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Integrated System Development Methodology Design And LCC (Life Cycle Cost) Data Process

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Abstract

The Architecture/Engineering/Construction (AEC) industry is one of the multidisciplinary domains in which collaboration among related parties is of utmost importance[1]. Despite the intense flow of information between design and LCC (Life Cycle Cost) professionals, there is a lack of research to better understand and manipulate these processes. Architecture design and LCC management is a process of planning a tangible building and cost on a tangible land through intangible work. Due to this characteristic of design work, conventional design management was conducted around the drawings as the final outcome, but actual individual processes of design and LCC (Life Cycle Cost) planning for facility were excluded. As a result, design work and LCC planning completely depended on the individual abilities and experiences of each architect and LCC planner. Even organization of information required for design and LCC process are considered to belong to the domain of individual ability. Therefore, this study proposes an integrated system development methodology of design and LCC process for an information oriented design and LCC management system, which allows architects and LCC planners to easily access information to be provided in each design stage and its relevant LCC planning process, and for design and cost management companies to improve the performance through the systematic storage and usage of data after the completion of an educational project. This research analyzes actual design and LCC processes in currently active companies and proposes a standard design and LCC process, and then examines input and output information for each task in the process in order to propose an information oriented standard design and LCC process. Based on this, Data Flow Diagram (DFD) and Entity Relationship Diagram (ERD) is designed for an information oriented design and LCC management system.

Keywords: Architectural Design, DFD (Data Flow Diagram), ERD (Entity Relation Diagram), LCC (Life Cycle Cost), Process

1. Introduction

The Architecture/Engineering/Construction (AEC) industry is one of the multidisciplinary domains in which collaboration among related parties is of utmost importance[1]. Despite the intense flow of information between design and LCC (Life Cycle Cost) professionals, there is a lack of research to better understand and manipulate these processes. Architecture design and LCC management is a process of planning a tangible building and cost on a tangible land through intangible work. Due to this characteristic of design work, conventional design management was conducted around the drawings as the final outcome, but actual individual processes of design and LCC (Life Cycle Cost) planning for facility were excluded. As a result, design work and LCC planning completely depended on the individual abilities and experiences of each architect and LCC planner. Even organization of information required for design and LCC process are considered to belong to the domain of individual ability.

Current planning practice takes little account of the interdisciplinary, iterative nature of the building design and LCC process. This leads to a compromised process containing inevitable cycles of rework together with associated time and cost penalties in both design

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and construction[2]. Design processes disproportionately influence the life-cycle value of the resulting products[3]. Although the total cost of design is relatively small, the design phase of an A/E/C project greatly influences the total project value. Also, the final project value generally increases with the number of different design options considered[4]. Research leading to new information management systems can improve design and LCC processes to increase project value. A/E/C struggles to collaborate around processes, share processes, and understand processes effectively and efficiently as project complexity increases[5]. Designers and LCC planners struggle to collaborate within projects, share processes across projects, and understand processes across the firm or industry [6].

These days, interest in the assessment and standardization of design and LCC processes is increasing among the large construction management companies, and there have been attempts to build this standard process into a system. In academic circles as well, there have been studies regarding the idea of approaching management from the perspective of information management[1,2,7]. LCC is a technique to estimate the total cost of ownership and represents the overall costs spent in course of the building's whole life cycle. There is a part of Whole Life Cost (WLC)[8]. LCC process usually includes the following steps: planning of LCC analysis, e.g. definition of objectives, selection and development of LCC, e.g., cost breakdown structure, identifying data sources and contingencies, application of LCC, and documentation and review of LCC results[9]. Even though these past studies surveyed the status of design management and techniques from theoretical viewpoint, they fell somewhat short in understanding the design and LCC process. Moreover, even though some studies defined important checkpoints in the progress of design work and the flow of knowledge and information, studies on actual design and LCC performance procedures and the generation and delivery of the information related to this were somewhat insufficient. Therefore this study analyzed design and LCC work processes at the working level through actual results data. We examined the work definitions by subcategories of actual operations, along with the input and output information for each process, so as to propose information oriented standard design and LCC process for the construction and maintenance and then supply a preliminary research backup for the future system development.

While it is possible to gradually improve the quality of designer and LCC planner who works on different outputs through education and training, the role of systematic management should be to guarantee similar levels of quality from different architect and LCC planner with similar abilities in similar projects. Therefore, efficient design and LCC plan, outside the domain of individual abilities, can be made possible simply by providing the appropriate tools for systematic management.

