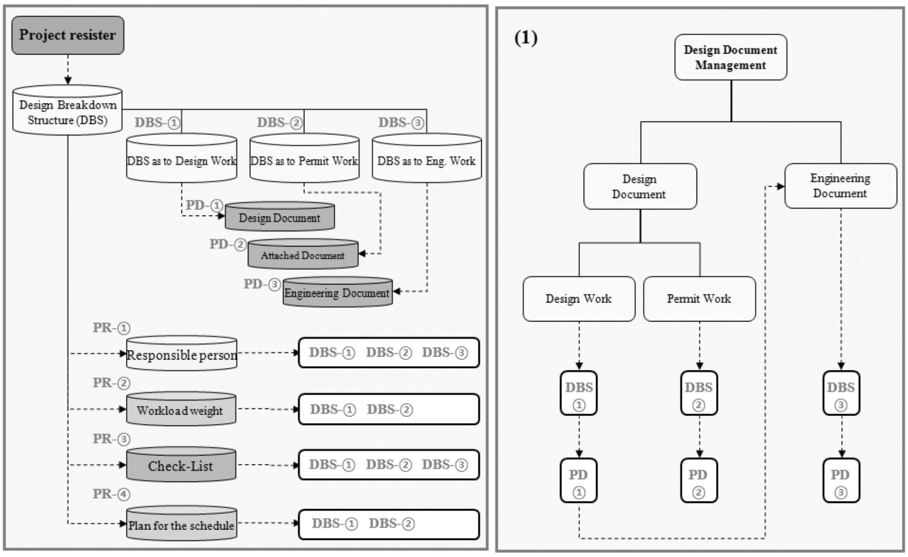

Fig. 4 System architecture and relationship-1

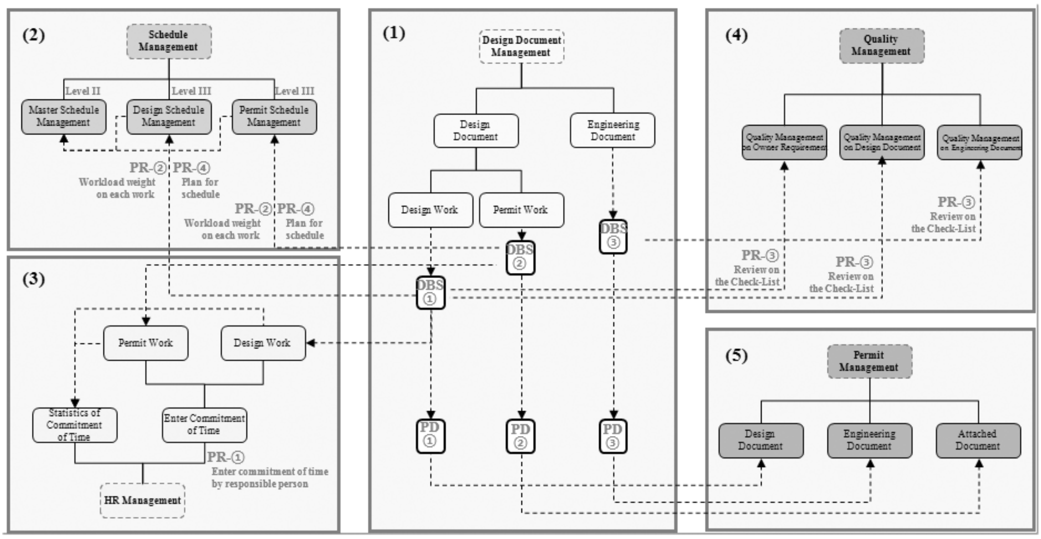

Fig. 5 System Architecture and Relationship-2

owner requirements, design documents and engineering documents. Such indices are deduced by using PR-③: ‘check-list’.

• Module (5): This module manages the administrative works and documents regarding building permits. When the design documents are uploaded to the designated databases in module (1), the IDMS assigns them to the proper database. The final three formats of the documents are the PD-①: ‘design document’, PD-②: ’attached document’, and PD-③: ‘engineering document’.

