

# Multidimensional Representation of Educational Facility LCC (Life Cycle Cost) Data

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## Abstract

A safe and comfortable study environment enhances educational performance. Thus, effective and efficient school facility management is very important. However, present school management systems are unreasonable because they depend mostly on the decision of the school principal or of non-expert administrators of educational facilities, instead of being based on the reliable Life Cycle Cost (LCC) data or information. The experts are often surprised to see a marked difference between their projected educational facility maintenance cost and the actual cost. The LCC of educational facilities produces a voluminous amount of quantitative data. Much of these data is created during the construction and maintenance phase of an educational facility and is related to cost, time, safety, quality, and administrative information. Recent storage and processing advances in computers increase the opportunity to monitor educational facilities in ways fundamentally different from those of the existing systems. However, the lack of a fundamental model of multidimensional data representation contributes to the inadequate application and implementation of the historical data in educational facility management. Therefore, this research presents a basic method of using data warehousing that will supply objective and reasonable LCC data or information for effective educational facility management.

**Keywords:** Data Warehouse, Educational Facility, Life Cycle Cost, Maintenance Cost, OLAP (Online Analytical Processing)

## 1. Introduction

Establishing an effective and efficient school facility management system is very important because a safe and comfortable study environment enhances educational performance. However, present school management systems are unreasonable because they dependent mainly on the decision of the school principal or of non-expert administrators of educational facilities, instead of being based on the correct Life Cycle Cost (LCC) data or information. The experts are often surprised to see a marked difference between their projected educational facility maintenance cost and the actual cost. The LCC of an educational facility is associated with obtaining, using, caring for and disposing of buildings, including feasibility studies, design, production, maintenance, and demolition; as well as all the support, training and

operations costs generated by the acquirement, use, and replacement of permanent educational facility.

A construction and maintenance cost plan facilitates the selection of the appropriate type of educational facility and of its construction method, as well as of the maintenance programs needed to promote the good performance of the educational facility. The LCC of an educational facility produces a voluminous amount of quantitative data. Much of this data is created during the construction and maintenance of the educational facility and is related to cost, time, safety, quality, and administrative information. Recent storage and processing advances in computers increase the opportunity to monitor educational facilities in ways that are fundamentally different from those of existing systems. However, the lack of a fundamental model of multidimensional data representation contributes

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to the inadequate application and implementation of the historical data in educational facility management. Therefore, this research presents a basic method of using data warehousing to supply objective and reasonable LCC data or information for effective educational facility management.

## 2. LCC Process and Researches Related to Data Warehousing in the Construction Industry

LCC planning must be systematic, flexible enough to handle unique activities, disciplined through reviews and controls, and capable of accepting multifunctional inputs. An LCC plan is a document on project work, from the start of the project to the maintenance of the facility. The life cycle of a project is illustrated in Figure 1.

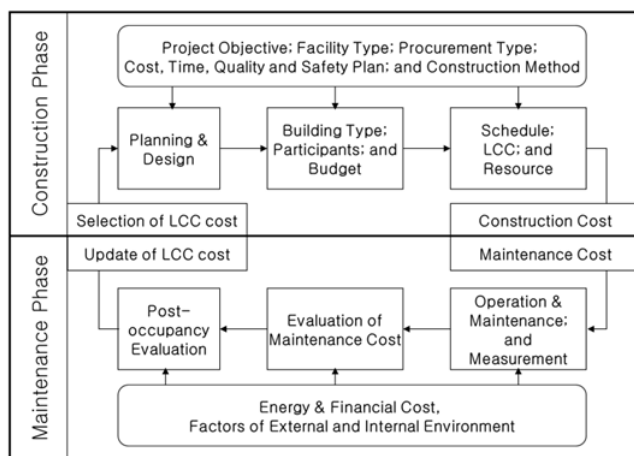


Figure 1. Cycle of project LCC data.