This study proposes an integrated system development methodology of design and LCC process for an information oriented design and LCC management system, which allows architects and LCC planners to easily access information to be provided in each design stage and its relevant LCC planning process, and for design and cost management companies to improve the performance through the systematic storage and usage of data after the completion of an educational project. This research analyzes actual design and LCC processes in currently active companies and proposes a standard design and LCC process, and then examines input and output information for each task in the process in order to propose an information oriented standard design and LCC process. Based on this, Data Flow Diagram (DFD) and Entity Relationship Diagram (ERD) is designed for an information oriented design and LCC management system.

2. Research Flow, Method and Scope

The design and LCC progress are analyzed by experts from major South Korean construction management companies. A standard design and LCC management process and the input and output information for each process of subcategories are derived based on an information flow oriented design and LCC process. The information flow oriented design and LCC management process can be utilized in design and LCC management operations. The research flow of this study is summarized in Figure 1.

We had an effort to propose a process that reflects actual design and LCC operations at the sites. However, many small and medium-sized design and cost management companies does not have an established internal process, or organized data. Therefore, we collected data mostly from large companies, which manage their process in a relatively systematic manner. We collected standard progress schedules and results data from projects of which projects have been completed recently. Among these, we analyzed ten projects with a size of 33,000 square meters or smaller. Many companies do not systematically man-

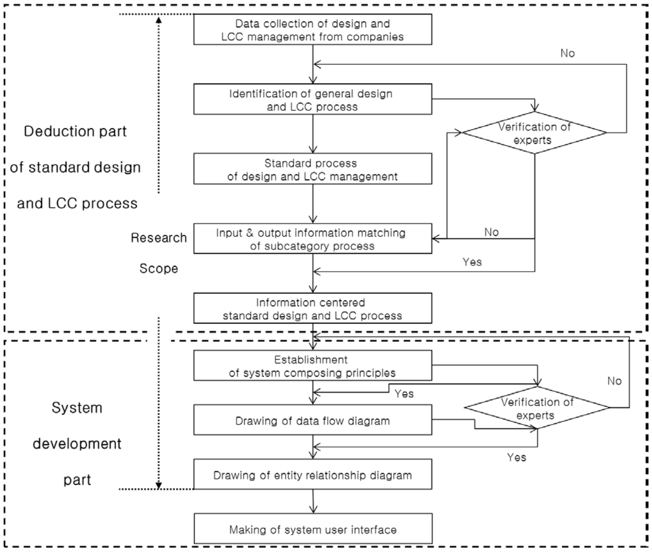

Figure 1. Research flow, method, and scope.

age the process data, we selected and analyzed the nine projects, example apartment, swimming gym, public office, research institute, and office, for which relatively detailed records existed, from six companies.

After sorting the collected data and deciding whether or not to include the tasks performed in each project to the common processes, we proposed a standard design and LCC process through expert verification. Then based on this standard process, we examined the input information required to perform the corresponding tasks for every subcategorized process, and the output information derived as a result of the tasks. After a second expert verification, we proposed the final information flow oriented design process. Based on the standard information flow oriented process, we deduced data flow and entity relation for the process. For design and LCC management based on information flow, we established the organization principles of a system that can smoothly support the information generated from the process, and drew up Data Flow Diagram (DFD) and Entity Relation Diagram (ERD) for each functional element comprising the future system development.

This study divided the hierarchy of the process largely into three levels: micro processes for units of actual operations, middle processes for units of design and LCC management where major decisions are made, and macro processes for units of operations from contractual viewpoint at the highest level. The level of macro processes was divided into four steps, which are widely used by most companies: schematic design, plan design, basic design, and performance design. Here, "schematic design" refers to planning operation, and "basic design" refers to intermediate design. The main process, which is the unit of design and LCC management, was not set at this stage, but was examined in later during the process information examination step. For the micro processes, we focused on the quantities and types of operations, and the sequence and relationships between mentioned micro operations.

3. Information Oriented Standard Design and LL Process

3.1 Proposed Standard Design and LCC Process

After preparing the total operations list, we deduced a summarized operations list as one process to propose a standard design and LCC process. Different expressions used by architects and LCC managers for the same operations were standardized for the sake of general agreement, after listening to the opinions of experts. Furthermore, we identified simultaneous processes, repetitive tasks, and tasks that require additional decision, and reflected them on the standard design process. In this process, we grouped some tasks from the total operations list into one micro process if we thought that it was more reasonable in consideration of the characteristics of the tasks, or if tasks were duplicated. Moreover, we added tasks necessary for general operations, although they were not expressed in the analyzed results data. In this way, we were ultimately able to summarize the total micro processes. We present the proposed standard design and LCC process derived from this analysis in a DFD, which can be understood intuitively. Figure 2 is DFD of the proposed standard design and LCC process at the design development stage.

