

Article

# BIM-Based Human Machine Interface (HMI) Framework for Energy Management

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**Abstract:** This study proposes a Building Information Modeling (BIM)-based Human Machine Interface (HMI) framework for intuitive space-based energy management. The BIM-based HMI supports building managers with a method of linking data between BIM and Building Energy Management System (BEMS), which are heterogeneous systems, and provides space-based real-time energy monitoring. This study also proposes a BIM and BEMS data linking framework for systematic BIM-based HMI development. Towards this end, the BIM-based HMI framework was defined after deriving the considerations and requirements necessary for linking the energy control point and BIM through a questionnaire designed by practitioners. Through case analysis, the authors implemented BIM-based HMI and analyzed its effects. The results of the analysis confirmed the positive effects (3.9/5.0) on the connectivity of BIM-based HMI, the benefits (4.3/5.0) for real-time data monitoring, the system function expandability, and the BIM-based spatial intuitiveness.

**Keywords:** BIM; HMI; energy; management; BEMS

## 1. Introduction

In 2020, zero-energy construction became mandatory in South Korea, especially in the public sector. As part of the move, the installation of the Building Energy Management System (BEMS) also became mandatory, along with the beginning of the work to establish the Korea Standard (KS). From 2020, the Ministry of Commerce, Industry and Energy of Korea will mandate BEMS for new buildings with a size of 1000 square meters or more. In addition, the Seoul Metropolitan Government has mandated the construction of BEMS on buildings.

If the Building Information Modeling (BIM) data, which are mandatory for construction projects of national public institutions, are well-utilized, synergy effects would be obtained by linking them with BEMS for energy monitoring.

BIM has a wealth of spatial and attribute information about buildings, whereas BEMS has the data needed for energy management. If the two can be connected to develop a BIM-based Human Machine Interface (HMI) that supports energy data monitoring, an effective energy management system can be developed.

However, BIM is not easy to handle. For example, in order to use the information required by BEMS, the relevant content must be defined in advance and this process may sometimes involve specialized programming. In the process, user requirements may be omitted or changed. Sometimes, the professional BEMS development process makes it difficult to predict which system users will use.

HMI is defined as the means of communication for human-machine interaction. It is widely used for equipment data monitoring. In particular, Supervisory Control and Data Acquisition (SCADA) is used as a core element of the system. HMI encapsulates technical complexity and focuses on how to interface between the user and the technology. This gives intuitiveness to system development

and usage from the user view. This study intends to apply the HMI concept from the perspective of BIM-BEMS.

This study proposes a BIM-based HMI framework to support effective energy data monitoring. The framework includes BIM and BEMS data linkage and utilization methods. In addition, this study defines the requirements and utilization procedures necessary for linking energy Monitoring and Control (M&C) points with BIM. Through this concept definition process, a BIM-based HMI is defined for intuitive building energy management, and a BIM-based energy management method using the proposed authoring tool is described. The research plans to develop the proposed BIM-based HMI through case analysis, and to analyze the effect through a questionnaire for practitioners.

To proceed with this research, the researchers will also investigate the related technology trends and derive BIM-based HMI framework requirements with the use of case research. Based on the requirements, the role of each component of the framework and related data items will be defined. In addition, a method of interfacing BIM and BEMS from the perspective of HMI shall be designed. To derive the effects of the designed BIM-based HMI framework, a questionnaire for working-level workers will be conducted and the results will be analyzed.

## 2. Related Works

The researchers will investigate the technologies related to this research and identify the matters needed for framework development.

There have been some studies on BIM interoperability for building operation and management support [1]. This study utilizes BIM as a database for Building Energy Simulation (BES) and for Autodesk Dynamo to simplify the energy management data exchange process when applying BIM to BES.

A study has been conducted on a life cycle analysis of facility management based on machine learning using BIM and Internet of Things (IoT) [2]. The study used data from BIM and IoT to perform machine learning-based life cycle cost analysis.

There was also a study on the development of a scalable Cyber-Physical System (CPS) data collection framework in a smart building environment [3]. The study proposed a method of connecting Industry Foundation Classes (IFC) and BACnet for scalable data collection in smart building environments.

Another study investigated the energy performance management method for building service systems [4]. It reviewed building energy estimation methods and examined six cases to propose effective energy management strategies. Additionally, there is a study on the Open IoT platform for energy data management [5]. The study pointed out that there are problems with proper processing due to the various forms related to energy management data, and proposed a FIWARE-based IoT-centric energy management platform.

Another study proposed a BIM information exchange method that supports the Building Automation System (BAS) [6]. The study focused on the development of information exchange methods between BACnet and IFC. There had also been studies on BIM-based facility operation and maintenance technology [7]. These studies confirmed the related effects, after investigating the BIM-Operation and Maintenance (O&M) technology and the CPS framework. A research and analysis study on BEMS technology [8] focused on research and analysis of BEMS-related data science, computing, communication, and control, and on minimization and system storage technologies.

Still another study focused on the development of a BIM-based CPS for building performance monitoring [9]. The study paper mentioned that there are many heterogeneous data in building performance management, and that interoperability should be considered. The study was aimed at constructing a smart sensor network using edge computers such as Arduino, and at automatically generating a data schema using RESTful and NoSQL.

One study predicted the energy management control of smart buildings using renewable energy [10] and confirmed that Model Predictive Control (MPC) can be optimized using BIM data.

A case study on BIM-based sustainable energy management [11] mentioned that BIM is required to achieve sustainability in the Waste and Resources Action Programme (WRAP). The study also examined the effectiveness of existing sustainability decision support tools.

