THE DEVELOPMENT OF AN AUTOMATED COST ESTIMATING SYSTEM USING 3D CAD AND RELATIONAL DATABASE

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Abstract: The successful construction of a facility highly depends on adequate planning, design, and control of the construction process. In an effort to better monitor and control the construction project, the construction industry has been engaged extensively in the development of a new computerized design and management system applying the concept of Computer Integrated Construction (CIC). The CIC is a new trend to improve the efficiency and accuracy of the entire construction process by integrating different types of information within computer based environment. The primary objective of this paper is to propose a model for the development and implementation of an automated cost estimating system using 3D CAD and relational database under the CIC system environment. The developed system automatically generates the quantities of both elements and work items directly from 3D CAD object model, and provides the cost estimating information including project and home office overheads, and profit of the entire construction work. Conclusions are made concerning the value of the effectiveness of the automated cost estimating system developed. Finally, it is anticipated that successful implementation of the automated cost estimating system presented in this paper would be able to bring the significant improvement of productivity and quality in both design and construction phases, and increase the efficiency of construction management as well.

Keywords: CIC, Information Technology, Cost estimating, 3D CAD, Relational database

1. INTRODUCTION

During the past decades, the construction industry has witnessed dramatic developments in electronic data generation and management technologies, and it has increasingly applied computer-based aids such as Three Dimensional Computer Aided Design (3D CAD) and relational database, and other computer assisted management tools. Construction has multi-stage production activities and a great amount of information is created and gathered throughout the construc-

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tion project life cycle; planning, design and engineering, procurement and construction, and operation and maintenance. However, the information produced in each phase has not been adequately integrated and managed causing both unnecessary overlapping works and loss of productivity during the construction [1].

To overcome this problem and better monitor and control the entire construction process, the construction industry has been thus engaged extensively in developing a new computerized design and construction management system using Computer Integrated Construction (CIC) and Information Technology (IT). Such management tools would improve the efficiency and accuracy of the entire construction process by integrating different types of information within computer-based environment. Especially, cost estimating that converts design information into construction information could be a core among the whole information related to construction projects. This paper mainly focuses on presenting the research efforts for the development of an Automated Cost Estimating System (ACES) using 3D CAD and relational database under CIC environment. The 3D CAD and relational database were used for:

1) Preparing architectural drawings
2) Defining the libraries for building shape, and its structural and finish elements
3) Taking off quantities for the elements and work items
4) Conducting actual cost estimating works
5) Reporting bill of quantity for bid preparation.

The developed ACES was applied and examined to a steel reinforced concrete apartment, and the automated cost estimating results were compared with those of a conventional method. Finally, it is anticipated that successful implementation of the ACES presented in this paper would be able to bring the significant improvement of productivity and quality in both design and construction phase, and increase the efficiency of construction management as well. Recommendations and future research works for further development of the system are also presented in this paper.

2. RESEARCH BACKGROUND

2.1 Construction Integrated Construction System

As previously mentioned, there is no doubt that the CIC is an effective management tool for improving the efficiency and accuracy of the entire construction process. Several researchers have defined the meaning of the CIC in various ways. For example, Sanvido defined the CIC as “a goal to make better use of electronic computers to integrate the management, planning, design, construction, and operation of constructed facilities” [2]. Recently, its definition has been extended as “the integration of corporate strategy, management, computer systems, and information technology throughout the project’s entire life cycle and across different business functions” [3].

That is, the CIC is a good project management and communication tool by which all the information produced during the entire project life cycle can be efficiently shared, managed and controlled among various business functions within an organization (Fig. 1). The ACES presented in this paper has been developed and successfully implemented under such CIC environment.

