BIM-based Data Mining System Framework to support an Effectiveness Decision-making for Energy Usage Management of Building Space

Tae Wook Kang, Senior Researcher, Korea Institute of Construction Technology, South Korea *(laputa99999@gmail.com)*

Hyun Sang, Choi, Research Fellow, Korea Institute of Construction Technology, South Korea *(hyunsang@kict.re.kr)*

ABSTRACT:

Buildings consume 40% of the primary energy globally. For sustainable smart buildings, an effective decision-making method is becoming more important for the management of building energy usage. It has recently become possible to simulate energy usage data using advanced technologies such as Building Information Modeling (BIM). In the future, a data mining method using various types of big data such as energy simulation and sensor-based data, including facility management data, will be needed to support effective decision-making for energy usage management. In this research, we propose a BIM-based Data Mining system framework for supporting building Space Energy Management (B-DM4SEM). The proposed system framework considers functional variability and extensibility. To identify its effectiveness, we developed and conducted a scenario related to building energy management, and analyzed the results.

KEYWORDS: BIM, Data mining, Energy Management, B-DM4SEM

1. Introduction

Energy consumption in buildings accounts for 40% of all energy consumed globally, and thus a decision-making method for the effective energy management and operation for sustainable smart building development has become increasingly important [1-3]. Most energy management systems in both Korea and abroad provide energy consumption using simple statistical processing and a visualization format. Furthermore, a database analysis for decision-making of the building operations and the development of management support functions remain at the research stage. To support such decision-making with more advanced information systems, a variety of data types such as energy consumption, the equipment conditions of the Building Automation System (BAS), and the surrounding environments of the buildings should be formalized and integrated; interoperable information technology is also required. In addition, it is necessary to predict and evaluate the energy demand to effectively support decision-making of the management and operation and thereby reduce the costs of energy-consuming buildings and facilities. To meet these needs, Building Information Modeling (BIM), which can integrate energy-management related data and visualize information three-dimensionally, and data mining technology that can support the decision-making process, may be effective methods. In this research, we propose a BIM-based Data Mining system framework for supporting Building Space Energy Management (B-DM4SEM). Through the proposed method, decision-making for energy usage management and the operation of building spaces can be effectively supported. To identify its effectiveness, we defined and analyzed the use cases for space-energy management using B-DM4SEM.

2. Study methodology

For this research, reviews of previous researches and the literature related to this study were conducted, and considerations and improvements were clearly identified through the B-DM4SEM framework. We aimed to create the B-DM4SEM framework to support BIM-based data mining and act as a platform; in addition, its components needed to be conceptualized and generalized so as to allow the framework to be independent of a specific programming language or Database Management System (DBMS). The figure below shows a flowchart of the methodology used in this study.

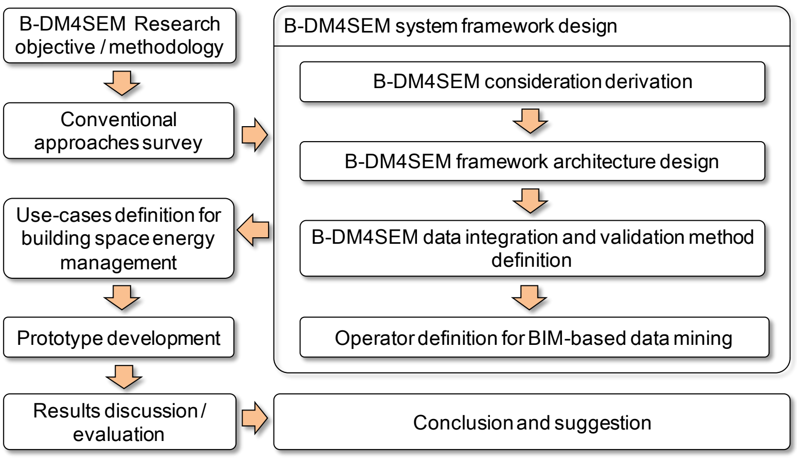

Figure 1 Research flow

In addition, methods for considering the reliability of BIM-based data processing are also defined. To verify the effect of the defined B-DM4SEM framework, energy usage management scenarios of building spaces are then defined and implemented based on B-DM4SEM.

3. Literature review

In this chapter, considerations of the proposed B-DM4SEM framework are derived and recent related studies are examined.