The LCC of a construction project is composed of the construction cost and the operation & maintenance cost, considering very dynamic internal and external conditions. Construction cost planning is performed based on the project objective, facility type, procurement type, construction method, and management plan. The capital investment in an educational facility applies to projects financed with traditional public capital as well as through the Private Finance Initiative (PFI) and Public-Private Partnership (PPP) procurement routes such as Build-Transfer-Lease (BTL) and Build-Transfer-Operate (BTO). Such educational facility construction cost is controlled during construction according to the educational objective and the management plan such as the cost, time, quality, and safety.

A construction project is a dynamic entity that is actively managed under many anticipated and unanticipated risks during construction. The exact LCC plan helps the participants take significant steps forward in attaining better value for their money. It is important to understand that the keys to the successful application of the LCC lie in four areas: the appropriateness of the methodology; the quality of the cost and the performance data used; appropriate treatment of risks and uncertainties; and involvement of the project stakeholders. Most of all, the complexity of the LCC depends heavily on the availability of the cost and performance data attached to many dimensions, including the school class such as an element school, middle school, or high school; the region such as urban, rural, seaside, and island; the type of educational facility such as a classroom, special classroom, laboratory, auditorium, restaurant, and gym; and the year of establishment.

At the start of a BTL educational project, a Specific-Purpose Company (SPC) is organized with an architect, a contractor, a facility manager, and a finance investor. Then an LCC plan is formulated to obtain a new project. A general contractor usually contracts to take full responsibility for dealing with the participants and for managing and coordinating the overall job performance to achieve the planned LCC objective. Construction projects fall into two distinct categories in the relationship between the construction site and the home office<sup>1</sup>. The three basic components of construction management are the head office, the field organization, and the subcontractors, as shown in Figure 2.

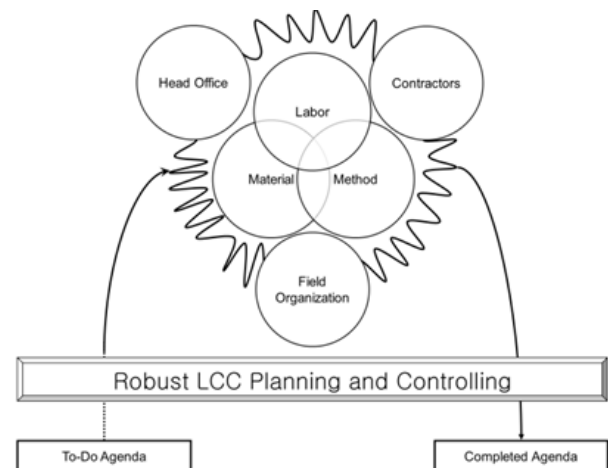


Figure 2. Three main components of LCC planning and control.

The head office should establish the LCC plan for the construction management during the construction phase, and for the operation and maintenance during the maintenance phase. The head office should gather and provide the financial support for the project, and assign field personnel to control all aspects of the field operations and to mediate between the subcontractors and the head office. In addition, the head office provides procurement services for major materials such as concrete, steel, and curtain walls; subcontractors; and equipment rentals such as the rental of a tower crane and temporary offices. Sometimes, the head office reviews the construction method and the estimated cost of change order proposals, and provides other forms of special assistance to the field organization.

Field engineers are trying to increase the reliability of the cost plan for proper labor at a proper time with prepared materials and machines. The field organization performs all the tasks not performed at the home office. The field organization actually applies the construction method, manages and coordinates the work of all subcontractors, and supervises the work of the crew. Field engineers integrate and update the construction cost. They also maintain the progress and record the history of the work to receive and pay out compensation for work performed.

Subcontractors require risk reduction by keeping the crew flow effective and efficient. Subcontractors predict the weather, prepare the employees, and anticipate problems or delays on the daily report. They usually request assistance such as materials, machines, and preceding work completion or clearance of other workers to reduce the anticipated risks before their work begins.

Consequently, the three basic components of construction cost management are the labor (constant labor and effective labor operation), material (timely order and timely supply), and construction method (systematic work relationships). To effectively manage the basic components, the cost plan should be reliable with regard to the space limitation (workable work management) and equipment (suitable equipment). As shown in Figure 2, the 'to-do agenda' can be a 'completed agenda' via the robust cost plan and control by the three main participants of a construction project.

Data warehousing technology has a great potential to bring insight into such construction manager's decision-making process in the construction industry<sup>2</sup>.