2.3. Scenario-based operating planning of IDMS

The IDMS was developed to support collaborative environments among multiple design practitioners such as design managers, designers and engineers (structural engineer, mechanical engineer, electrical engineer, etc), and it has expanded its management arena to clients through the integration of all the design-related information [18]. Thus the IDMS could be used in a variety of scenarios depending on the role and requirements of each individual user as shown in Fig. 6. The hypothetical scenarios of the system operation are described to correspond with the serial numbering of the intended system users as follows:

• Owner(1) could search for similar projects and review the codes and relative information regarding the construction site through the ‘Owner requirement (OR) management’ module. The owner could not only discuss his or her requirements but also exchange the corresponding information with design managers(2) or designers(3).

• Design manager(2) could initialize a new project and set up the system in correspondence with the project characteristics. The design manager could establish a series of processes for composing the design team responsible for the design work, analyzing the details of the design work, arranging the role-sharing and collaboration procedure, and preparing other standards for the design process in the ‘Project register’ module. These results would be intimately connected to the design management indices of the IDMS.

• Designers(3) could upload the design documents produced via actual design process in module(1): ‘design document management’. The due date for each task will be assigned and continuously controlled in module (3): ‘HR management’. After each design work is completed, Designer(3) could review it by using checklists provided by PR-③: ‘check-list’. Design Manager(2) could reconsider it from the owner’s standpoint. If design manager(2) has any other comments on the final documents, it will be revised after discussion with the relevant person.

• Engineer(4) could complete engineering documents by using the design documents delivered from Design Manager(2) or Designer(3), and upload them in module (1): ‘design document management’. Designer(3) could reconsider them by using checklists provided by PR-③: ‘check-list’. If any problem is detected, it will be resolved after discussion with the corresponding person.

• Lastly, owner(1) could review the final design and engineering documents. If owner(1) has any other comments on the final documents, it will be fixed after discussion with the relevant person.

3. Validation on system implementation and its effectiveness

This section is intended to validate the system implementation and its effectiveness. Two characteristics have made this research significantly different from previous studies. Firstly, the users of the system including the architects and other design professionals were continuously involved, starting from the development phase to the validation phase. The other unique characteristic is that the actual design project was applied as a test bed in the final validation stage. The research team applied the actual data which had been generated during each business process, and the effectiveness of the system implementation was verified. The evaluation results performed in this section and comprehensive analyses are summarized in Chapter 4.

3.1. Strategic plan for validation

In this study, a strategic validation process based on the intended users’ participation was suggested to facilitate the system implementation. The development of IDMS and its evaluation were mainly monitored in terms of three categories: i) implementation of the design process and related tasks, ii) contribution to business improvement, and iii) ease of system operation. The evaluations were carried out through three stages of validation process, where a significant progress of the system has occurred.

As described in Table 1, the IDMS is constantly revised and modified while it is designed and developed. Thus the implementation was verified through three stages. In the 1st stage, the review tasks focused on verifying the practical suitability and practical improvement of individual modules. The reviewers of the system validation have verified the practicality of the individual modules by using a functional description on how to use them. They then wrote an evaluation report regarding error corrections and system improvements on the respective modules, which were used to create a more practical system. This process was repeated until all the corrections were reflected in the system. As a result, the individual modules of the IDMS were significantly improved, and they were efficiently integrated as a seamless system.

In stage 2, the main purpose was to verify the usability of the system including revising the system user’s manual. The reviewers have verified the usability of the integrated system by using the instruction manual. Based on actual usage, the reviewers wrote an evaluation report regarding the targeted subjects.

In stage 3, the primary tasks are involved in validating the IDMS by applying a previous real design project. The research team selected a design project that was executed by affiliated researchers. A general scenario and a detailed timeline for the validation process were established based on a consensus among participants in the system validation study.