Kim et al. (2012) studied platform middleware designs that can integrate a large amount of data for energy management with spatial information [4]. In their study, they proposed a platform middleware architecture along with a method for visualizing energy consumption using Google Earth. A study on the use of extract, transform, and load (ETL), which is mainly utilized in data warehouse construction, was also applied to building energy management [1, 5]. In these studies, complicated energy-related datasets were integrated through ETL, and a method for interlinking a dataset using BIM information was proposed. Furthermore, Bank et al. (2010) proposed a method for integrating data related to the decision-making required for a sustainable building design [6]. In their study, an application program interface (API) was used to integrate the design tools, and open database connectivity (ODBC) was applied to integrate the external data sources.

Additional researches in this category were conducted to define methods for integrating and exchanging various types of data from an architectural point of view. However, studies on how to formalize data integration and which scheme to apply, along with how to verify the reliability of integrated data, are lacking. Dong et al. developed an information structure based on BIM for building energy fault detection and diagnostics (FDD) [7]. Their study aimed to resolve the complexity of FDD workflows and information exchanges through the use of BIM. Another study on an optimization of the structures, systems, services, and management factors using data mining techniques of building-energy related characteristics was also conducted [8]. This study defines a model for predicting a building performance using data mining.

A study on the development of an integrated model for building information and a sensor data model that considers the context data for data mining was also conducted [9]. This study suggests that a flexible sensor data model structure should be provided for data mining because a large amount of sensor data is stored in various formats. This study also proposed an addition and absorption (A&A) method as a viable data structure. Data related to a building performance such as the energy consumption are multi-dimensional. In this regard, a study on the development of a multi-dimensional building data model was conducted [10]. A study on the development of a dynamic sensor data model supporting data mining from infrastructure monitoring was also conducted [11].

The analysis results regarding the characteristics of the examined researches verified that solving the following issues are important in terms of the systems used to effectively manage the energy use of building spaces.

1. A method for the integration of various types of energy-related data sources and synchronization

2. The minimization and generalization of BIM-based data query and processing operators

The present study differs from other studies in the follow ways:

First, few studies have been conducted on the detailed components of BIM-based data mining system frameworks and their interlinking methods for the effective energy management of building spaces, which are the main interests of the present study. Second, generalized frameworks can be a great help to the reusability and scalability of system developments. In this regard, the present study proposed the B-DM4SEM framework architecture based on data integration and reliability, operator generalization, and service scalability.

4. B-DM4SEM framework

4.1 Design considerations

This chapter discusses issues regarding energy-management data and service diversification to help determine items of consideration when designing the B-DM4SEM framework. From the viewpoint of data integration, there are numerous data types and sources used for energy management of building spaces. Data related to energy management can include not only the name and area of the building space, number of occupants, and energy usage, but also data on the temperature, humidity, scheduling for obtaining calorific information on human users, and lighting, equipment, and air conditioner loads. Such data types are also required to execute energy simulations such as DOE2, EnergyPlus, E-Quest, and Trace7. The data sources include not only BAS equipment, sensors, and building energy management system (BEMS) databases but also legacy data files such as Excel files for energy management collection and Word text files for management work records. The data diversity may increase the complexity at the time of the data extraction and computation, thereby making it difficult to focus on solving problems by engineers and degrading the processing performance. For the above reasons, a variety of data types obtained from various data sources need to be normalized and stored as a type of database record, thereby interlinking with BIM objects. From a service-scalability perspective, decision-making support services for energy-space management need to consider service diversity such as classification of the energy consumption patterns, classification of excessive or limited energy usage space based on the reference usage, energy consumption per space, and a group analysis of the consumption patterns. Service diversity may induce complexity in the service management and usage, as well as create a difficulty in the reuse of business logic for the developed services. Thus, services should be implemented in a way that can be reused and can be plugged in. The following aspects should be considered for managing the complexity of systems owing to the data and service diversity mentioned above.

1. Management of data diversity
   Flexible and simple forms of Integrated Data Model (IDB), Data model transformation (DMT), Data model validation rule (DVR), Data binding method considering BIM object (DBM)
2. Management of service diversity
   Service extensibility (SEB) consideration, Service management method considering reusability (SRU), Problem description method for implementing services (PDM)

4.2 Identification of the framework structure

The B-DM4SEM framework structure is identified based on the considerations mentioned in the previous chapter. To support each of the considerations, the components of the B-DM4SEM framework were identified, and are shown in the following table.