For the design development stage, we can see that the outputs from the previous plan design stage and the requirements of the client are reviewed and summarized before the design development is started, and the design of the LCC engineering company also begins simultaneously with the design progress. When the design development finished, the basic design drawings, schematic construction LCC, and schematic specifications are prepared and ultimately approved by the client. When the drawings are approved, the architect delivers the basic design drawings while at the same time pursuing the deliberation, approval, and licensing by government offices. In this stage, the basic design data must be summed up before the actual design

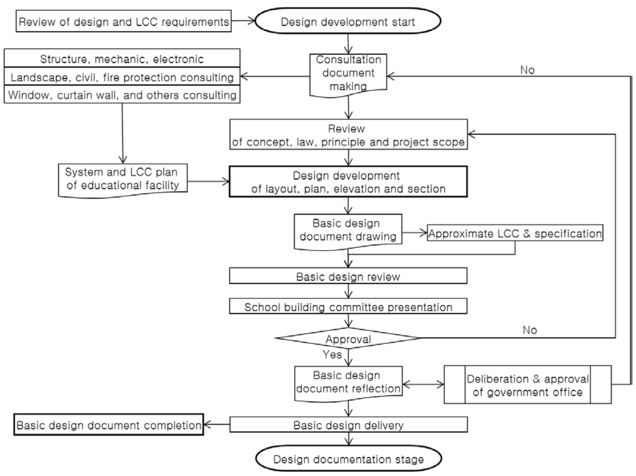

Figure 2. DFD of the proposed standard design and LCC process at the design development stage.

stage begins, although this is not carried out systematically in many design and LCC companies. The proposed standard design process is the most basic process regardless of project type, and can be partially modified for actual application to a specific project such as educational facility contracted and delivered by BTL, depending on the circumstances and conditions of the project.

3.2 Examination of Information of Each Process

The expression format of the proposed standard design and LCC process is effective for graphical representation of the design and LCC process, and understanding of the overall progress. However, if we are to implement the process defined by the relationships between activities into a system, the connections between activities must be reset whenever activities are added or deleted to define another design process. To solve this problem, we examined the input and output information for each micro process, and reconfigured the total design and LCC process in such a way as to define connections between activities through the connections between the corresponding pieces of information.

This study defined the micro processes, which are units of actual operations in a design project at the lowest level of the main category of processes, and examined the input and output information for each micro process based on the reclassification mentioned above. Table 1 is an excerpt for the basic design and LCC process part in the list of input and output information for each micro process.

As shown in Table 1, there is no limit to the number of micro processes that can linked to one piece of input information, but there can be only one micro process linked to one piece of output information. This can be understood from the perspective of the creation and use of information. Input information is the output of the previous process, and different tasks may require the same information. On the other hand, if the same information is output from different processes, it can cause confusion when saving the information and it is difficult to determine from which process the information was generated. For example, the draft drawings of a basic design are developed and changed along with the progress, but they must be differently expressed, e.g., as layout review draft, floor plan review draft, and so on. Likewise, even if the same information is developed along with the progress, the changed information must be named differently.

The information oriented standard design and LCC process proposed in this study has many more pieces of information named “review” and “plan” than is normal in conventional design operations. The reason for this is that we want to express the content of implicit or oral discussions resulting from actual design and LCC operations in a form that can be managed on a system. This study defined the micro processes, which are the units of actual operations in a project, and examined the input and output information for each micro process based on the reclassification described above.

4. Data Flow Diagram and Entity Relationship Diagram for System Development

In order to implement an actual design and LCC management system from the derived information oriented standard process, we need to design DFD and ERD that can systemize information flow during the process. Basically, a process begins when the previous process generates output information, which is then provided to the next process as input information. If there is one person in charge of a process, the person in charge generates output information and saves the final version in the system, and it is automatically delivered to the following process as input information.