3.2. A case project overview at test-bed

A design project for an office building located in the Seoul CBD (Central Business District) area was selected as a real

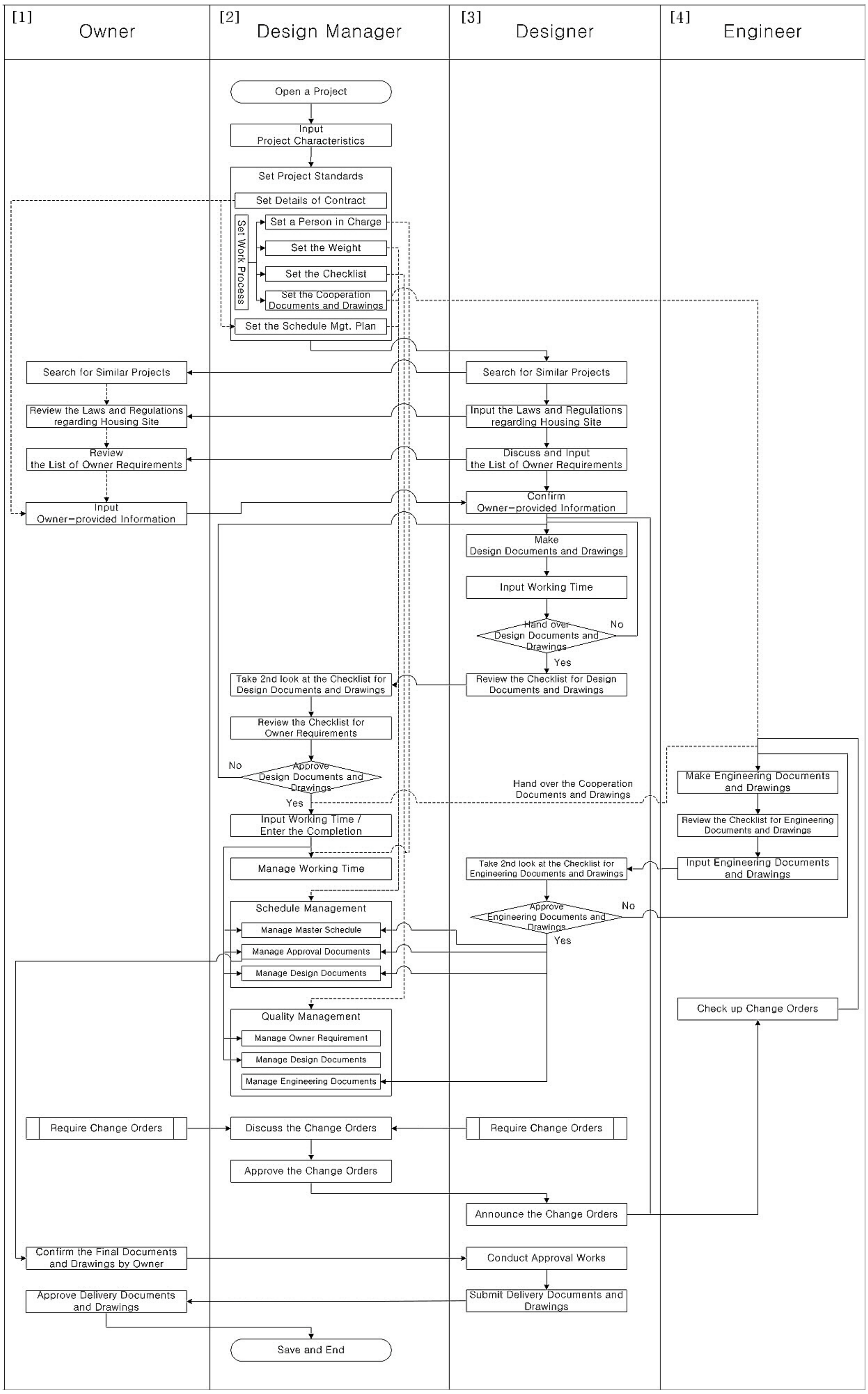

Fig. 6 System operating scenario among multiple participants

case to verify the effectiveness of the developed system. Design Development was conducted from May 2008 to August 2008, and Construction Documentation was carried out from September 2008 to January 2009. An overview of the project is described in Table 2 below.