Table 1 Relationship between considerations (Cons) of B-DM4SEM and framework components

Cons	Framework components and Role description
IDB	BIM-based Integrated Database (B-IDB): A database integrated with flexible and simple data schema structures is supported.
	BIM Server (B-SER): The integrated database is serviced through various interface methods.
DMT	BIM-based ETL (B-ETL): A method of conducting ETL of external energy-related data is supported.
DBM	BIM Object Data Binder (B-ODB): A scheme that combines external data and BIM objects is supported.

DVR	BIM-based Data Model Validation Rule set (B-DVR): Verification rules for the reliability of a BIM-based integration data model are supported.
PDM	BIM-based Data Mining Operator (B-DMO): BIM-based data mining operators are provided.
	Data Mining Function Library (DM-FL): Data mining functions with respect to classification, prediction, grouping, and correlation models are supported for decision-making support service developments.
	BIM-based Data Mining Script (B-DMS): Scripts for BIM-based data mining processing are provided.
SEB	Service Plug-ins (B-SPI): Plug-in scheme for service scalability is supported.
SRU	BIM-based Service Container (B-SCT): Life cycles such as service searches, loading, execution, termination, and service recyclability are supported.

The following figure shows a block diagram of the B-DM4SEM framework in consideration of the components.

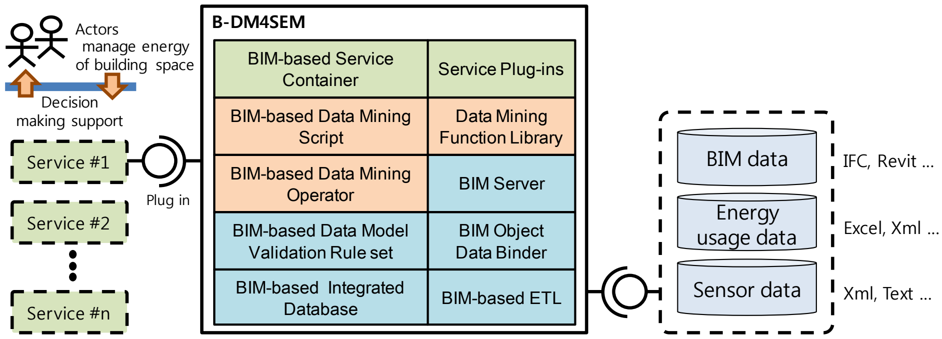

Figure 2 Block diagram of B-DM4SEM framework

4.3 Method definition of BIM-based energy management data integration

This chapter defines content regarding the above-mentioned IDB, DMT, DBM, and DVR. A verification method for data model reliability and a flexible integration data model structure reduce the complexity of data mining processing of the various data sources and types used for energy management. IDM is divided into B-IDB and B-SER. B-IDM supports flexible and scalable BIM data structures. B-SER plays a role in supporting service interfaces needed in other components. B-IDB should be managed using object-oriented data structures, which can be very simple and expandable. The B-IDM schema can be divided into two parts: a domain schema part that defines the domain data schema structures, and an object container part that manages objects. The domain schema manages the types and classification of objects and attribute information, and includes information that can verify the reliability of integrated data models. DMT, DBM, and RM, which define how to ensure reliability and BIM object integration along with an external data transformation for energy management, consist of B-ETL, B-ODB, and B-DVR, and thereby integrate and verify the external data, as shown in the following figure.