A Construction Management Decision Support System (CMDSS) was developed as a data warehouse integrated information management prototype<sup>3</sup>. The CMDSS separated the analysis database from the operational database, and used multidimensional data models for dynamic data presentation. Recognized the lack in the construction industry of a fundamental model of project data representation, and thus, a framework for developing visualization strategies for multidimensional data control was provided, and cost/budget data visualization layouts using a tree-map strategy was developed<sup>4</sup>. A decision support system (DSS) that uses data warehousing and OLAP technology to support site selection for residential housing development also was presented<sup>5</sup>.

A Project-Oriented Data Warehouse (PDW) from the perspective of a construction contractor was presented<sup>6</sup>. The PDW was designed with dimensional data models that consisted of dimension tables for storing general descriptive information, and fact tables for detailing various facts captured in the life cycle of construction projects. A prototype that represents two On-Line Analytical Processing (OLAP) cubes for cost control and manpower allocation was developed and tested across five dimensions: the time, participant, task, product, and cost type<sup>7</sup>. Through several project management scenarios, the authors evaluated the feasibility of mapping OLAP with project management activities. Although data warehouses had been widely used in business decision-making, the effort needed to perform multidimensional data modeling for information integration in the construction industry is still comparatively limited. Therefore, previous researches have not yet addressed well the maintenance cost information of educational facilities using the beneficial aspects of OLAP or the data warehousing technology.

### 3. Data Model for Presenting the Objective LCC of an Educational Facility

#### 3.1 Multidimensional View of the LCC Data of an Educational Facility

An educational facility LCC produces a voluminous amount of quantitative data. Much of these data is created during the construction and maintenance phase of an educational facility and is related to cost, time, safety, and

administrative information. Recent storage and processing advances in computers increase the opportunity to monitor educational facilities in ways fundamentally different from those of existing systems. However, the lack of a fundamental model of multidimensional LCC data representation contributes to the inadequate application and implementation of the historical data in educational facility control methods.

Multidimensional representation of the LCC data of an educational facility has great potential for easing planning, control, and communication difficulties. However, without correct data-gathering, visual explanation, and collaborative decision-making, the massive amount of LCC data available to the participants results in data overload. Therefore, improved multidimensional LCC data of educational facility displays are basically needed to overcome the possibility of data overload.

Resolving the disparity between multidimensional LCC data display needs and the reality within an educational facility project provides many benefits to both researchers and practitioners. These include:

- Simplification of the process of creating LCC data representations;
- Provision to participants of information-rich overviews regarding the status of various LCC aspects of the educational facility;
- Reduction of the time needed to explain and understand various aspects of the LCC of an educational facility;
- Increase of the speed at which day-to-day decisions can be made;
- Reduction of the stress associated with managing large numbers of LCC documents; and
- Improvement of the accuracy and completeness of user-attained LCC data.

Needs-based practices within construction project control promote the reactive development of display methods. For example, the following questions are asked: "What is the budget?" "How much is the LCC of a middle school?" "How often and how many must a certain component of the facility be repaired or replaced?" and "When must those components be repaired and changed?" These query-based explanations only provide answers to specific queries. Current data displays are typically limited to representing one-dimensional or two-dimensional data. These layouts lack the information density required to provide the relationships and perceptual content needed for effective decision-making.

However, in the real world, the LCC data of an educational facility reveal multidimensional features. For example, they answer the following questions: "How much is the repair cost of a pair-wise window in an elementary school established 10 years ago?" "What is the replacement cycle and rate of a toilet bowl in a high school established 20 years ago?" etc. Corresponding to each set of LCC data are the dimensions of the specific school; the school class such as an elementary school, a middle school, or a high school; the region such as a city, rural, seaside, or island region; the work such as water proofing, window and door installation, and toilet bowl installation; and the year of establishment of those products, to identify the duration of use, among others.