3.3. Scenario-based system operation

In order to perform use-case validation, a scenario-based system development was applied. A scenarios description of the system operation was created to establish more effective

Table 1 Overview of the validation through three stages

No.	Period	Target subjects & contents
1st stage	2009. 8. ~ 2009.12.	· Implementation of design process · Contribution to business improvement · User manual draft
2nd stage	2010. 2. ~ 2010. 4.	· Ease of system operation · User manual revision
3rd stage	2010. 4. ~ 2010. 6.	· Use-cases validation

Table 2 Overview of a case project

Item	Description
Plottage area	3,200.93 ㎡
Structure type	Reinforced concrete & steel reinforced concrete
Land ratio	39.14 %
Floor ratio	415.98 %
Total floor area	Above ground: 13,398.41 ㎡, below ground: 5,821.52 ㎡
Number of stories	12 stories above ground, 3 stories below ground

and efficient practices in system validation. A series of work processes based on the user scenario are shown in Table 3. The design work process was thoroughly examined by analyzing the design documents and related information. By using the scenario-based method, the research team intended to confirm whether critical functions of the system were properly implemented and intimately connected to one another. The exemplary scenario applied in this study consists of a 16-step process which includes a responsible person and the detailed task descriptions and related modules of the system are described in Table 3.

3.4. Evaluation report summary

An evaluation report on each module was written at each of the 3 steps of the validation process. As shown in Figs. 7 and 8, modification requests were reported with 302 cases during the three phases of system evaluation process. When the analysis is organized by module, the requests are distributed

Table 3 A detailed timeline for the third phase of validation

No	Module	Task Description	Responsibility
1	Project Register	▪ Registration of contract document, amount and duration ▪ Scope: architectural design, structure, mech., elec., etc.	Design Manager
2	Project Register	▪ Work process : design, engineering and permit documents ▪ Input data : design and engineering documents ▪ Attached files : permit documents	Design Manager
3	Project Register	▪ Responsible person : design, engineering and permit process ▪ Scope : architectural design, structure, mech., elec., etc.	Design Manager
4	Project Register	▪ Define work load weight: design and permit process ▪ Setting up added work process with notification alert	Design Manager
5	Project Register	▪ Checklist : design and engineering process ▪ Setting up added work process with notification alert	Design Manager
6	Project Register	▪ Cooperation work : design process ▪ Setting up added work process with notification alert	Design Manager
7	Project Register	▪ Plan for the schedule : design and permit process ▪ Scheduling related to the contract duration and work load weight	Design Manager
8	Community	▪ Upload minutes regarding on the results of Kick-Off Meeting ▪ Notice of completion for project register and start-up	Design Manager
9	Document Management	▪ Information management provided by owner	Designer
10	Document Management	▪ Making design documents in design development phase ▪ Register design documents and review them with checklist	Designer
11	HR, Schedule, and Quality Management	▪ Commitment of time by responsible person ▪ Check progress status in HR, Schedule and Quality Management	Designer
12	Document Management	▪ Exchange of design documents between designer and engineer	Designer
13	Document Management	▪ Making engineering documents in design development phase ▪ Register engineering documents and review them with checklist	Engineer
14	Document Management	▪ Send design and engineering documents for building permit process to design manager	Designer
15	Document Management	▪ Review the received documents with checklist and approve it	Design Manager
16	HR, Schedule, and Quality Management	▪ Check progress status in HR, Schedule and Quality Management	Designer