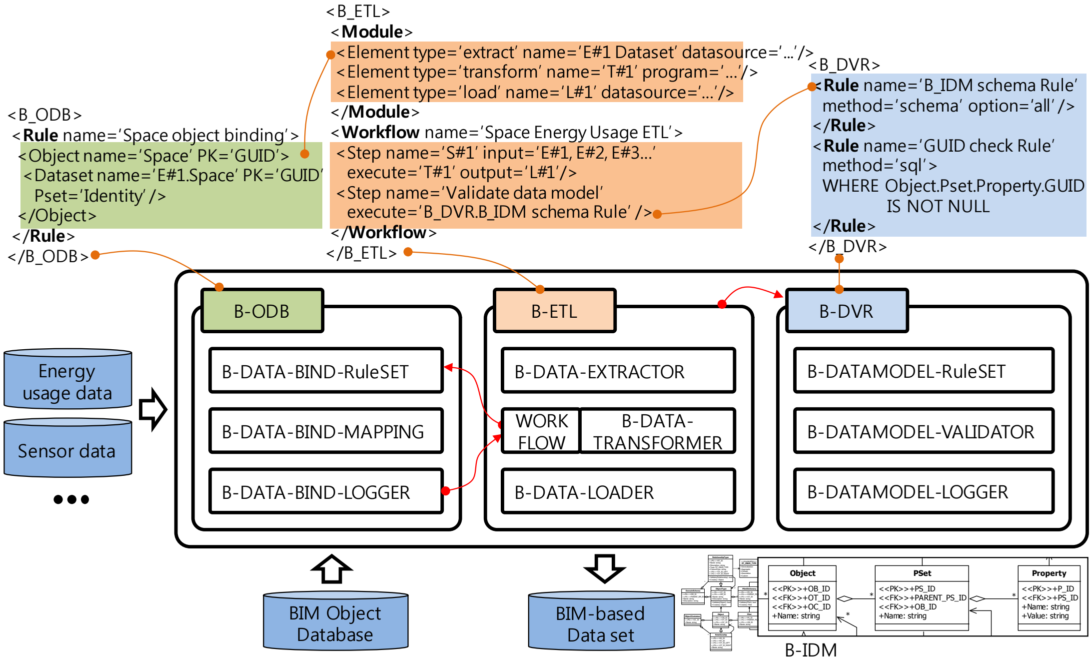

Figure 3 Operational concepts and correlations of DMT, DBM, and DVR in B-DM4SEM

4.4 Definition of operators for BIM-based data mining

In this chapter, the PDM mentioned above consists of DMF, B-DMO, and B-DMS. DMF consists of libraries that support general data-mining functions. B-DMO defines B-IDB-based data operators. B-DMS, which uses operators, supports scripts that can solve various problems, registers through which operators and functions are registered, and a logger that records the script processing procedure. The operators should support IDB, DMT, DBM, and PDM, which are the considerations of B-DM4SEM.

Core operators that support the above features are shown in the following table. The operator definition is divided into CRUDE in consideration of MECE. Here, CRUDE and the "*" mark have the following definitions.

C, create; R, read query; U, update query; D, delete; E, execute; and *, plural indicator of an object

Table 2 B-DMO operator description (O, support needed; X, support not needed)

Operator	Namespace	Operator-Supported Object
CRUDE	B-DET-OP	Data Extractor (TDE), Data Transformer (TDT), Data Loader (TDL)
	B-ODB-OP	Data Binding Rule (BRU), Data Binding Logger (BLG)
	B-DVR-OP	Data Model Validation Rule (MRU), Data Model Validator (MVA), Data Model Validation Logger (MVL)
	B-DM-OP	Classification Model (DMCF), Prediction Model (DMPD), Clustering Model (DMCL), Association Model (DMAS)
CRUD	B-DMS- OP	DomainSchema (BDS), ObjectType (BOT), RelationshipType (BRT),

		PSetDictionary (BPD), PropertyType (BPT), ObjectContainer (BOC), Object (BOJ), Relationship (BRS), PSet (BPS), Property (BPR)
CD	B-DET-OP	Data Source (TDS)
	B-ODB-OP	Binding Data Source (BDS)

Using these defined operators, the attribute values including the space area and wall properties in relation to the energy consumption computations and interpretation managed using objects are acquired, and information needed for decision-making can be obtained through data-mining operators.

5. Case study

To verify the effect of the B-DM4SEM proposed in this study, use cases for the management of building-space energy usage were conducted along with a case study applying the BIM model for the main building at the Korea Institute of Construction Technology and its energy management data. The number of buildings managed by the Institute was 23 and the number of rooms where power consumption was measured is at least 364, in which measurement locations were increasing for power management.

Use cases for the defined building-space energy management applied in this study are as follows.

1. Which spaces and users of those spaces exceed the specific reference amount of annual energy usage?
2. When was the first time this reference amount was exceeded, and for which space, based on the trend of annual energy consumption?