A study on the management of recognizable facilities from smart objects [12] noted that cognitive facility management can improve information communication problems by using CPS technology. The study proposed an eight-layer Facilities Management (FM) framework that consists of related environments, perceptions, data, communication, computation, application, behavior, and evaluation.

Other studies related to predictive control and schedule optimization for energy management [13] focused on predicting energy consumption and calculating the optimal control schedule. A study on an energy CPS through residence prediction [14] proposed the possibility of implementing the CPS for effective energy management. The study was conducted to simulate the number of residents who use Wi-Fi, and to verify the actual ground true value. BIM was used to supply the data needed for the simulation.

A study on the performance management of building environments using the IT system [15] focused on design and methodology development. Through relevant case studies, an effective method was proposed to support the decision-making needed for performance management. Another study on a BIM-based digital twin for O&M [16] proposed a digital twin framework for smart asset management.

In building energy management, various studies on decision-making support technology using BIM data [17] measured the effect of BIM on building energy management and presented the results. A study on digitalizing building heating and cooling control [18] proposed a method that can save energy by improving the efficiency of controllable heating through digitalization.

There is also a study that aimed to improve the energy performance monitoring method using a parametric technique [19]. The study refers to the HEART project funded by the EU Horizon 2020 program, and proposes a parametric simulation method as part of the move.

A study on the real-time semantic energy management method [20] used IoT for energy management. The data obtained from IoT sensors were used to improve energy management performance using genetic algorithms and artificial neural networks. A study on effective building management based on artificial intelligence [21] focused on investigating cases of building management using artificial intelligence.

There has been a study to improve the BMS-based project management method using BIM technology [22]. In this study, methods such as code integration and identification number generation were proposed for BIM and BMS connection. There is a case of implementing Virtual Facility Energy Assessment (VFEA) using BIM and GIS technology [23]. This study focuses the feasibility analysis, established the system framework of VFEA, and discussed the use case of CSU, Fresno campus for VFEA implementation. In order to save energy, there was a study that proposed an integrated design method at the level of the whole life cycle [24]. This focuses on developing a facade system that considers energy savings.

Through BIM-based energy performance simulation, a service-oriented platform development study was conducted [25]. This study focuses on developing and integrating a Building Energy Performance Simulation (BEPS) service in a versatile service-oriented BIM platform using IFC. A facility management method linking facility management and real-time data in a 3D game environment was studied [26]. This study analyzed the performance according to mesh complexity when representing BIM objects related to facility management data using the Unity game engine.

There has been a review study on cognitive-based city management technology in the energy domain [27]. The review focuses on learning and cognitive solutions that improve energy sustainability through Semantic Web technologies. Situation-aware Building Information Models for next generation building management systems were also studied [28]. In this study, a conceptual framework for performing facility management according to the situation was proposed. A study was conducted to express data for facility management in a semantic model [29]. This study focuses on the data connection method of facility management between semantic model and BIM.

Many of the previous studies presented examples, technologies, or methodologies using the latest technologies such as IoT and AI for energy management. There have been studies that defined these technologies through the concept of digital twins and CPS and suggested methodologies.

To analyze the results of literature research, the existing studies were classified into five groups centered on keywords. Classification keywords are data exchange, ICBM (IoT, Cloud, Big data and Mobile), CPS, case studies and simulation. Others were summarized as in other studies. Table 1 shows the classification results.

**Table 1.** Classification of existing studies.

Classification	References	Description
Data exchange	[1,22,28]	The studies in this category are concerned with data integration and interoperability between heterogeneous systems. The solutions for these studies use code classification, standard data model such as IFC, API (Application Program Interface) and BIM software add-in technology.
ICBM	[2,5,15,18,20,21,26,27,29]	The studies in this category apply the latest technologies to the field of energy management. They mainly use ICBM technology to explore effective energy management method or solution.
CPS	[3,7–9,12,14,16]	These studies propose and implement digital twin framework, concept for energy management. The studies in this category often describe techniques based on CPS.
Case studies	[4,11,17,23]	These studies are related to case studies and analysis related to energy management.
Simulation	[10,13,19,25]	The studies in this category focus on energy management and simulation for savings and usage prediction.
Others	[6,24]	Among the unclassified studies, studies on hardware technologies for energy saving are also included. These solutions are related to building walls and automation. They are not relevant to this study.

As a result of classification, it can be seen that many studies are of interest in the order of CPS, ICBM, and simulation. In particular, CPS is being discussed in terms of a specific solution development method due to the rapid development of artificial intelligence or ICBM technology.

This study is close to ICBM and CPS. However, there are differences in this study aims to improve energy management efficiency from BIM-based HMI framework which support effective energy data monitoring and defines related components. The framework includes BIM and BEMS data linkage and HMI authoring tools. In addition, this study defines requirements and utilization procedures needed to link energy M&C points and BIM. The proposed framework is then used for case analysis, and its effectiveness is confirmed through interviews with practitioners.

### 3. BIM-Based HMI Framework Design

#### 3.1. Overview

To apply BIM-based HMI to energy management, a standardized method of outputting energy management data to the HMI by linking it to the BIM model is required. To this end, the energy data monitoring system construction process was investigated, through which the requirements for frame design were derived. Based on the derived requirements, the framework components were derived, and the roles of each component were defined.

