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A Decision Support Model for Intelligent Facility Management through the Digital Transformation

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Abstract: Information on the energy consumption of buildings that can be obtained through conventional methods is limited. Therefore, this study aims to develop a model that can support decision making about building facility management through digital transformation technologies. Through the IoT sensor, the building's energy data and indoor air quality data are collected, and the monitored data is visualized through the ELK Stack and produced as a dashboard. In addition, the target building is photographed with a 360-degree camera and maps using a tool to create a 360-degree tour. Using such digital transformation technologies, users of buildings can obtain various information in real time without visiting buildings directly. This can lead to changes in actions or actions for building management, supporting facility management decisions, and consequently reducing building energy consumption.

Key words: digital transformation, facility management, 3d digital twin, building energy performance, indoor environmental quality, real-time monitoring and diagnostics

1. INTRODUCTION

1.1. Background and Objectives

There have been various plans to reduce the CO^2 emissions globally to address the global warming issue, which is due to the continuous rise in the CO^2 concentration in the earth's atmosphere. Based on the primary energy consumption level, South Korea is the eighth country in the world with the largest primary energy consumption. As South Korea does not produce energy sources like oil, the energy-saving efforts of the government or civil movements are more important [1]. According to the Fourth Report by Intergovernmental Panel on Climate Change (IPCC), 40% of the global energy consumption is from buildings [2]. Additionally, a 2007 survey by Internal Energy Agency (IEA) showed that building energy consumption accounts for 25% of the total annual energy consumption in South Korea. The energy consumption in buildings is closely linked to the building occupants, whose behaviors are extremely difficult to monitor and control. In particular, as the information about the building energy consumption that can be offered to the building occupants is extremely limited, it is difficult to convince them to save energy. An energy bill is a well-known example of such information offered to the building occupants, but it has limitations. First, it shows the energy costs one month after they are incurred, and as such, it cannot offer the building occupants real-time information on their energy consumption. Also, it does not provide detailed information on energy consumption(e.g., information by space, equipment, or time of day), thus not allowing the energy consumption pattern to be identified. Finally, it does not offer information on the indoor environmental quality (IEQ) and cannot obtain information on the sustainability of the space and the degree of comfort of the building occupants.

To address these limitations, it is necessary to conduct a study on the development of a system that can monitor in real time the information on the building energy consumption by equipment and IEQ, based on which the energy efficiency and IEQ by space can be diagnosed. Therefore, this study aimed to develop a decision-making model that could support intelligent facility management through digital transformation. Towards this end, it aimed to realize the digital transformation through the following two approaches: (i) software-based digital transformation; and (ii) hardware-based digital transformation. Software-based digital transformation involves monitoring and diagnosing real-time data (energy efficiency and IEQ) through IoT-based sensors, whose results are then visualized and produced as dashboards. Hardware-based digital transformation, on the other hand, is to take panoramic images with a 360º camera and produce a 360º tour model. By integrating and applying these digital transformation technologies, the proposed decision-making model allows building occupants to verify real-time information on energy efficiency and IEQ per space remotely, without visiting the actual space. Furthermore, by using the information offered through the digital transformation, the proposed model can offer building occupants a comfortable and sustainable space and encourage changes in the occupants' energy-saving behavior.

1.2. Scope and Methodology

This study established as its spatial scope Sangju Wonkwang Preschool located in Sangju, Gyeongsangbuk-do, South Korea <Fig. 1>. The building consists of a three-story main building and a two-story annex. On the first floor are a teachers' room and two classrooms, and on the second and third floors are a learning preparation room and three other classrooms.

Figure 1. Sangju wonkwang kindergarten (main building)

The real-time data collected with Internet of Things (IoT)-based sensors (energy and indoor environmental sensors) were used to realize dashboards with which to monitor and diagnose the energy efficiency and IEQ per space in real time. Furthermore, a 360º camera was used to take panoramic images, based on which a 360º tour model was produced. The duration of this project was from September 2018 to June 2019, and the data collected during this period were used in the study.