4.1 DFD of Design and LCC Management System

A DFD is a graphic expression of the definitions of data connections and movements for each function necessary

Table 1. Input / output information of micro level during basic design and LCC process

Middle Level Processes	Micro Processes	Input	Output
Preliminary Design and LCC	Legal review of the plan	-Legal review checklist -Plan design ground and elevation drawings -Alternatives for machinery, electricity, and structure plans -Material system list -Calculation sheet for estimated LCC -Main material review report	-Detailed legal review report (Plan)
	Technical review of the plan		-System plan report
	Review of architecture plan, layout, and spatial organization	-Plan design ground and elevation drawings -Alternatives for machinery, electricity, and structure plans -Plan design model -System plan report	-Basic design draft -Program review report
	Internal and external design drafting	-Basic design draft -Program review report	-Basic draft drawings for each part of building -Main material finishing sheet
	Budget review	-Basic design draft -Basic draft drawings for each part of building -Main material finishing sheet	-Approximate LCC review report
Design and LCC Development	Layout	-Basic design draft -Main material finishing sheet -System review report -Detailed legal review report (Plan) -Structural calculation report -Divisional load calculation report -Equipment review report	-Layout review draft
	Floor plan		-Floor plan review draft
	Elevation		-Elevation review draft
	Section		-Section review draft
	Engineering discussion		-Estimated load calculation report -Structural calculation report -System analysis results report -Approximate LCC calculation report -Equipment drawing review draft
Drawing	Preparation of basic design drawings	-Layout review draft -Floor plan review draft -Elevation review draft -Section review draft -Main material finishing sheet -Guidelines to the preparation of basic design drawings	-Basic design drawings -Approval and license documents -Perspective drawings
	Preparation of engineering drawings	-Basic design drawings	-Engineering basic design drawings
Documentation	Calculation of approximate LCC	-Basic design drawings -Basic design drawings of engineering part -Calculation sheet for estimated LCC -Guidelines to construction LCC estimation	-Tentative construction work statement -Unit price comparison sheet -Calculation sheet for estimated LCC by division
	Preparation of schematic specifications	-Basic design drawings -Basic design drawings of engineering part -Calculation sheet for estimated LCC -Calculation report for approximate LCC -Tentative construction work statement -Guidelines to the preparation of specifications	-Schematic specifications -Plan design explanation report -Main materials and equipment plan

Middle Level Processes	Micro Processes	Input	Output
Discussion with client	Presentation	-Perspective drawings -Schematic specifications -Plan design explanation report -Main materials and equipment plan	-Client explanation data
	Approval	-Client explanation data	-Approval for basic design and LCC
Governmental deliberation and approval	Legal review and analysis	-Legal analysis checklist	-Legal analysis report
	Preparation of drawings and documents for deliberation/ approval/license	-Approval and license documents	-Approval and license drawings and documents
	Modification and revision of drawings and documents	-Approval and license drawings and documents	- Delivery drawings and documents

to implement a system. This is one of the most important parts of the system design process, because the structure of each function of the system to be developed is graphically illustrated. Therefore, the data defined in the DFD of each function must be logically interconnected with the database. Figure 3, 4 and 5 are excerpts showing the key points of the DFD design for the system. Figure 3 is the system's default information setting DFD, which sets the data required for the registration of users and the information setting of the standard design and LCC process which will be provided by default. This data is set and stored in each server of the web-based system, and remains saved in the system regardless of the project.

After the system's default information is saved, a project is set up, as shown in Figure 4. The basic project information must be entered, and this information is saved as metadata in the file database, for easy retrieval in the event that a similar project happens in the future. Furthermore, for each project, the design and LCC process can be reset to correspond with the project, on the basis of the standard process and default setting data, which will be turned into a design and LCC process database for the project.

Figure 5 defines the registration and confirmation flow of the information generated and delivered, which can be generally divided into four information types: drawings, meeting minutes, images, and other data. The system has been designed in such a way that as soon as any information is saved in the file database, it will immediately be delivered to the persons in charge of all corresponding and connected operations in the process, on the basis of the input and output information in each micro process defined in the standard process.

4.2 ERD of Design and LCC Management System

The ERD is a graphical representation of the relationships among entity types derived from each analysis of operations. This is the most important notation and output describing the correlations between data flow and process in actual projects. ER method is a popular data modeling approach to database design that was first published by Peter Chen in 1976. The ER approach is a high-level data modeling language that can be used to understand and complex systems[10]. What we wanted to implement most on the system is the connections and configuration of design and LCC process, project, and users based on information. To this end, we defined all list of information as the common denominator rather than as a specific project. Further, we linked each micro design and LCC process to the person in charge, so that the confirmation and storage of information required by the architect and LCC manager will be conducted systematically. Figure 6 is a partial illustration of the ERD of the system.