Each component has data needed for linking BIM-BEMS and HMI. In particular, it is necessary to designate a BIM space to be controlled and to connect it to the M&C point in order to use BIM,

which involves heterogeneous data, from the viewpoint of energy management. The M&C point must be connected to the sensors installed in the space and facility. These connection data are the configuration information of the concept of metadata, and must be managed in the framework component.

In general, BEMS development follows a waterfall development process. This process verifies step-by-step results each time the design, installation, and operation phases are completed, and proceeds to the next step only if there are no problems. It is inefficient to redevelop the system according to the project requirements. Therefore, the results of BIM-based HMI development should be written data, not a programming code. The framework was designed in consideration of this.

### 3.2. Process Analysis

The energy management system construction process was investigated through expert advice to define the BIM-based HMI framework. The main steps in developing a general BEMS are as follows.

- S1. Energy management system establishment requirements and stakeholder definition;
- S2. System utilization scenario and process definition;
- S3. Energy M&C point and data item definition;
- S4. Energy M&C device and sensor definition;
- S5. Energy management system architecture decision and development;
- S6. Energy management development, installation, and testing.

The following points should be considered in steps S1 to S6.

#### R1. Classification of responsibility

The energy management system includes software and hardware development. The design, installation, and operation phases must be developed with detailed planning so that the energy management system can be applied to the building in operation. The installation phase includes installation of monitoring devices such as sensors and networks in the field. System development owners may wonder if this phase can be short and handled reliably. For this reason, the roles of system design, equipment installation, and operation should be separated from each other.

#### R2. Application-oriented customization and variability

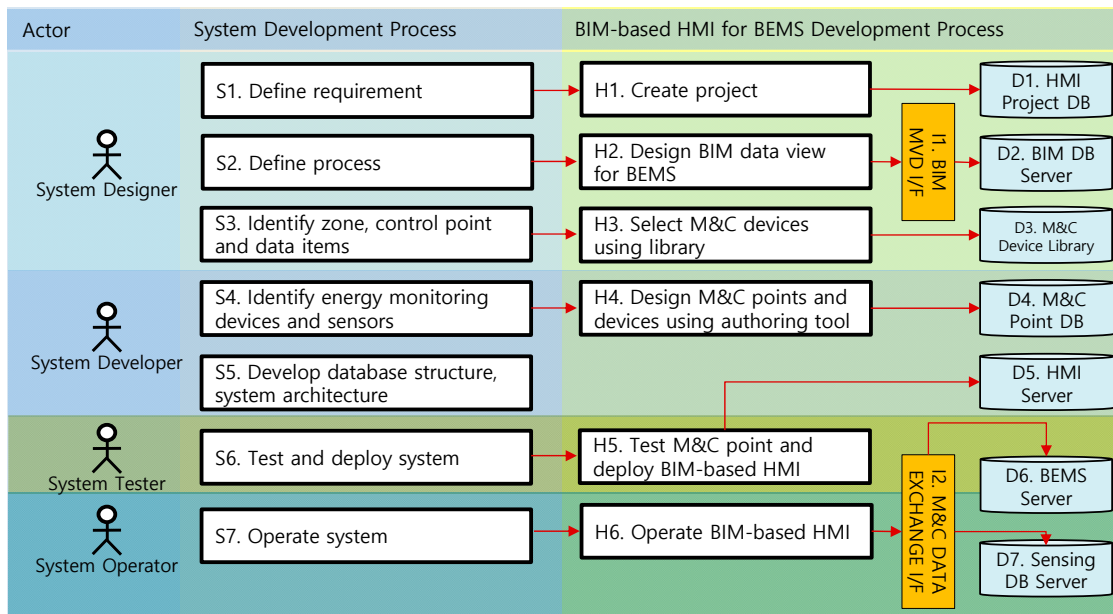
The system architecture depends on the user requirements, and the implemented system is also developed differently depending on the situation. For example, S3's M&C points and data items are developed according to the purpose of use. BIM-based HMI needs to consider the variability according to the purpose of its application to enable utilization of the architecture in various situations. Instead of redeveloping the sensors and control points, the BIM-based HMI uses an authoring tool to import the from the library and to define the control points. Through this, it is possible to develop a system that can be customized.

#### R3. Reusability

Functions such as M&C device information and M&C points that change only the data content and not the data processing method increase reusability through configuration information definition and library management. Through this, corresponding parts are not redeveloped, but functions can be implemented through item selection in the authoring tool.

Figure 1 shows a conceptual diagram of how to map the energy management system development process to the BIM-based HMI development process.





**Figure 1.** Building Information Modeling (BIM)-based Human Machine Interface (HMI) development process mapping concept.

The existing energy management system development process can be mapped to the BIM-based HMI development process as follows.

$$\{S_{(1..4)}\} \rightarrow \{H_{(1..4)}\}, \{S_{(6,7)}\} \rightarrow \{H_{(5,6)}\} \tag{1}$$

BIM-based HMI provides a method of creating a project (H1) and authoring, not a method of redeveloping a system. The BIM data that the project wants to use for energy management are defined using the Model View Definition (MVD) Interface (I/F) (H2). M&C devices are selected through a predefined library (H3 and H4). After setting information for energy data monitoring, the operation must be tested and distributed to the HMI server (H5). Then BIM-based HMI must be operated on the deployed server (H6). Here, the BIM server refers to a database system compatible with IFC. The BEMS server provides energy monitoring data.

### 3.3. Framework Design

To confirm the requirements of the BIM-based HMI framework component, the authors investigated the expected effects of, and the obstacles in, the BIM-based energy management system. Interview items were defined through related technical surveys and expert advice, and a five-point Likert scale was used to develop the questionnaire.