2. THEORETICAL OVERVIEW

2.1. Preliminary Survey

Digital transformation is the application of digital technologies like cloud computing, IoT, big-data solutions, and artificial intelligence (AI) to the existing societal structure, and the innovation of the overall services and operational processes in the society as a result. Digital transformation in the construction industry can be examined through two general approaches. The first is the software-based approach, in which the various data generated in the lifecycle of a building are digitized. The occupants' location and behavioral information, energy efficiency, and IEQ information per space, and other data generated in the maintenance stage of a building, are collected and analyzed in real time to establish an intelligent facility management system. The second is the hardware-based approach, in which the external elements of a building, like the site arrangement, building structure, and indoor finishing, are digitized. Often called "3D digital twin," this approach is widely used for various purposes in South Korea and abroad. Mainly applied in the design stage, this 3D digital twin method is less often applied in the maintenance or disposal stages [3]. The cases in South Korea where it was applied in the maintenance stage are POSCO's "Smart Factor System" and SK Telecom's "3D In-building Facility Management System," among others.

POSCO's Smart Factor System used a real-time big-data analysis method to analyze the quality factor defect elements based on the facility conditions. This system applied an "active alarm" to rotation and exchange items to improve the accuracy of the quality factor defect elements offered in real time.

On the other hand, SK Telecom's 3D In-building Facility Management System was realized for the establishment of a communication facility maintenance guidance system for VIP customer facilities, with the aim of reducing the repair time in the case of communication issues. With this system, the maintenance workers can easily identify the locations and statuses of communication facilities as well as the locations and network systems of the related facilities based on the 3D digital twin technology.

2.2. Real-Time Dashboard Realization Technology

2.2.1. IoT-based Sensor

The realization of dashboards requires the monitoring and diagnosis of real-time data. This study used two IoT-based sensors for real-time data collection: (i) Enertalk; and (ii) Awair <Fig. 2>. Enertalk collects energy information like the power consumption of a building by space and equipment to present the hours of usage of facilities and equipmentss as well as the standby power consumption, electricity consumption pattern, and power consumption by appliance. Awair, on the other hand, is an indoor environmental sensor. It collects information on the temperature, humidity, CO_2 concentration, chemicals, and ultrafine dirt per space, and digitizes and expresses each index.

a) Enertalk b) Awair

Figure 2. Types of sensors

IoT-based sensors are connected via a communication network like WiFi, and the collected data are sent to a server in real time. As such, the collected data can be monitored and diagnosed in real time.

2.2.2. ELK Stack

ELK Stack, a system that analyses data in various formats from diverse resources, is key to the realization of a dashboard. As an open-source system offered by Elasticsearch, ELK Stack includes various software programs, and the first letters of the three most popular programs, Elasticsearch, Logstash, and Kibana, were used to name it "ELK." Elasticsearch is an open-source search and analysis engine that supports the search, analysis, and storage of data; Logstash is a data collection pipeline, and Kibana is an extensible UI tool with which to visualize data and construct and manage all the functionalities of ELK Stack. Using each of these functions, the user can realize a dashboard that can visualize the results of the real-time data monitoring, diagnosis, and analysis.

2.3. 3D Digital Twin Realization Technology

2.3.1. 3D Digital Twin

Digital twin can be defined as an object that contains a series of virtual information models and data [4][5], or as a technology or means, like a simulation [6]. Generally, it can be defined as a digital profile of the past or present status of a physical object or process. In addition, different definitions can be used based on the functions in various fields [7]. In the construction industry, 3D digital twin means "the digitized data of the images or drawings of a site or building." Different from the existing computer-based design, it is significantly more than mere digitized data [8]. Models based on the 3D digital twin technology allow for swift and simple extension and connection with IoT technologies. Therefore, it can lead to the best business results as it is repeatedly adjusted to make it adapt to environmental or operational changes [9].

The core of the 3D digital twin technology is to realize a site or building in 3D. As it is limited to realizing 3D data in conventional images, 3D digital twin uses panoramic images with a wider angle of view. Thus, the best method of acquiring the data required for the 3D digital twin is using a 360º camera <Fig. 3>.

Figure 3. 360° camera

2.3.2. 360º Camera

Unlike the conventional cameras, a 360º camera offers wider vertical and horizontal angles of view. Thus, it can offer spherical panoramic images with only the two lenses attached to the front and back parts of the camera, which are called "360 panorama.". While a 360º panorama can be realized with the images taken by a conventional camera, it is not suitable for use as the resulting image can cause considerable distortion in the 3D image stitching process.