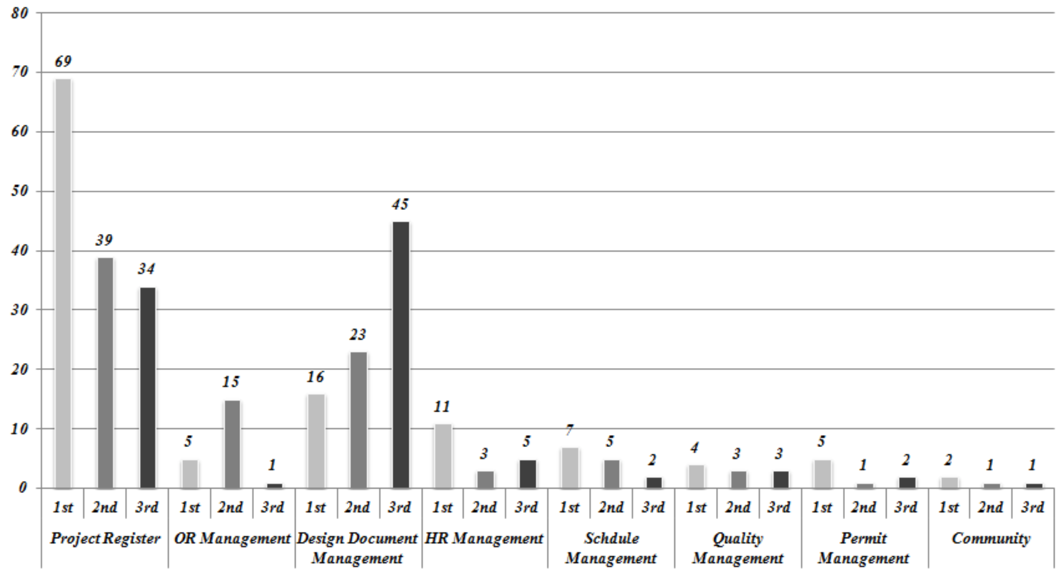

Fig. 7 Summary of system modification requests

mainly in the 'project register' and 'design document management', of which the proportions are respectively 47.0% and 27.8%. Especially, in the first and second stages, most of requests (58.0%, 43.3%, respectively) are deduced from 'project register' module. In stage 3, major modification requests (48.4%) are related to 'design document management' module.

To summarize in terms of contents by subject, modifications on system operational errors and revisions of business process on which the system is based are the main issues in the 1st evaluation stage. In the 2nd phase, most of the comments are associated with the system openness and flexibility to a support continuous system operation.

In the 3rd phase of evaluations, the effectiveness and suitability of the system operation was investigated by applying the actual design project which had been performed in the past by the evaluators themselves. System improvements were suggested on the user interface to utilize management indicators provided by the system, and comments regarding the operation of the integrated system were mainly proposed.