There were 53 interviewees. The interviewees’ work experience fields were architecture and urban (88.7%) and facility (11.3%). The most experienced process fields were design (49.1%), construction (17.0%), construction management and supervision (13.2%) and planning (5.7%). BIM practical experience is less than 2 years (37.7%), 5–10 years (20.8%), 2–5 years (20.8%), 10–15 years (18.9%) and 15 years or more (1.9%). The interviewees knew energy management and some had practical experience.

The expected effects of BIM-BEMS linkage were high in the order of spatial intuitive personality (Q1-2.4.2), BIM information recycling, and information search time reduction (Q1-3.4.0) when monitoring BEMS data, which suggests that many respondents expected that the data search function using spatial information included in the BIM would be helpful in effective energy management in Figure 2.

No	What are the expectations when using BIM in BEMS?	Expectation
Q1-1	BIM data reusability related to BEMS database development	4.0
Q1-2	Spatial intuitiveness in energy data management and searching	4.2
Q1-3	Reduce the time to find the needed information	4.0

Figure 2. Expected effects of BIM utilization in the energy management system.

On the other hand, obstacles to the use of BIM for energy management include: the burden of time and costs for changing the working method of practitioners (Q2-8.4.1); compatibility with existing systems (Q2-10.4.1); poor environment for BIM system introduction (Q2-1.4.0); insufficient field data and reliability issues (Q2-3.4.0); poor environment for BEMS system introduction (Q2-2.3.9); and excessive data input and construction cost (Q2-11.3.9). The problems are pointed out in order in the figure below.

Among the obstacles listed in Figure 3, those related to BIM-based HMI requirements are Q2-3, Q2-4, Q2-5, Q2-10, and Q2-11, not the institutional and environmental aspects. The priorities are Q2-10, Q2-3, Q2-11, and Q2-5, which point to compatibility issues, excessive data input, and insufficient data reliability issues. For reference, Q2-1, Q2-2, and Q2-8 correspond to the user environment; Q2-6, to the system provider problem; and Q2-7 and Q2-9, to government roles.

No	What are the obstacles when using BIM in energy management system?	Obstacles
Q2-1	Poor environment and conditions to introduce BIM system	4.0
Q2-2	Poor environment and conditions to introduce BEMS system	3.9
Q2-3	Insufficient field data and reliability	4.0
Q2-4	Data security issues	3.0
Q2-5	BIM data requirements for unclear purposes	3.6
Q2-6	Excessive system development cost	3.8
Q2-7	Lack of institutional support	3.9
Q2-8	When introducing the system, burden of time and cost for changing the working process	4.1
Q2-9	Lack of incentives for practitioners when introducing the system	3.7
Q2-10	Need to solve connection problem with existing energy data management system	4.1
Q2-11	Worry about excessive data input and system deployment costs	3.9

Figure 3. Obstacles to utilizing the energy management system and BIM.

The BIM-based HMI framework is defined as shown in Figure 4, which considers the obstacles found in the investigation.

C1. BIM-based HMI Design Authoring Tool	C2. BIM-based HMI Deployment Tool	C3. BIM-based HMI Operation Dashboard
C1-1. Project Setup	C2-1. BIM MVD I/F	C3-1. BIM-based HMI Viewer
C1-2. BIM MVD Setup	C2-2. M&C Point Connector	C3-2. M&C Point Data Dashboard
C1-3. M&C Point Setup	C2-3. M&C Device Connector	C3-3. M&C Data Exchange I/F
C1-4. M&C Device Setup	C2-4. Deployment Test	C3-4. M&C Data ETL
		C3-5. BIM-BEMS Database Server

Figure 4. BIM-based HMI framework.

Each component of the framework is defined in Table 2 by reflecting the previously described BIM-based HMI requirements, development process, and investigated obstacles.

**Table 2.** BIM-based HMI framework component definition (\* = multiple).

Component	Related Elements	Description
C1. BIM-based HMI Authoring Tool	H1, D1	A writing tool that defines the screen, BIM space control area, M&C point, M&C device, dashboard, etc. in the BIM-based HMI development project
C1-1. Project Setup	H1, D1, D5	Sets the basic information of the project to be energy-monitored Project = {ID, name, description, position, CRS, BIM_DB.source, BEMS.DB.source} ID = identification CRS = coordinate reference system (e.g., GCS, WGS84, and TM) BIM.DB.source = BIM server connection Uniform Resource Locator (URL) string and log-in information BEMS.DB.source = BEMS server connection URL string and log-in information
C1-2. BIM-BEMS MVD Setup	H2, D2, I1	MVD is set up to define (by selectively filtering) the BIM data items required for energy management. BIM_MVD = {ID, name, description, data.filter *} data.filter = {BIM.object.type, element.member, condition, comparison.value, [data.view.format]} BIMobject.type = BIM object such as IfcDoor, IfcSpace etc element.member = {property   geometry} condition = {'<', '>', '<=', '>=', '==', '!='} comparison.value = compared value dataview.format = defines the format for displaying the BIM data filtered by condition on the screen
C1-3. M&C Point Setup	H4, D4	Sets the monitoring and control points on the BIM-based HMI screen M&C.pointset = {M&C_point *} M&C.point = {ID, name, description, tag *} tag = {ID, name, tag, BIM.object.GUID, position, device.ID, sensing.phase, format} tag.BIM.object.GUID = Global Unique Identification (GUID) of the BIM object whose data is to be monitored position = local coordinates within the BIM object for monitoring data If the value is NULL, the center coordinate of the space pointed to by the specified tag.BIM.object.GUID becomes the position. device.ID = ID of the device specified in the tag sensing.peroid = time interval for acquiring data from a device (in seconds) format = defines the format for displaying the sensor values obtained from the tagged device
C1-4. M&C Device Setup	H3, D3	Device settings required for monitoring and control The device information is obtained from the pre-registered M&C device. M&C.devices = {M&C.device *} M&C.device = {ID, name, description, registered.device.ID, sensor.ID} registered.device.ID = specifies the ID registered in the M&C device library database sensor.ID = The device can contain several types of sensors. The sensor to be monitored must be designated.
C2. BIM-based HMI Deployment Tool	H5, D5	Distributes the BIM-based HMI settings set by the component C1 to the actual operating HMI server