A 360º panorama can offer better reality and immersion to a site or building than the conventional images. Thus, it can be used to help improve the building occupants' understanding of the space.

2.3.3. 360º Tour Model

A 360º panorama taken by a 360º camera can be used to restructure a 360º tour model, and this study used Cupix's tool for this purpose [10]. The information that can be expressed by individual panoramas is limited because it does not offer spatial continuity. To address this limitation, Cupix's tool can be used to convert the 360º panorama to a 360º tour model. When consecutive 360º panoramas are uploaded to the tool, a road-view-like format can be produced in the order of the images. By revising the result, a 360º tour model can be constructed. Such a 360º tour model can improve the building occupants' understanding of the space and can make the usage of the dashboard more intuitive.

3. RESEARCH FRAMEWORK

3.1. Installation of IoT-based Sensors

First, an energy sensor and an indoor environmental sensor were installed in the target building to collect, monitor, and diagnose real-time data. In this study, energy and indoor environmental sensors were installed in eight classrooms in Sangju Wonkwang Preschool, and the data collected from such sensors were used. The normal operation of the installed sensors can be confirmed by each application of sensors.

3.2. Production of the Real-Time Dashboard

A dashboard was created with ELK Stack to visualize the data monitored from the IoT-based sensors. In this process, the sensors should always be connected to a communication network, and the real-time data should be sent to a server. ELK Stack should immediately visualize the incoming real-time data. The real-time dashboard produced as such offers energy efficiency and IEQ information by space and equipment in various formats.

3.3. Imaging of 3D Panoramas

A 360º camera should be used to take pictures of the target building. Before taking pictures, the characteristics of the space should be determined in advance, and the image shooting should consider these characteristics. For an indoor space that is relatively small and has many variables, images should be taken with smaller gaps. More care should be taken to take pictures of doors that separate two different spaces because if the shooting gap is too wide, the spatial characteristics cannot be sufficiently detected by Cupix's tool, halting the mapping process. If in an outdoor space, there are fewer obstacles and more marked signals (trees, buildings, etc.) than in an indoor space so that pictures can be taken with wider gaps than those of indoor images, thus reducing the shooting time.

Sangju Wonkwang Preschool, the target building of this study, has similar-looking spaces arranged in repetition; as such, pictures were taken with smaller gaps. Based on an arbitrary point in the shooting area, pictures were taken by moving zigzag at fixed distances (indoor: 1-2 m; outdoor: 3-4 m), without any missing area so that a natural-looking panorama tour could be created. The zigzag shooting method is more useful than the spiral shooting method for mapping purposes.

In this way, images of all the spaces, from the first to the third floor of the main building, were taken, and a sufficient number of 3D panoramas were acquired.

3.4. Production of the 3D Digital Twin

The panoramas are uploaded to Cupix's tool by setting the name of the file as well as the number of sections, selecting and uploading files, and confirming such files. Among these processes, the setting of the number of sections can be used when the target area is wide or when the target area consists of several spaces (e.g., Room 1, Room 2, and Bathroom). Once the desired number of sections is entered, each section name can be determined <Fig. 4>, and the panoramas suitable for each section can be uploaded.