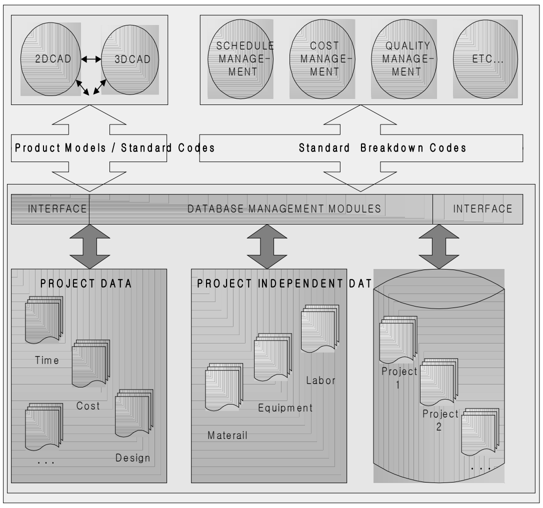

Fig. 1. Conceptual Diagram of a Computer Integrated Construction System Environment

2.2 Construction Information Breakdown Structure

A standardized construction information breakdown structure can be defined as a unified language (code structure). It is required to increase the efficiency of information flow and project management in especially design and construction phase. By establishing the construction information breakdown structure, the design and construction information can be systematically managed and controlled. It can be operated in a variety of forms and should be able to be reorganized adequately, depending on the requirements and aims of the participants including owner, architect/engineer, and contractor in a particular construction project.

In this paper, a standardized construction information breakdown structure for a steel reinforced concrete apartment construction was established for the development of the ACES to be operated under the CIC environment (Table 1). The facet breakdown structure of International Standardization Organization (ISO) and CSI Masterformat were mixed to establish the construction information breakdown structure presented in this paper. As shown in Table 1, the construction information breakdown structure was classified into several fields so that the construction information needed in each phase over the entire project life cycle can be easily retrieved, sorted, and reorganized in accordance with the requirements and aims of the participants.

Table 1. An established Construction Information Breakdown Structure

	Project	Facility	Zon	Building	Section	Spa	Hou	Ar	Pa	Ty	Work It			Resour
											1st Lev	2nd Lev	3rd Lev	
Figures	5	4	3	4	3	6	3	4	4	3	4	2	2	5
Initial	P	F	Z	B	C	S	U	A	P	T	AR			M ,L
Cod	P005	F001	Z01	B129	C01	S130	U101	A83	P21	T01	ARD	A2	00	M00
Desc	Name	APT	1st Zone	129th Building	Steel Beam	1st Floor	101st House	27m²	Column	Cubic	Form /Finishing /Vertical			Woo

2.3 Sharing Information in Design and Construction Phase

Generally speaking, construction cost estimating is to know beforehand the expected cost of a project, in varying degrees of accuracy, at different phases of the project by taking off the quantities and calculating the unit prices[4]. It plays a very important role in the decision making process that leads from concept to completion of a project. The resource information including material, labor and equipment for conducting actual construction works is also required for accurately measuring the quantities and the unit prices. By using 3D CAD and relational database, the quantities and the unit prices of both elements and work items can be directly measured based on the design information, and they can be used for more effective schedule and cost planning and control in construction phase.

Entity Relation (ER) diagram shown in Fig. 2 represents the information flow and attributes in each design, estimating and construction phase. As shown in the ER diagram, the attributes of basic quantity information in the design phase for cost estimation include the data from project ID to element type, based on the established construction information breakdown structure. Attributes such as material type, dimensions and area of each element are then followed. All attributes are defined and arranged as fields in the database table.

Once the quantity take off of all elements and work items is done using basic quantity information (attributes) measured from the 3D CAD object model and the bill of quantity for bid is then created by connecting the quantity information with resource information in construction phase.

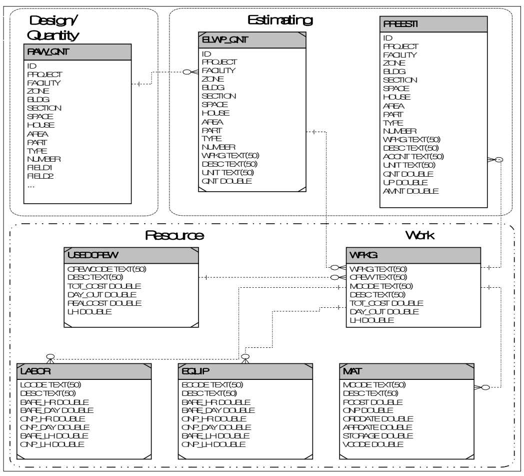

Fig. 2. Entity Relationship Diagram by Construction Phases

3. REPRESENTATION OF DESIGN INFORMATION

3.1 3D CAD System

Architectural DeskTop (ADT) as a 3D CAD application was used for effectively representing the graphic information in design phase. Fig. 3 shows a 3D object model for the steel reinforced concrete apartment selected for embodying the ACES. Representing all element libraries and connecting the design information with schedule or cost information in construction phase can be easily done by using the ADT. The ADT can represent the basic quantity information of 3D object library components as attributes in a table form (Fig. 4).