### 3.2 Data Model for LCC Management of Educational Facilities

Based on the previous discussions, one of the major knowledge management challenges is the development of a conceptual model of organizational knowledge and its effective implementation using information technology, which would enhance access to the right information at the right time<sup>8</sup>. The LCC planning process descriptively traces what actually happens in the LCC formulation of an educational facility, and determines the improvements needed for its more effective or efficient performance. In addition, the process model prescriptively defines the desired processes and how the system could be performed. The process explains the LCC rationale and establishes an explicit link among processes and the requirements they must fulfill. The process can also provide a semantic connection between the users and the system developers, and models what the system does.

Normally, all the data needed for the LCC plan are available in legacy systems such as educational facility management systems, ERP systems, and PMIS. The LCC data source contains the information that the analysis services use to connect to the source database. It contains the data provider name, the server and database name, and the authentication credentials that analysis services will use<sup>9</sup>.

However, they cannot be properly integrated into the proposed data warehouse system without an appropriate data model. The main objective of a data model is to provide flexible, timely, and secure access to the correct data source to enhance its accessibility. In addition, data modeling can be defined as the process of formalizing data

requirements using a conceptual modeling technique<sup>10</sup>. LCC planners usually refer to general project information and work data in searching for similar LCC data. Thus, the data model is charted to conceptually represent such information for the general purpose of the data warehouse system.

The source data must be contained in a relational database. Analysis Services connects to a relational database using a .NET or OLE DB data provider. The proposed data model is thus developed using the Entity Relationship Diagram (ERD), the dimensions of which are represented with rectangles for the region, school, school class, building outline, budget, and high- and low-level work, and the attributes of which describe the characteristics or properties of the dimensions.

Data models enable the proposed system to represent data or information for access to the right information at the right time from the data warehouse, as well as legacy systems such as educational facility management systems,

ERP systems, and PMIS. We used MS SQL Server 2008 to make the proposed system. MS SQL Server 2008 Analysis Services is the multidimensional OLAP component that integrates relational and OLAP data [9].

To implement the data warehouse technology, multidimensional relationships were modeled, as shown in Figure 3. The OLAP technology of a data warehouse can provide a platform for obtaining the maintenance cost data or information of school facilities.

The multidimensional data structure of OLAP matches various maintenance data well, including the budget, school type, school facilities, life cycle, location, class, work, time, LCC, and maintenance cost. Data on the dimension can be updated, that is, added and deleted, as data accumulated in the system. Thus, the data warehouse can provide flexible and efficient analysis as well as data mining of the school facility maintenance cost.

A dimension may contain more than one attribute, but each dimension has only one key attribute. Any other