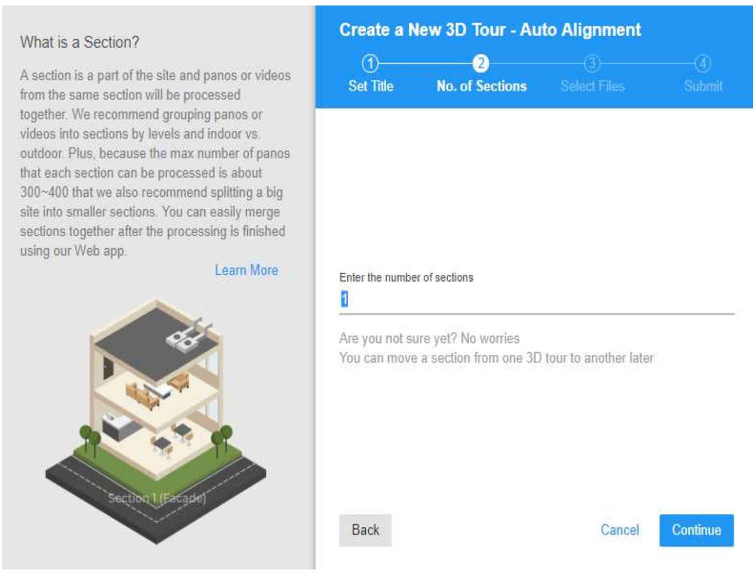

Figure 4. Setting up sections within the Cupix tool

As has been explained, Sangju Wonkwang Preschool consists of similar-looking spaces allocated repeatedly. Therefore, the section was divided into the first floor, the second floor, and the third floor of the main building, and was uploaded as such. While the main building has three floors, the panoramic point is expressed on a plane; as such, the panoramas at each floor may become tangled, making it impossible to distinguish one from another. Furthermore, if some panoramas are not identified during the mapping, the other panoramas can also be affected, and all the panoramas may end up failing to express spatial information. Therefore, the section should be further divided to reduce such risks.

Once the uploading is completed, more detailed editing processes, such as the setting of the coordinate axes, the setting of the floor level, and the selection of unused panoramas, can be performed in the editing stage. Here, unused panoramas do not express spatial characteristics, and therefore, even if they are entered to the section manually, the coordinates, viewpoint, height, etc. should also be manually determined. It is crucial to shoot images with suitable gaps so as to not generate any unused panorama. While taking images with a 360º camera, personal information, including portrait rights, can be unintentionally included in the images. People's faces are automatically detected and blurred by Cupix's tool, but other personal information, like the license plate of a car, should be identified and processed carefully. Once all these editing processes are completed, a 360º tour model is produced to realize an actual 3D digital twin, which can then be used by the building occupants to browse through the target space anytime and anywhere.

3.5. Synchronization of the 3D Digital Twin and the Dashboard

For the synchronization of the 3D digital twin and the dashboard, the "pin" function in the tour editing stage of the mapping process is used. The pin function allows texts or external video links to be added in the space so as to help present information that cannot be expressed with the 360º tour model. Through the use of this function, the dashboard produced by ELK Stack can be expressed in the 360º tour model. This improves the user's understanding of the space and helps identify the energy efficiency and IEQ information clearly. Shown in Fig. 5 is an example of the spatial characteristics using the pin function of Cupix's tool.

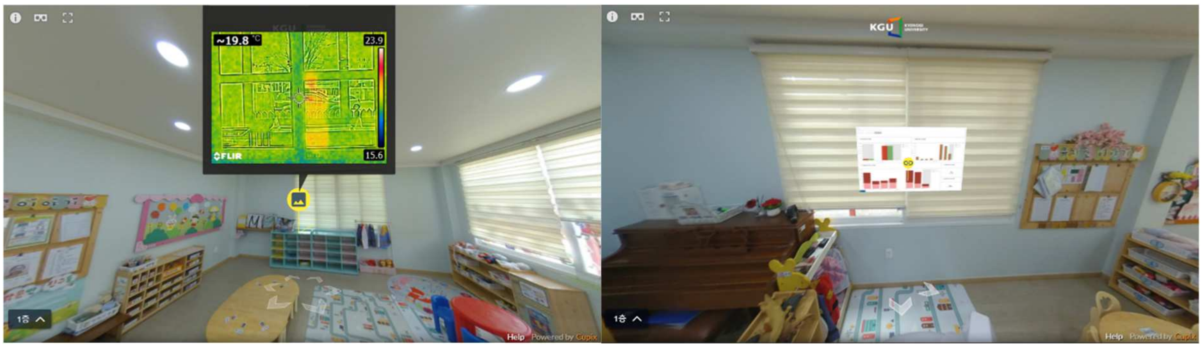

Figure 5. Example of using Pin functions

4. RESULTS

4.1. Realization of the Real-Time Dashboard

This study aimed to realize a real-time monitoring and diagnosis system of the information of a space (energy efficiency and IEQ) so as to support the building occupants' decision-making on the degree of spatial comfort and sustainability. A dashboard was created to offer real-time data on the energy efficiency and IEQ data of each space of the target building, Sangju Wonkwang Preschool. Using this dashboard, the users can check the statistical analysis results and graphs on the energy consumption of the target space by equipment, the energy consumption pattern by the time of day, and the recommended standard and comfort level by IEQ index, without physically visiting the space <Fig. 6>.