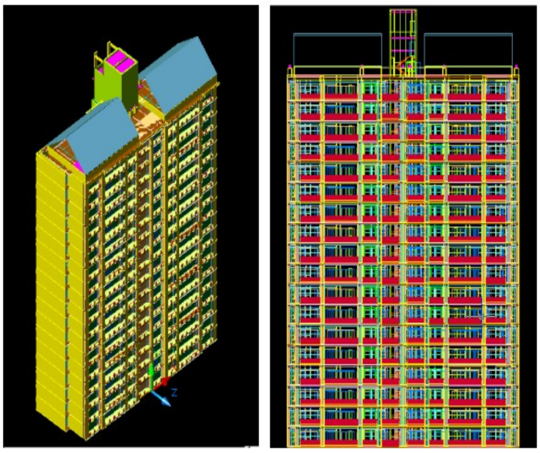

Fig 3. 3D Object Model of an Steel Reinforced Concrete Apartment Using ADT

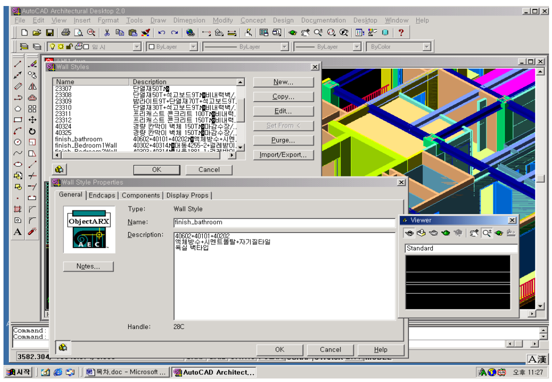

Fig. 4. Representation of Wall Attributes Using ADT

3.2 Definition of Design Elements

In most commercial cost estimating software, estimators should have in-depth knowledge in both two dimensional drawing and specification, and put the design information revealed from the drawing and specification directly into the cost estimating software. The cost estimating software then takes off the quantities by the formulas that it originally has.

The quantities calculated by the cost estimating software are classified into two parts: structures and finishes. The structural quantities are calculated by elements such as foundation, column, beam and wall etc., while the finish quantities are taken off by spaces such as room or kitchen. Because the basic concepts of quantity take off process for structures and finishes are different, there have been some limitations in integrating design and construction information for effective project management and controls under a computerized system environment.

In taking off the quantities, the ACES regards both structures and finishes as an object model (element) and defines the design attributes of each element (Fig. 5 and 6). The elements and their attributes are then recorded in the database table for subsequent cost estimation processing. For example, the structural element as an object model would include foundation, column, beam and wall, and such elements are composed of the quantity information such as steel frames, concrete, reinforcing bars and forms. In order to take off the quantity of each structural element, the element has its own design attributes according to the shape; height, length, and material type, etc. Fig. 5 shows an example of definition and design attributes of a cubic column.

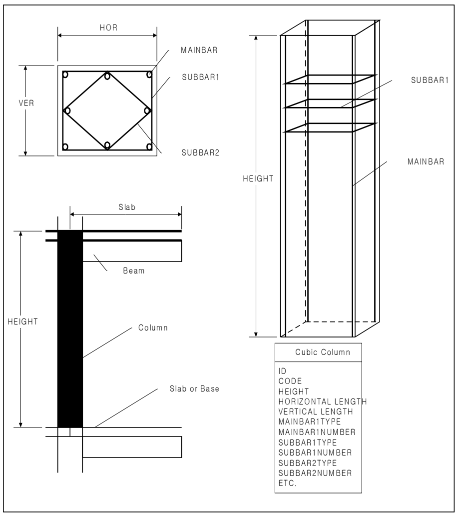

Fig. 5 An Example of Definition and Design Attributes of an Element (Cubic Column)

The quantity information in finishes is seldom applied to any specific elements as in the case of the structures, and can be dealt with an object model, which is changed according to the type and variation of the finish element. When installing wallpaper on a wall, if there are any changes in the wallpaper object due to any windows on the wall, the wallpaper objects in all possible cases should be defined, and their attributes such as height and length need to be identified for accurately taking off their quantities as well. Fig. 6 shows several examples of the structural and finish elements and their attributes.