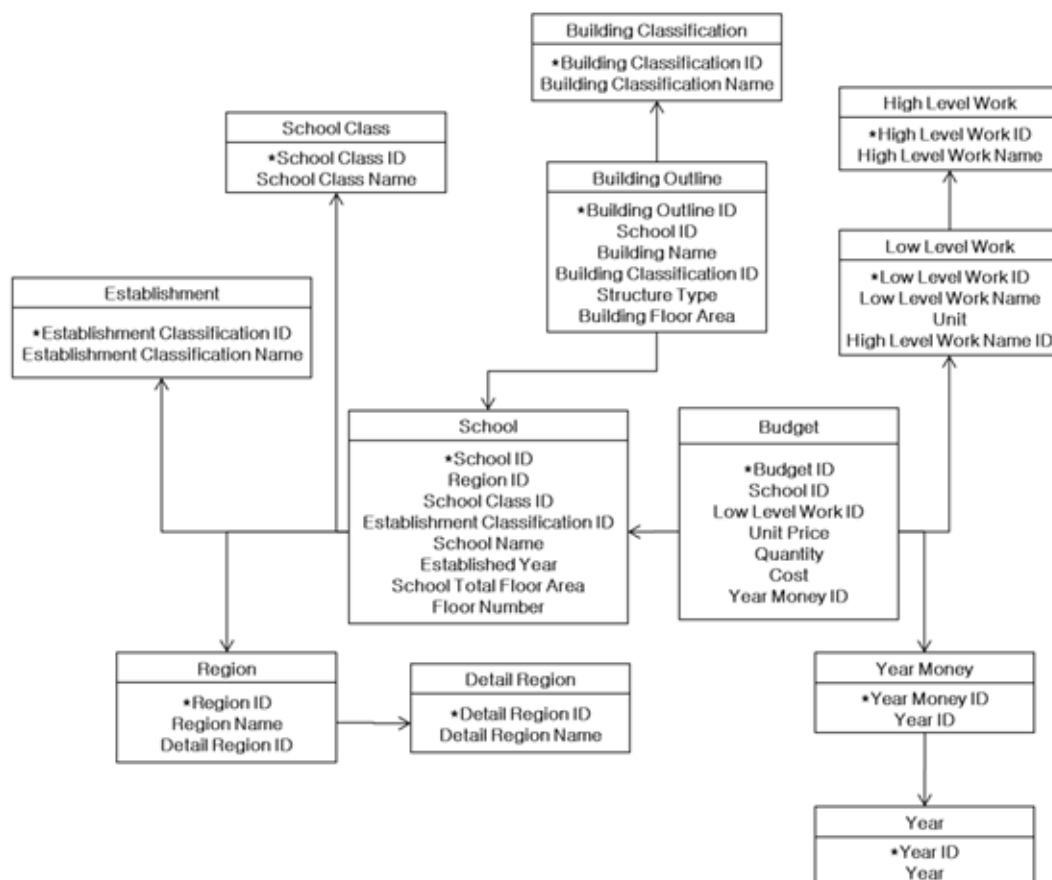


Figure 3. Data Model for LCC Management of Educational Facilities.



attributes related to the key attribute belong to the same dimension. Because attributes belong to dimensions, attribute members are also dimension members.

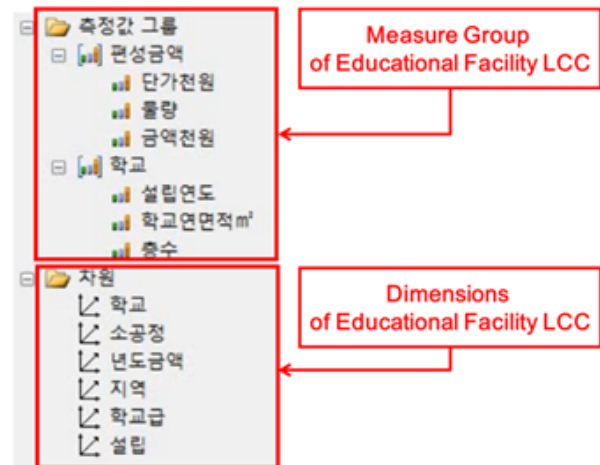
A database primary key designates the column that uniquely identifies the rows in a table and does not allow any row to have duplicate values in the primary key columns. As initially arranged, the spreadsheet format of the LCC report contains 9,062 budget ID rows, 703 school rows, 585 detailed work item rows, 12 building type rows, five school class rows, etc. A dimensional data warehouse has a data storage and retrieval layer. The data warehouse is stored in a Relational Database Management System (RDBMS) composed of a set of tables. Each table has rows and columns.

In a dimensional data warehouse, the dimensions are stored in dimension tables. Measures are called *facts* and are stored in fact tables. In a dimensional data warehouse, a table that stores the detailed measurements or facts is called a *fact table*. Table 1 gives a conceptual view of the first few rows of the budget fact table. It stores the quantity, cost, and unit price by school, year, and low-level work.

In the above sample rows from the budget fact table, the first four columns--i.e., the Budget ID, School (ID), and Year (ID)--are key columns. The values in the key columns relate the facts in the fact table row to a row in each dimension table. The three remaining columns--i.e., the Quantity, Cost, and Unit Price--contain the numerical facts. Each column in the budget fact table is either a key column or a fact column. A fact table has a column for each measure. Different fact tables have different measures.