Table 2. Cont.

Component	Related Elements	Description
C2-1. BIM MVD I/F	H2, I1	Using the BIM MVD setting value (C1-2), serves as an interface that filters data from the BIM server and converts them into the format required for display
C2-2. M&C Point Connector	H4, D4	Connects the M&C point (C1-3) set in the BIM-based HMI Authoring Tool and the data source
C2-3. M&C Device Connector	H3, D2	Connects with the set M&C device (C1-4)
C2-4. Deployment Test	H5, D5	Before distribution to the HMI server, a test is performed to ensure that the data related to BIM and energy monitoring is displayed correctly.
C3. BIM-based HMI Operations Dashboard	H6, D6, D7	Provides the BIM-based HMI operation functions
C3-1. BIM-based HMI Viewer	H6, D2, I1	Provides a BIM viewer
C3-2. M&C Point Data Dashboard	H6, D4, D3, D7, I2	Where the data connected to the M&C point are outputted
C3-3. M&C Data Exchange I/F	H6, D6, D7, I2	Interface for obtaining data connected to the H&C point from the BIM, BEMS, and sensor data server
C3-4. M&C Data ETL (Extract, Transform, and Load)	H6, D6, D7, I2	Converts the data obtained using component C3-3 and loads them into the sensing DB server
C3-5. BIM-BEMS Database Server	H2, H3, H4, H5, H6, I1, I2	Provides the BIM and BEMS database servers required for control

The devices described in Table 1 are all needed for energy management and monitoring. Examples of such devices are smart meters, current sensors, voltage sensors, temperature and humidity sensors, and environmental sensors. In general, the communication protocol can be TCP/IP-based MODBUS, MQTT, RESTful API, and others. The M&C Data Exchange I/F (C3-3) must be able to support communication protocols.

The data acquisition cycle and method must be set in the device with sensors to monitor the data set in the M&C points. The data acquired from the set data acquisition cycle are stored in the server before being outputted to the HMI dashboard.

The M&C Data ETL (C3-4) may have the logic for sensing data. The method of acquiring and converting data using the previously designated sensors and setting values may differ depending on the purpose of the data use.

### 3.4. Considerations for BIM Database Development

The following points must be considered before providing the BIM data needed for energy management.

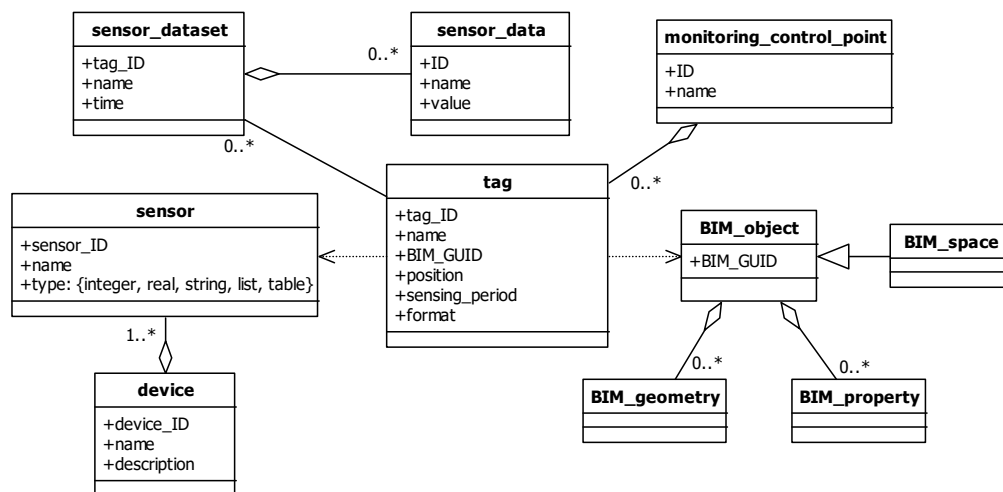
In general, when BIM is used for heterogeneous systems, the modeled BIM data are converted into an IFC file, which is a standard format. However, it is difficult to use the modeled BIM data structure if it does not fit into the energy management system. Table 3 shows the requirements for developing a BIM database when using BIM data in the proposed BIM-based HMI.

**Table 3.** Requirements for BIM database development for energy management.

No.	Requirement	Description
B1	Separation of control space	Considering the energy monitoring control space, the BIM model is spaced and modeled.
B2	Modeling only the elements necessary for control	Elements such as furniture, machinery, and electricity are modeled only when necessary.
B3	Classification system definition and input	If the classification system for each BIM object element is well-defined, it is easy to set the GUID when connecting the control points.
B4	Object GUID value present	Objects must have a uniquely distinguishable GUID value.
B5	No overlap between objects	There should be no overlapping chips between objects.
B6	Space alignment	Spaces defined in BIM must be in contact with each other without overlapping.