The ERDs among the design and LCC progress information related to the storage of drawings include the same entities (example project entity, process entity, user entity, I/O list) as the system default ERD. Another entity that needs to be noted among the drawing storage ERDs is the drawing information group. The drawing information group consists of drawing information entity, drawing file entity, drawing quality management information entity, and data transfer information entity. Every piece of process information including drawings and LCC data is set in the total I/O list. Therefore, every piece of information is assigned to each micro process operation of the cor-

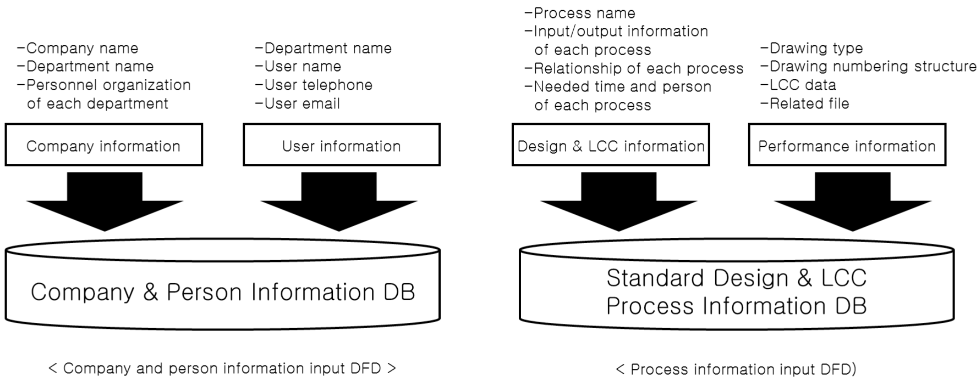

Figure 3. Default information setting DFD.

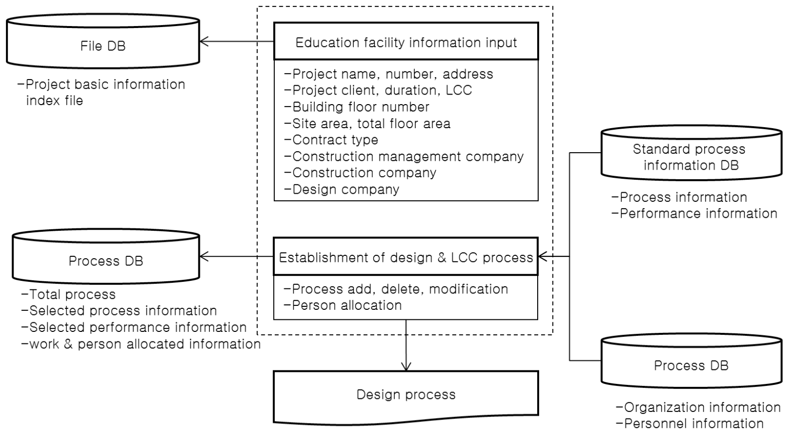

Figure 4. Project and process making DFD.

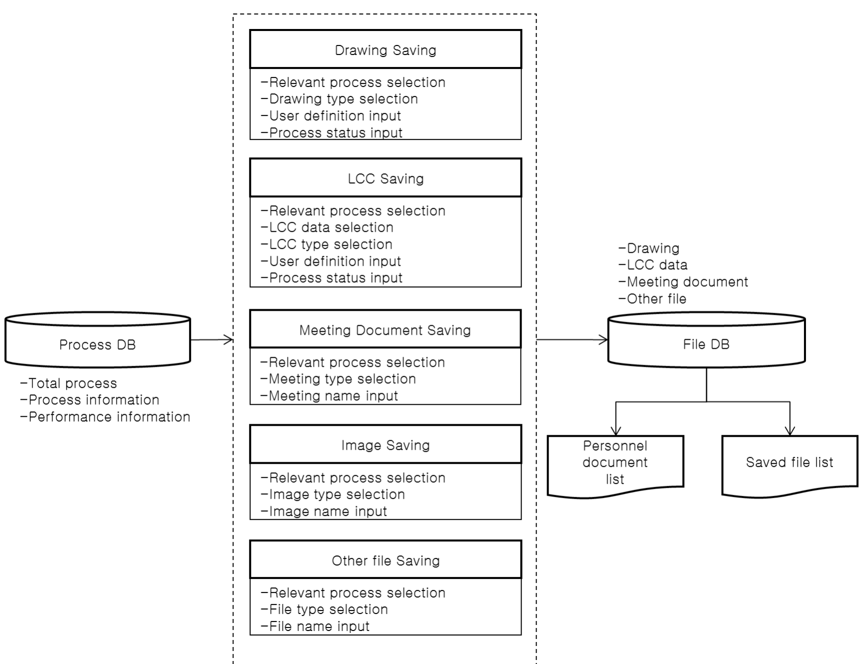

Figure 5. Information saving DFD.