**Table 1.** Budget Fact Table

Budget ID	School (ID)	Year (ID)	Low-level Work (ID)	Quantity	Cost	Unit Price
EC2001	S401	YC0001	LL1516	650	55,900	86
EC2002	S401	YC0002	LL1422	190	152,000	800
EC2003	S402	YC0003	LL1459	2	36,600	18,300
EC2004	S402	YC0004	LL1937	200	6,820,000	34,100
EC2005	S402	YC0005	LL1949	4	21,000	5,250
EC2006	S403	YC0006	LL1724	1	2,630	2,630
EC2007	S404	YC0007	LL1785	277,496	34,687	125
EC2008	S404	YC0008	LL1818	814	101,750	125
EC2009	S404	YC0009	LL1828	48	38,400	800
EC2010	S405	YC0010	LL1524	1	25,000	25,000
EC2011	S405	YC0011	LL1937	300	10,230,000	34,100
EC2012	S405	YC0012	LL1903	100	8,700	87



**Figure 4.** Measure Group and Dimensions of an Educational Facility LCC.

The multidimensional OLAP database resides between the data storage and retrieval layer and the presentation layer. It converts the relational data warehouse into a fully implemented dimensional model that makes it fast and flexible to create analytical reports and data visualizations. The columns with numerical data in a fact table correspond to the measures in a dimensional model, so each fact table is a group of measures. Analysis Services organizes the information into a logical construct called a *measure group* that corresponds to a single fact table and its related dimensions. A measure group is conceptually similar to a fact table. Figure 4 shows the user interface of the LCC measure group and the dimensions of the proposed system in the MS SQL Server 2008.

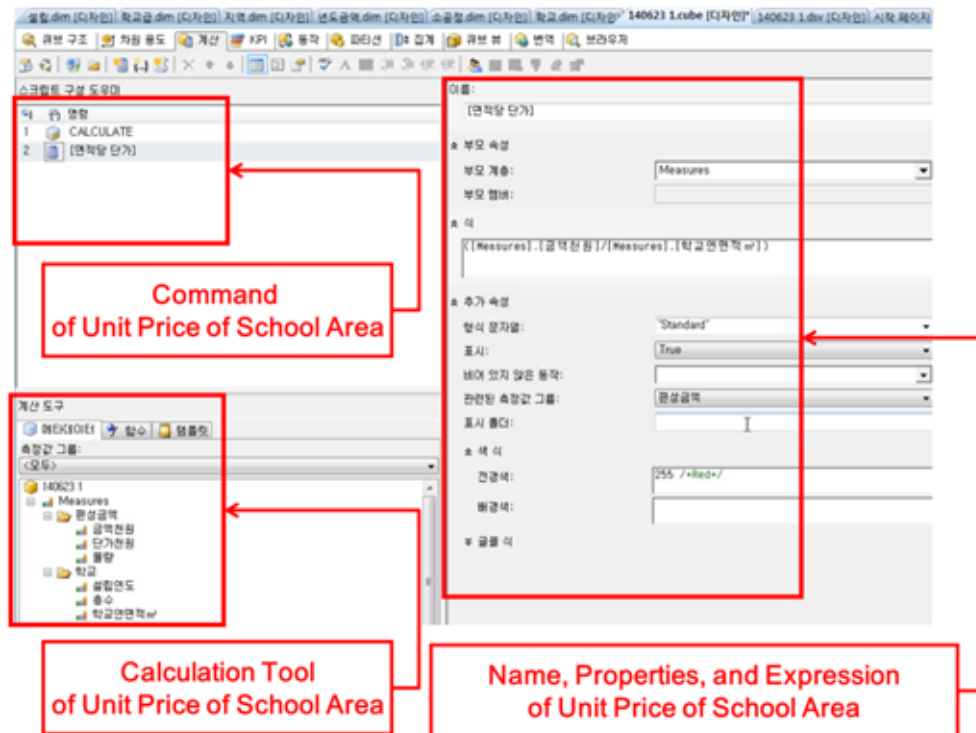


Figure 5. Calculation of the LCC cube dimensions.