### 3.5. Sensing Database Design

The data acquired from the sensor device are stored in the Sensing DB Server (D7) as a database with a structure that can be linked to BIM. Figure 5 shows the essential data structure UML (Unified Modeling Language) that considers interrelationships.



**Figure 5.** Sensing database structure (Unified Modeling Language (UML)).

Table 4. describes Figure 5 in detail.

**Table 4.** Sensing database structure.

Entity	Description
sensor_data	Saves the sensor data ID: sensor data identification name: sensor name value: the sensor value; saved according to the type specified in the sensor
sensor_dataset	Manages the data obtained from the sensor attached to the tag tag_ID: sensor tag ID time: time at which the sensor data were acquired
montring_control_point	Manages tag information on the M&C points

Table 4. Cont.

Entity	Description
tag	Manages tag data tag_ID: tag identification BIM_GUID: BIM object GUID position: position information associated with the BIM object sensing_peroid: defines the data sensing interval format: defines the format of the sensed data output
BIM_object	Defines the BIM object and manages its geometry and properties
BIM_geometry	Defines the BIM object geometry
BIM_property	Manages the BIM object properties
BIM_space	Manages the BIM spatial information and defines a spatial coordinate system that includes shapes
sensor	Manages the device sensor information sensor_ID: sensor identification type: sensor type; classified into integers, real numbers, strings, lists, and tables, depending on the data acquisition type
device	Manages the device and sensor information device_ID: device identification

#### 4. Case Study and Benefits Analysis

##### 4.1. Case Study

In order to test the BIM-based HMI proposed in this study and analyze its effects, a test case was constructed as follows. Based on this case, the researchers operated the BIM-based HMI with the help of practitioners, and analyzed its effects by receiving feedback.

- T1. Building K BIM data development.
- T2. Installation of systems and devices for acquiring energy management data in K buildings.
- T3. BIM-based HMI development and demonstration.

The building modeled in relation to T1 has a building area of 1398.83 m<sup>2</sup>, 5th floor above the ground and 1 underground. BIM modeling was performed using Autodesk Revit, as shown in Figure 6. The modeling took about one month. It was performed after selecting a space for energy monitoring. Existing drawings were used; and in the case of spaces without drawings, the dimensions of the space were measured through a survey.

The BIM model was developed by referring to Table 3 so that it can be used for energy management. The modeled data were converted to the IFC 2 × 3 version and uploaded to the BIM DB server.

Regarding T2, a clip-type meter for measuring power consumption was installed at each control point. The installed information was saved in the Sensing DB.

Regarding T3, a BIM-based HMI framework was implemented using the development tools shown in Table 5. In fact, the part into which a lot of development efforts were put is the component part related to the initial HMI design.

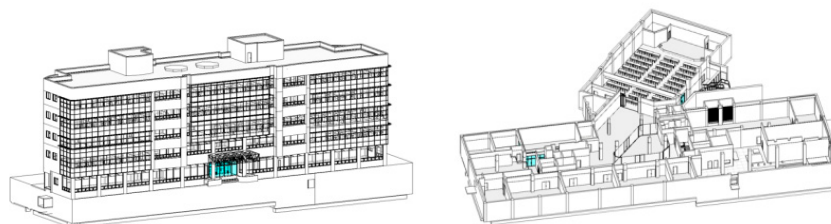


Figure 6. BIM data model.

**Table 5.** BIM-based HMI framework component development method.

Component	Development Tool
C1-1, C1-2, C2-2, C3-1	javascript, node.js, java, python IfcOpenShell
C1-3, C1-4	xbim toolkit, javascript
C2-1, C2-3	java
C3-2	bootstrap
C3-3	RESTful API, MODBUS, MQTT, TCP/IP
C3-4	Talend
C3-5	BIMserver.org, MySQL

The implemented BIM-based HMI log-in account was divided into three phases: design, installation, and operation. The design phase was executed following the steps listed below, using the BIM-based HMI Design Authoring Tool. (The design stage can be performed at high speed because there is no need for a development process such as programming. The process uses only drag and drop and setting. In addition, in similar projects, related setting information is easy to recycle).

1. Create a new BIM-based HMI project.
2. Select and load the BIM and BIM MVD file.  
The modeled BIM data are filtered by MVD to reduce complexity, because the space and objects required for energy monitoring are part of it. Thereafter, the lightweight BIM data are stored in the BIM server.
3. Select the M&C device from the Device Library.  
The M&C devices are already registered in the library. The sensor information that can be used for each device is predefined. In this step, only selection of the devices required for monitoring is performed.
4. Create the M&C point.
5. Allocate the M&C device's sensor to the M&C point as a tag.  
The sensor of the created M&C device is assigned to the M&C point.
6. Allocate the M&C point to the BIM space or element object.
7. Deploy the BIM-based HMI project to the HMI server  
Since the information required for control is set, the created project is distributed to the HMI server.

When the installation process is completed, the perspective of the HMI UI changes according to the account type after log-in to the BIM-based HMI (Figure 7). The control screen displayed after the log-in (U1) is largely divided into three types (U2). The menus and components that can be used are changed according to the perspective of the HMI UI. On the left side of the screen, the space included in the BIM and the BIM object tree (U3), including the elements, are displayed. Clicking on the control space displays the BIM Viewer for controlling the energy data in the middle of the screen (U4). When a node is selected in the BIM object tree (U5), the control points are listed at the top (U6), and a dashboard (U8) is displayed in the lower part for each tag (U7) set at the control points.