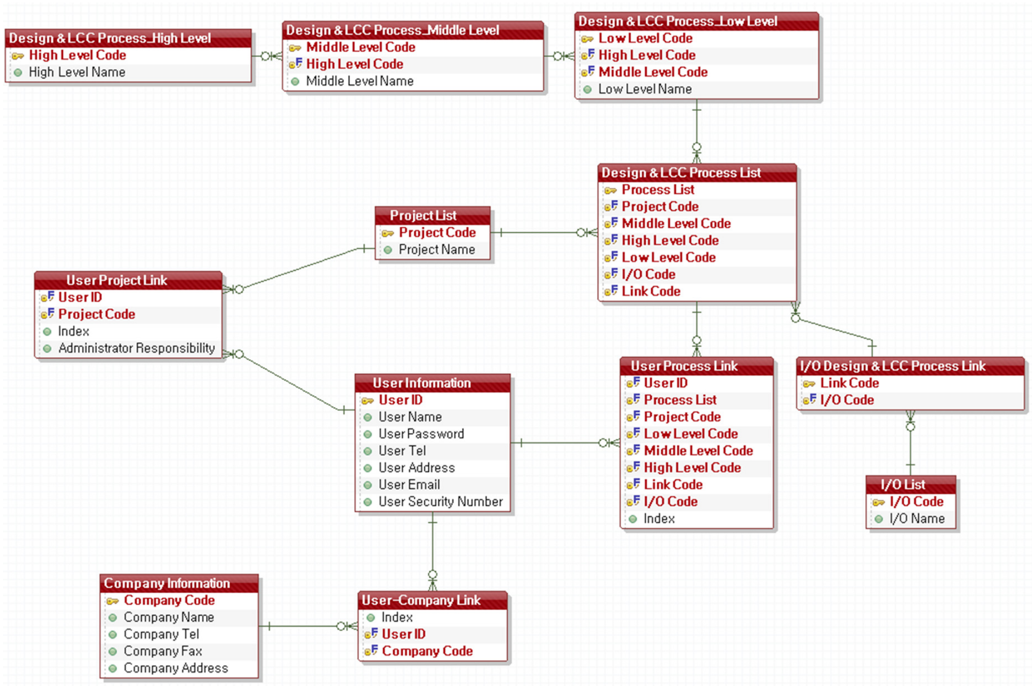

Figure 6. Basic ERD of the system.

responding project, along with the corresponding code information. As there is a person in charge set for each process, each drawing and LCC data contains information about the person in charge as well.

Data transfer codes are set to prepare for cases when data must be sent to other subcontractors during the process of collaboration. In particular, drawing quality management codes were also set because drawings are the target of quality management. Even though the standardization of drawing information number settings were not set up in detail because they were not included in the scope of this study, we also included code assignment for drawing files and automatic naming of drawings in the drawing storage ERD to prepare for additional studies, or the possibility of government guidelines regarding drawing standardization in the future.

5. Conclusion

Until now, there are no clear standards for design and LCC process in the construction management companies. Design and LCC operations depended on the past experiences of the persons in charge, and design and LCC management mainly depended on the drawings and LCC results data. Recently, interest in a standardized process is raising among the large construction management companies, but they are pursuing their own standards, which is an activity that is far from one standard covering the entire process. This study proposed a standardized design and LCC process, which can be used for construction management companies to improve organizational efficiency by enabling effective collaboration in large projects participated in by many players, and for architects and LCC managers to improve their personal abilities by enabling consistent performance regardless of the company they belong to.

This study not only proposed a standard process, but also examined the information produced and exchanged in the standard process. If a system is constructed on the basis of this information oriented standard process, DFD, and ERD, a process can be defined by interconnections between required information and the output of each task, instead of interconnections between operations, giving flexibility to the actual use of the standard process.

In the future, we may be able to develop a design and LCC management system based on this study, and improve the international construction management competitiveness through the systematic storage of design and LCC information, flexible application that is adapted to the characteristics of the project, and consistent facility maintenance quality. The methodology of this study can be applied identically to all participants in construction industry, from design, cost, and engineering companies to construction management companies.

6. Acknowledgment

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