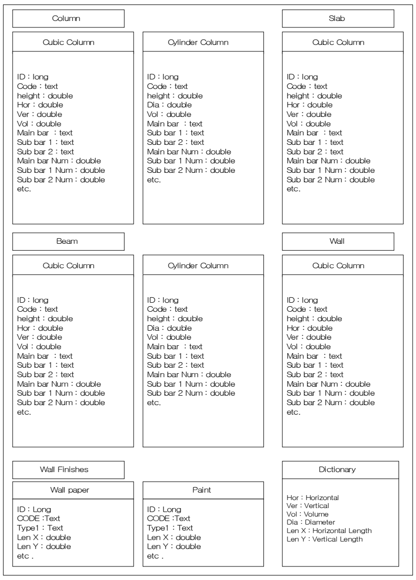

Fig 6. Representation of Elements and Their Attributes

3.3 Quantity Information Table

A quantity information table represents the basic quantities of the structural and finish elements defined as object models in the design phase using the ADT, and lists their attributes. Types of each element are set on rows and its attributes are arranged on columns (fields) in the database table. For example, the 53rd type of a reinforced concrete beam (element; P223) and its attributes are set on the table as shown in the 1st line of Fig. 7. In this case, field 1, 2, 3 indicate the beam length (3000㎝), width (350㎝) and height (500㎝) attributes, respectively. The types of main and sub bars and their numbers are also shown in the fields of the database table and these attributes are then directly used to take off the quantities related to the beam.

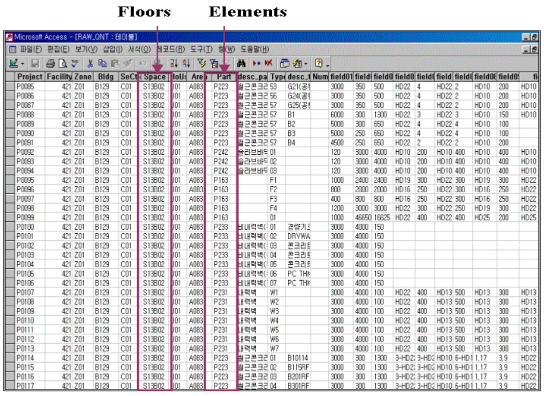

Fig. 7 Basic quantity information Created in Design Phase

4. IMPLEMENTATION OF ACES

4.1 Cost Estimating Process of the ACES

The developed ACES takes off the quantities in the structural/finish elements and work items, and reports some forms of bill of quantity as well. Then, the results can be used for the effective cost and schedule management and controls in construction phase by querying the preferred field codes, according to the requirements and aims of users. Fig. 8 briefly describes the entire cost estimating process of the AES. First, once the basic quantity information is gathered from the 3D object models (elements) created in design phase, the quantities of each structural and finish element are taken off. Such quantity information includes the volume of concrete, area of form, type and length of reinforcing bar, and horizontal and vertical length of finishes and so on. Second, the quantity information of the elements is then diverted into the work items, and the unit prices of resources such as materials, labors and equipment including overhead cost are applied to the quantity information of the work items. The quantity or cost information by elements, work items and floors can be easily identified by manipulating the fields of the database table, according the preference of the users. Finally, the ACES reports some forms of bill of quantity (Fig. 8).

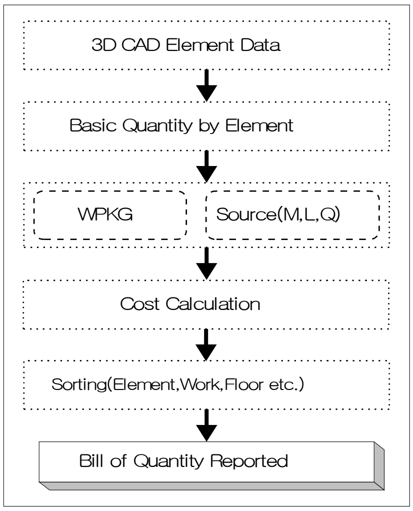

Fig 8. Entire Cost Estimating Process by ACES

An operating module of the ACES consists of several steps; 1) user registration and project selection (Fig. 9), 2) quantity take off by elements and work items through data processing (Fig. 10), 3) creation of reports of bill of quantity by applying the unit prices to the quantity information (Fig. 11).