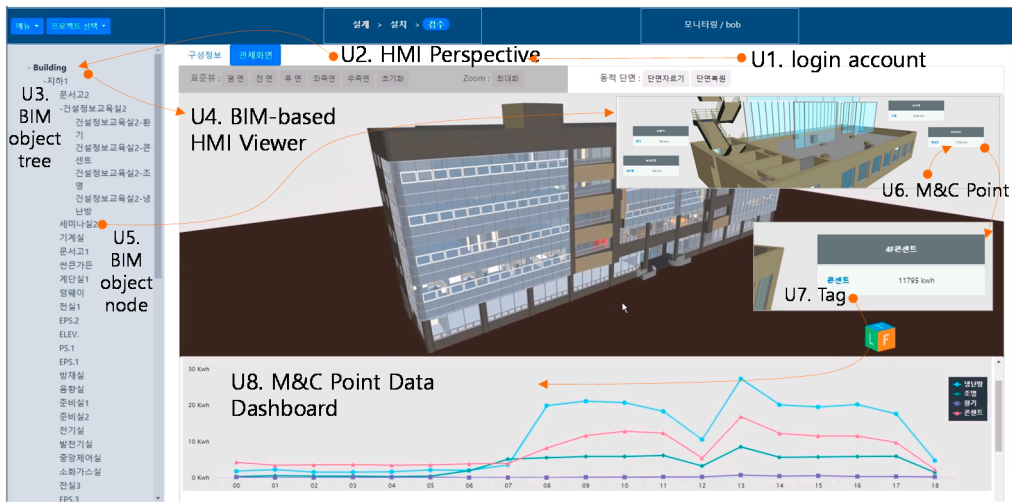


Figure 7. BIM-based HMI UI (user interface).

The BIM Viewer (U4) displays the space being monitored for energy, and allows checking of the location by setting the camera at various viewpoints. If the web-based operation is connected to the Internet, the energy monitoring information can be checked in real time at any time. In addition, by supporting mobile devices such as smartphones, related locations or data can immediately be checked on the site (Figure 8).

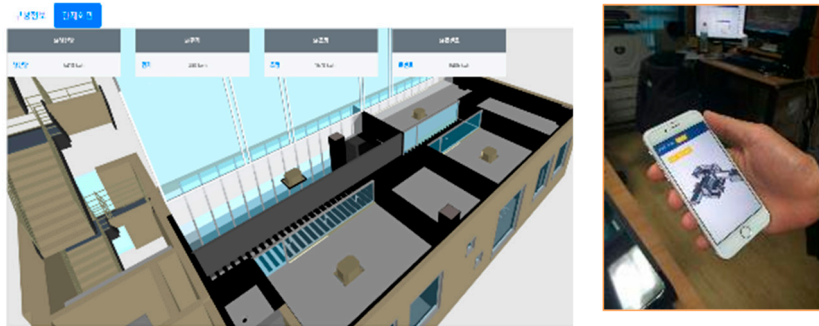


Figure 8. BIM-based HMI M&C point and mobile use in the field.

The data obtained for each tag specified in the control point are outputted in the format specified during the design. The sensor name, ID, and data are outputted on the dashboard and can be monitored in various graph formats. If a tag is attached to the BIM element object, it can be clicked to check the related sensor data (Figure 9). In this case, the object is highlighted, and the sensor data are displayed on the right.

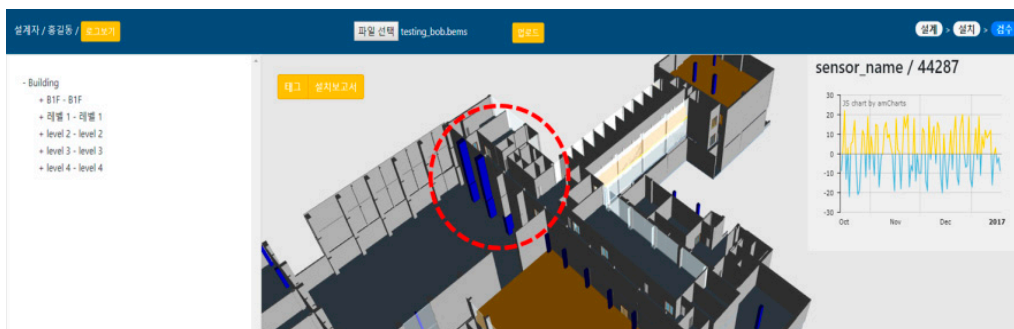


Figure 9. BIM-based HMI.

#### 4.2. Analysis of the Interview Design and Benefits

To analyze the effects of the BIM-based HMI, the researchers conducted interviews with practitioners using a questionnaire after they were asked to use the software. The interviews were held for a month, from 1 October 2019. There were 32 interviewees. The main questions are as follows.

Q3. What do you think is the benefit of BIM-based HMI?