Use case 1 can be conducted through simple queries, whereas use case 2 can be achieved using a data-mining prediction model like regression equation to acquire information required for the decision-making process. If use cases 1 and 2 are conducted using existing methods, both the attribute information and drawings should be manually searched and integrated. Furthermore, a trend analysis is required to conduct use case 2, which requires special knowledge to develop a prediction model and make the appropriate datasets. Such tasks require a great deal of time and cost. To conduct such tasks using B-DM4SEM, the data mining model was defined. The reference usage value for use case 1 was 1,000 kWh, and that for use case 2 was 5,000 kWh. As shown in the follow figure, the results of each use case are marked using numeric tables, charts, and BIM spaces.

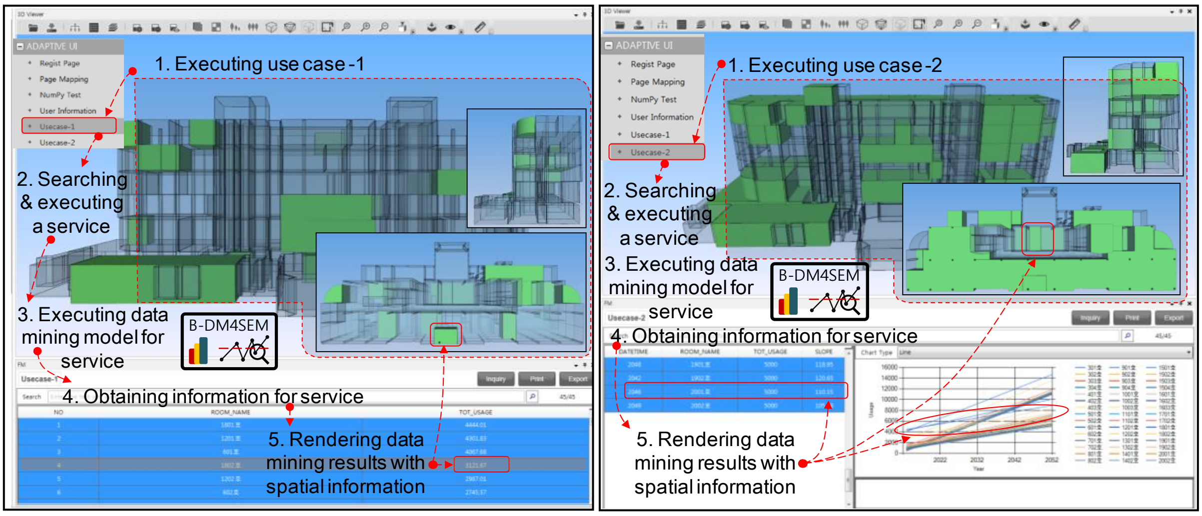

Figure 4 Results of BIM-based data-mining model (left, results of use case 1; right and bottom, use case 2)

6. Conclusion

In recent years, BIM-based energy simulations have been achievable during the design phase owing to the development of advanced information technology. However, few studies have been conducted on technology and systems to effectively support the decision-making process for energy management during the building management and operational phases. In this study, a B-DM4SEM framework that can support effective decision-making for the management of building-space energy usage was proposed. Through the present study, the considerations, components, technologies, and operators required to develop effective space-energy management systems were identified, and the B-DM4SEM framework, which structures the relationship among components, was defined. To verify the effect of the proposed method, use cases for space-energy management were defined and conducted by facility managers. The performance evaluation showed the positive effect of the proposed method. For future research, big data processing acquired from sensors and real-time decision-making support systems, in link with a BAS based on B-DM4SEM, will be studied.

7. Acknowledgements

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Name of the Presenter: Tae Wook, Kang

Author (s) Affiliation: Korea Institute of civil engineering and building Technology

Mailing Address: (Daehwa-Dong) 283, Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do, 411-712, Republic of Korea

Email Address: laputa99999@gmail.com

Telephone number (s): 82-10-3008-5143

Fax number (s): 82-31-9100-031

Author(s) Photograph:

Brief Biography (100 words):

I'm senior researcher who is responsible for developing BIM (building information modeling. ex-movie), 3D point cloud-based vision R&D projects in KICT. I wrote 9 books including two e-books such as BIM principle, BIM interoperability and platform, Civil BIM with Autodesk Civil3D, Collaborative Architecture Design with BIM, BIM-based Facility Management, Smart Building System, Arduino-based Smart Home Automation, IPD Studies, Social-based Media Art.