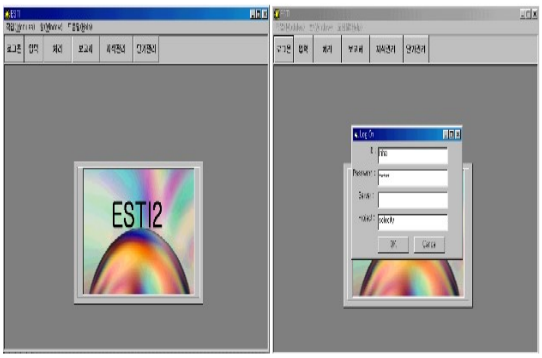

Fig. 9 User registration and Project selection

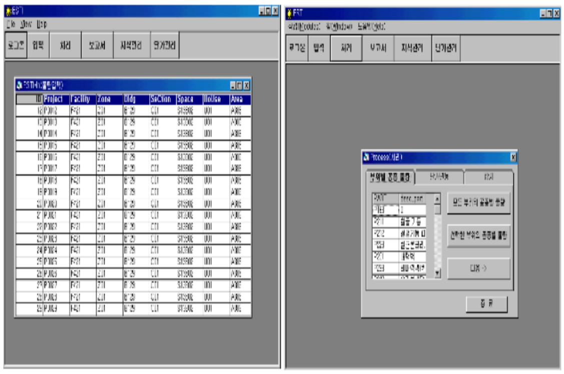

Fig 10. Quantity Take off by Elements and Work Items

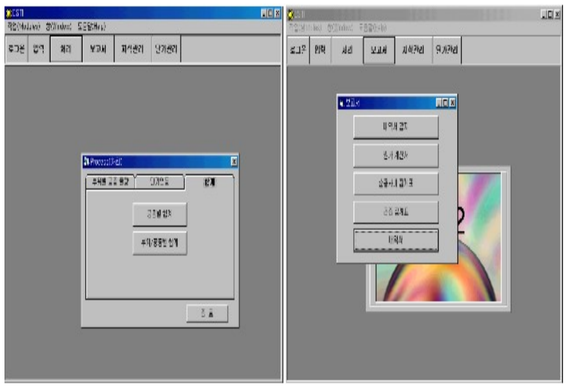

Fig 11. Cost Estimating and Report Functions

4.2 Quantity Take off Table and Reporting Bill of Quantity

The basic quantity information obtained from 3D object models created by the ADT is directly used as the parameters of functions (formulas) established for creating the specific quantity information tables in cost estimating phase (Fig. 12). With these functions, the quantity information by elements, work items and floors can be represented in the forms of table (Fig. 13). From the tables, the information needed in construction phase can be queried according to the purposes of users. For example, the quantity information queried by floors or elements can be used for schedule management, while the quantity information by the work items can be used for cost management and controls.

Calculating the unit prices can be done using the information provided by owner and commercial cost data. The unit price for a work item is composed of material, labor, equipment, and overhead cost as shown in Fig. 14.