1. Prompt information verification—prompt acquisition and verification of necessary information.
2. Helps save energy—savings through energy monitoring.
3. Intuitive use of spatial information—management is possible in connection with spatial information such as BIM.
4. Scalability—services can be flexibly customized or developed as needed.
5. Real-time service—internet can be accessed anywhere and at any time.
6. Connectivity—internet-based systems and connected services, e.g., sending a text message when an incident occurs.
7. Proactive response—predicting and responding to future management information through data learning

The interviews were conducted with practitioners who have experience in both energy management and BIM. To check the distribution of the respondents, inquiries were made by classifying them into their work field, experienced process stage, working experience, and research experience. The respondents’ fields of work were architecture (40.6%), environment (34.4%), and energy (25.0%). Most of them had practical experience that spanned five to 10 years (37.5%), and the rest, two to five years (18.8%), less than two years (18.8%), 10 to 15 years (15.6%), and 15 years (9.4%) in Figure 10.

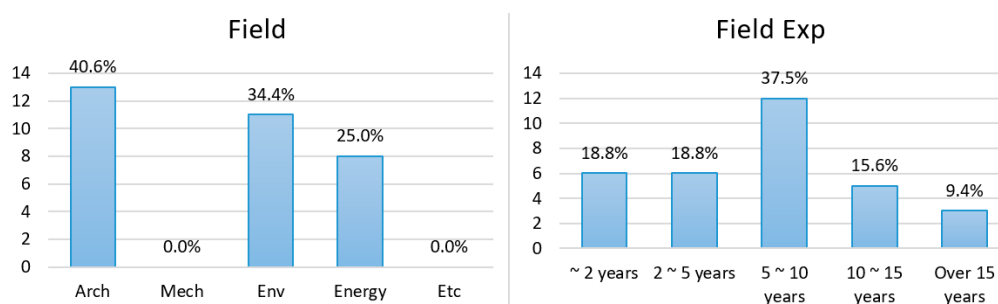


Figure 10. Distribution of the survey targets.

The identified effects of using BIM-based HMI are connectivity (Q3-6, 4.3), real-time service (Q3-5, 4.3), quick information check (Q3-1, 4.2), intuitive use of spatial information (Q3-3, 3.9), scalability (Q3-4, 3.9), and energy-saving help (Q3-7, 3.8) (average: 4.0) in Figure 11. The Cronbach-Alpha value of the survey results was 0.85, indicating good consistency.

No	What do you think is the benefit of BIM-based HMI?	Benefit
Q3-1	Rapid information acquisition and verification of necessary information	4.2
Q3-2	Helps to support energy-savings through energy monitoring	3.7
Q3-3	Intuitive use under BIM spatial information-based management is possible	3.9
Q3-4	Services can be customizable, flexible as needed	3.9
Q3-5	Real-time service with internet access	4.3
Q3-6	Connected services available	4.3
Q3-7	Information prediction and proactive response using data mining	3.8

Figure 11. Analysis of the benefits of the BIM-based HMI data support.



The interview results showed that the problems that were investigated as requirements when designing the BIM-based HMI framework (Figure 3) are being solved to some extent.

$$\{Q2-10\} \rightarrow \{Q3-6, Q3-5\}, \{Q2-5, Q2-11\} \rightarrow \{Q3-1, Q3-3\}, \{Q2-8\} \rightarrow \{Q3-4\} \quad (2)$$

The profit distribution of the BIM-based HMI was relatively examined (Figure 12). It was seen that the respondents perceived that Q5-5 and Q5-6 are relatively more profitable than Q5-2 and Q5-3. As a result, the advantage of BIM-based HMI is recognized as its linkage of the BIM, the sensor device, and the energy management system, and its real-time data monitoring function. However, the survey results showed that the respondents were not clearly aware of the savings effect of energy monitoring. This can be observed only after one has been operating the system for a long time. It seems that the survey questionnaire failed to capture this information.

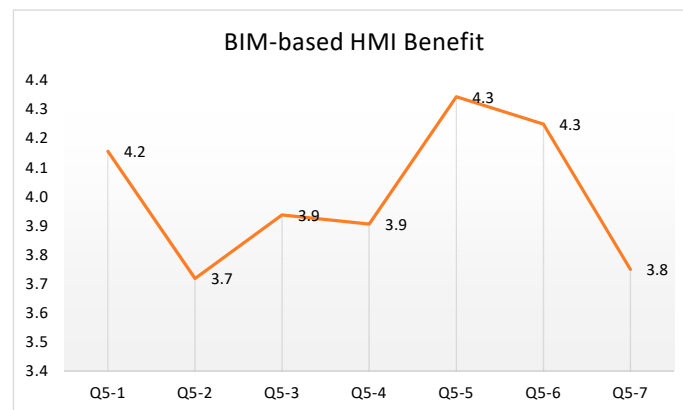


Figure 12. Analysis of the benefits of the BIM-based HMI data support.

## 5. Conclusions

This study proposed a BIM-based HMI framework for effective energy data monitoring. To support the proposal, related technology trends were investigated, and the requirements for the BIM-based HMI framework were derived through case investigations. Based on the requirements, the role of each component of the framework and related data items were defined. Through this process, the authors designed a method of interfacing BIM-BEMS from an HMI perspective. As part of the move, 13 components, up to C1-3, were derived. Through case analysis, the proposed BIM-based HMI was developed, and its effects were analyzed through a questionnaire survey of working-level practitioners. The results of the analysis showed that BIM-based HMI had benefits in real-time data monitoring (4.3/5.0), and positive effects in system function expandability and BIM-based spatial intuitiveness (3.9/5.0).

However, this study had limitations. It failed to investigate the energy saving effects after long-term system operation. In a future study, the researchers plan to acquire long-term data from the energy data monitoring device installed in the building to be tested, and to analyze the quantitative effects of the system built with the proposed framework. In addition, the researchers plan to check the effectiveness of the proposed technology for more diverse buildings.

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