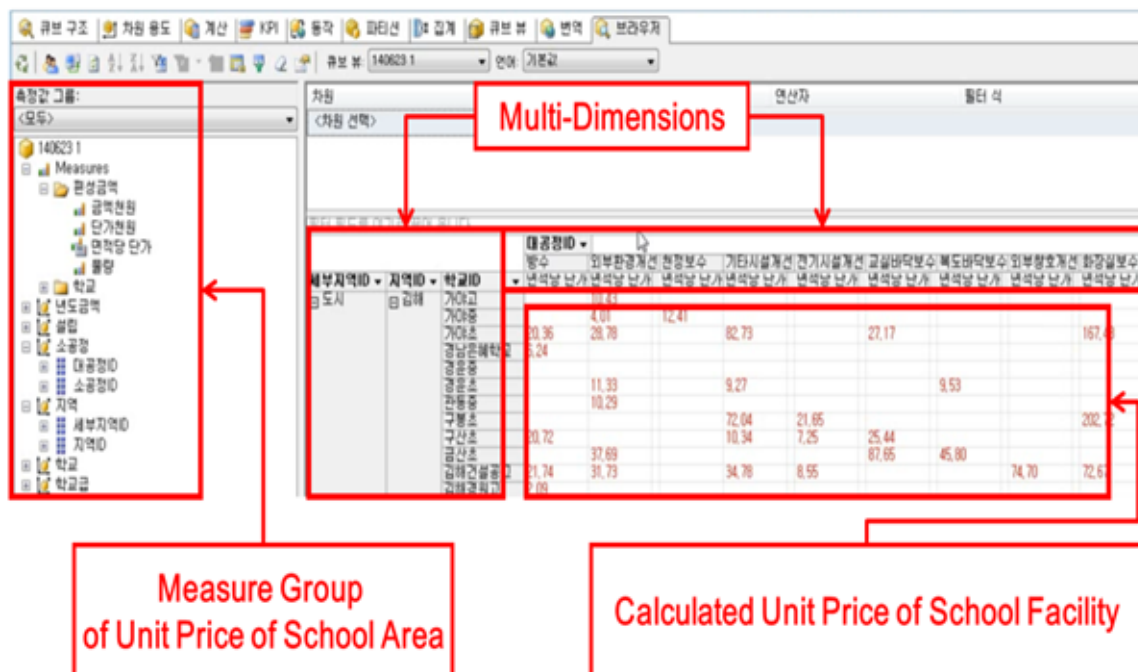


Figure 6. Browsed Results of the Multidimensional Unit Price of the Educational Facility LCC.

### 3.3 Multidimensional View of the Maintenance Unit Cost of a School Facility

A database is a general structure for storing the data needed for good analysis. However, the data in a database is of little use until it is converted into the information needed by decision-makers. OLAP is one of the best technologies for converting data into information. One term that is almost always associated with OLAP, but never associated with relational databases, is cube. A cube is a collection of measure groups that contain numeric data called measures<sup>9</sup>.

The measures in a measure group are all related to the same set of dimensions and have the same level of detail. The values in a cube are consistent with the values in the source database, and the measures aggregate correctly. In addition, it is beneficial to add calculation formulas to the LCC cube by creating a new unit price member in the LCC cube dimension and storing the formula in the member, as shown in Figure 5. The calculation formula divides the unit price of the maintenance cost by the total school floor area.

The OLAP browsing result is shown in Figure 6. The proposed data model is designed with dimensional tables for storing general descriptive school facility data, and fact tables for detailing various facts, including the maintenance cost in the life cycle of school facilities.

The proposed data model can store the historical construction maintenance cost, i.e., the life cycle cost that can be extracted from an existing school; maintain and operate databases or systems; and generate objective and important information on the life cycle cost, including the repair and replacement cost of the school facility components.

## 4. Conclusions

This research provided a framework and methods for developing display strategies for the multidimensional LCC data of educational facilities. OLAP encourages an interactive process and the efficiency of LCC data representation. The proposed method will be an appropriate tool for enhancing the process of visually displaying the LCC data of an educational facility.

This research presented an OLAP and data warehouse prototype for supplying information on the maintenance cost of an educational facility that can trace and accumulate the scattered LCC data from the perspective of the life cycle of an educational facility, and then will help the

participants, including the educational facility manager, to analyze the repair and to replace the information, maintenance cost, etc.

The proposed system underscores the need for accurate and honest data entry from the LCC planners to facility operations and maintenance managers. Without quality data entry, multidimensional data or information is meaningless. Incorrect estimations of quantities or a dishonest LCC can lead to wrong interpretations of the maintenance unit prices.

## 5. Acknowledgment

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