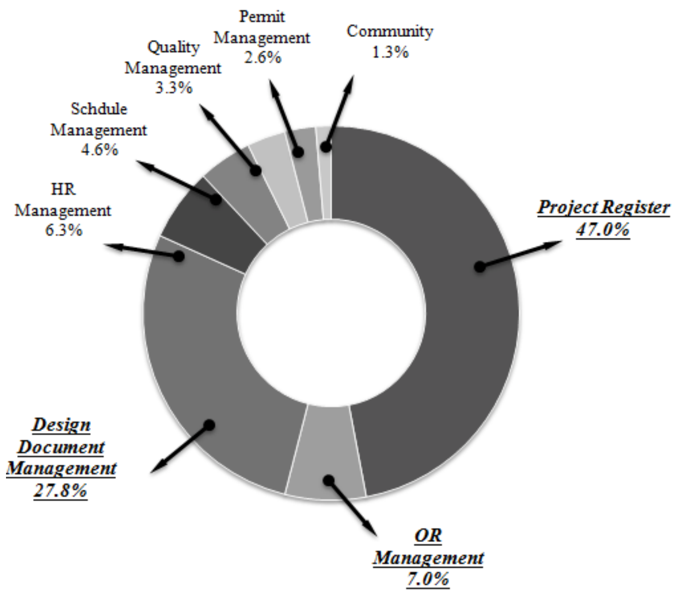

Fig. 8 System modification requests on individual module

4. Evaluation results and discussion

IDMS was effectively developed by the direct involvement of the intended users from the early stage of the system development, and it was improved tremendously through continuous feedback on the evaluations. These two facets have enabled IDMS to differentiate from other similar systems which handling the design process. As presented in previous researches, communication between the project participants could be available via drawings and design reviews either informally or formally [10], [12]. Such a design should be planned, managed, and controlled around the flow of information by using a coordinated and effective solution. The objective of this communication is to exchange the right information with the right person at the right time. However, practitioners responsible for design works are hampered by the limitation of current design information management system. Most of systems are merely developed based on the critical path method which could not properly deal with interrelated tasks occurred in the design process. To solve this problem, many researchers suggested improved models such as Last Planner [19], Workplan [20], ADePT: Analytical Design Planning Technique [21], and DePlan [22]. While many design supporting systems were developed as mentioned above, practical analyses have been merely reported which were resulted from the implementation of previous projects over whole design process [23], [24], [25].

In this section, the direction for the future study will be discussed based on the quantitative analyses of evaluations on the 8 individual modules of the IDMS. Regarding the evaluation of the system implementation of the design process, the system has been improved gradually along with the progress of each validation phase, where each module is measured on the identical scale (e.g., 1=very low, 2=intermediate, 3=medium, 4=intermediate, 5=very high). As shown in Fig. 9, ‘quality management’ and ‘permit management’ modules are relatively more improved than other modules (respective scaled scores are 4.7 and 4.3). In terms of ‘quality management’, it is assumed that step-wised checklists and double-check function on those checklists by responsible persons are very suitable for practical design management process. From the perspective of ‘permit management’, it is analyzed that automatic distribution function on final outputs is appropriate for administration process.

However, the score of the ‘schedule management’ module is relatively lower than that of other modules. The reason could be the architect’s fundamental hostility towards design management. Analysis also suggests that many architects had presented different opinions on the workload of each task that is suggested as a guideline for schedule management in this study. These analyses were reflected fully in the final version of the system by modifying the relevant menu for the sake of the user's ease. Such feedback, ultimately, has improved the flexibility of the system operation.

When investigating the evaluation of the business improvements achieved by introducing the IDMS, overall satisfactory results were gained, except for the ‘Human resource management’ module (Figure 10). This result was considered to be due to the architects' reluctant attitude in which the performance evaluations on their design tasks would be managed based on time. Such a misconception should be removed for the brisk dissemination of the IDMS. In other words, the role of the design management system is not simply controlling the design tasks. The system enables the users to perform their jobs in an effective way, and supports all the design professionals in collaborating with each other. The proper understanding of the design management system is most critical in widening the system deployment. From this point of view, the IDMS relies significantly on the function of ‘design document management’ module, since this module is intimately connected to design management indices. When design documents are uploaded to designated databases in ‘design document management’ module, the IDMS continuously creates monitoring indices regarding on schedule, quality, permit, HR management.

From the analyses on the result shown in Fig. 11, the system usability was proven to have been improved gradually as the system evaluation progressed. However, the evaluation scores of the ‘Human resources management’ module were slightly lower than those of the other modules. With reference to the evaluation report, the users felt that the input task is an excessive burden, which is derived from the detailed classification of the work attribute.

To resolve the raised issue, the determination of work attributes has been so simplified that only two classifications of information are requested as input values; design phases and additional work caused by change orders.