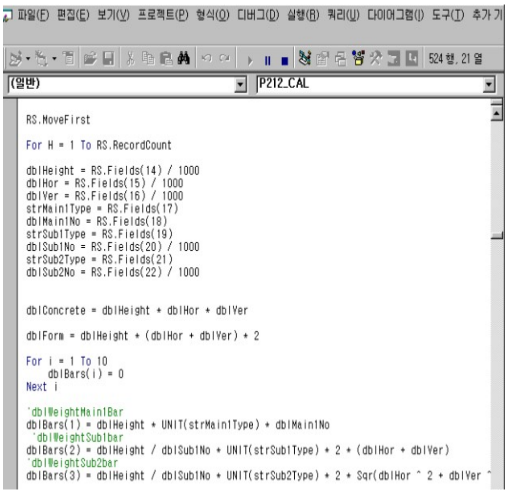

Fig. 12 Functions Defined for Quantity Take off

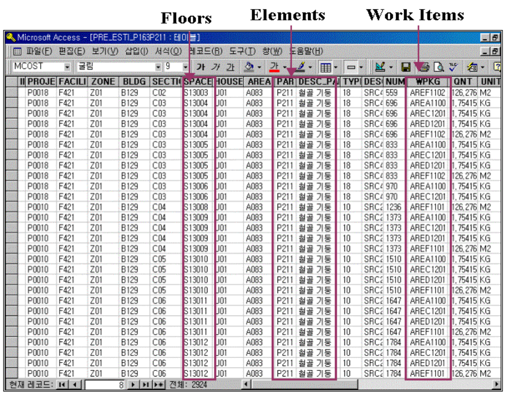

Fig.13 Quantity Take off Table for an Element (Column)

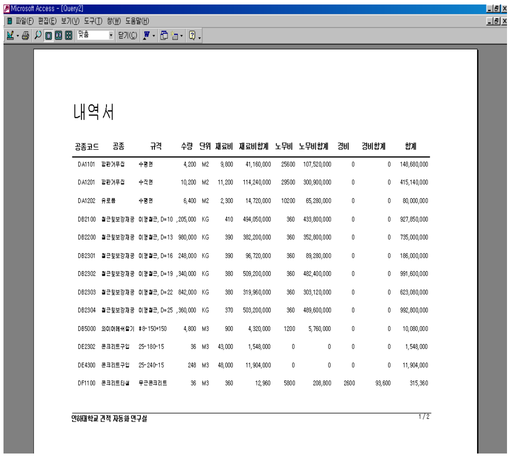

Fig.14 An Example of Bill of Quantity Reported

4.3 Experimental Result of ACES

The developed ACES was examined by comparing the results of quantity take off between the ACES and an estimating expert using a conventional method (Table 2). In the comparison, only the results of quantity take off between the ACES and the conventional method were compared and analyzed because any unit prices can be applied to both methods. As a result, the quantities calculated by the ACES were less than those by the conventional method. There was about 0 to 8% difference in the quantities. It was due to the fact that the ACES took off the quantities based on only visual elements and attributes defined and expressed by 3D CAD, while the estimating expert applied an extra quantities or rates depending on his own experience in taking off the quantities. As a future study, the use of an expert system is thus recommended for more accurate cost estimating using the knowledge base of human experts.

Table 2. Comparison of Quantity Take off Between ACES and a Conventional Method

Element	Work Item	Type	Unit	Conventional Mehtod	ACES	△(%)
Colume	Reinforcing bar	HD22	Ton	78,34	73,54	6,13
Colume	Concrete	25-240-12	M3	304,33	304,33	0,00
Colume	Concrete pouring	25-240-12	M3	304,33	304,33	0,00
Colume	Form	Wood	M2	2667,42	2667,42	0,00
Partition	Dry Wall	T100	M2	3685,50	3671,24	0,39
Porch	Terrazzo Finishing	Grinding	M2	171,36	161,77	5,60
Bathroom	Tile	Slab	M2	123,12	113,83	7,55
Front Door	FSD	900*2100	EA	36,00	36,00	0,00
Bedroom	Wall Paper	Daedong	M2	1282,32	1210,32	5,62
Base	Varnish Paint	H100	M2	429,70	421,06	2,02

5. CONCLUSTIONS

This paper mainly focused on presenting the research efforts for the development of an automated cost estimating system that can be operated under Computer Integrated Construction environment. The ACES was developed using 3D CAD and relational database, and the overall cost estimating process of the ACES was also briefly described in this paper. The developed ACES was successfully demonstrated by applying the system to an actual steel reinforced concrete apartment, which is currently being built. The result of the quantity take off by the automated method was then compared with that by a human expert. For more accurate cost estimating, the use of an expert system shell using the knowledge base of human expert was also recommended in this paper. Finally, it is anticipated that successful implementation and further development of the ACES presented in this paper would be able to bring the significant improvement of productivity and quality in both design and construction phase, and increase the efficiency of construction project management as well.

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