5. Conclusions

This study developed a web-based system for integrated design management (IDMS) which consists of 8 modules including the design document, schedule and quality management. The significant feature which differs from the

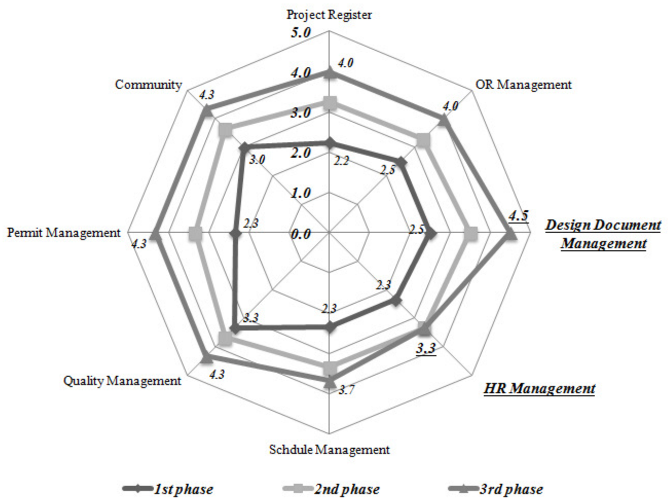

Fig. 10 Evaluation on improvements by system usage

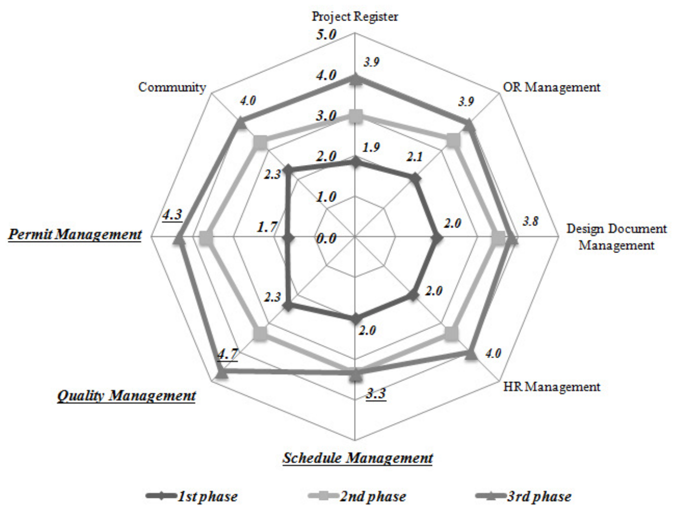

Fig. 9 Evaluation on process implementation

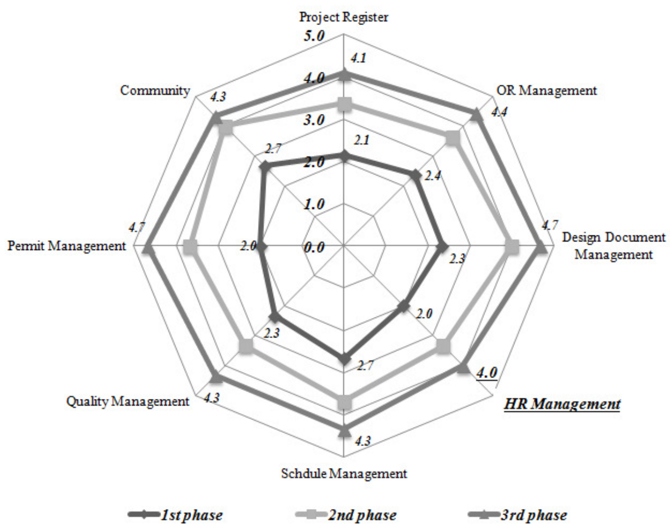

Fig. 11 Evaluation on system usability

previous studies is that the design professionals have participated from the early stage of the system development throughout the system implementation. The other unique characteristic is that the actual design project was applied as a test bed in the final verification stage. The research team applied the actual data which had been generated during each business process, and the effectiveness of the system implementation was verified.

The IDMS developed in this study was designed to improve the interoperable communication among design professionals and to respond to the changes of the project conditions. Since the IDMS was developed on the basis of a web-based system, the users could take advantage of many aspects such as easy access to the system, enhanced collaboration among users, etc. Recently, due to the emergence of IBMs, the DMS should adapt to the change of the actual design process and improve the function of the system through future researches.

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