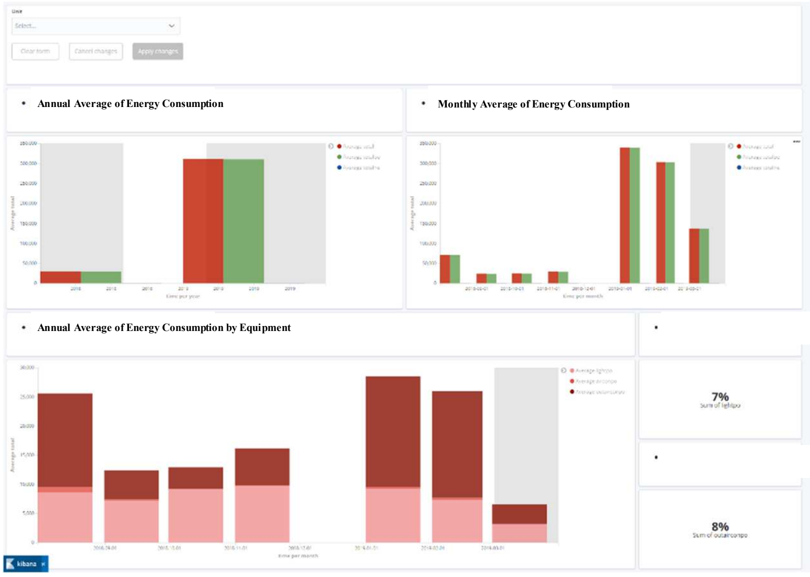

Figure 6. Example of Energy Consumption Dashboard

4.2. Realization of the 3D Digital Twin

The target building was divided into a total of three sections (the first, second, and third floors of the main building), and a 360º camera was used to take images of each section 1-2 m apart, to create 360º panoramas. These panoramas were uploaded to Cupix's tool and were mapped by spatial continuity to create a 3D digital twin. Using the pin function of Cupix's tool, the 3D digital twin was linked to the dashboard. In this way, the structure and characteristics of the actual space were identified remotely, and at the same time, the energy efficiency and IEQ information of the space could be analyzed.

4.3. Applications and Expectations

4.3.1. Remote diagnosis

In the past, building or facility occupants had to visit the site in person or seek help from energy measurement specialists to acquire data on their energy consumption. Also, most of the data were superficial data offered by energy statements or energy consumption bills, and the same can be said of the IEQ information. By using the model (particularly the real-time dashboard) developed in this study, however, real-time data that used to be difficult to acquire could now be collected, and also, additional data from various points of view can be simply verified by adjusting the parameters of ELK Stack

4.3.2. Acquisition of the information of a space

. It is relatively easy for the building occupants to understand the building information by space (energy efficiency and IEQ) because they possess some background knowledge of the space and information. Those who are neither occupants nor facility managers, however, usually lack understanding of the space and information, and it is difficult for them to make an informed decision based on simple data. Using the model developed in this study (and particularly 3D digital twin), their level of visual understanding of the space and information can be improved.

4.3.3. Link to BIM

Further analysis of the space is possible by using tools like Cupix. In other words, besides the spatial shape, information on the lengths and thicknesses of the walls, although somewhat limited, can be acquired. If such technology continues to be developed, it can be linked to BIM and used for the maintenance of a building [11].

5. CONCLUSION

In this study, a decision-making model was developed for supporting intelligent facility management through digital transformation. The spatial scope of the study was Sangju Wonkwang Preschool in Sangju, Gyeongsangbuk-do, South Korea, and the duration of the study was from September 2018 to

June 2019. First, a dashboard that would offer the real-time monitoring and diagnosis results of the building energy efficiency and indoor environmental quality (IEQ) was developed. Also, the panorama images from a 360º camera were mapped to produce a 360º tour model. By integrating these two outputs, a 3D digital twin model was created. In this way, the study established a framework based on which building occupants could verify and take action on the energy efficiency and IEQ information of the target space remotely, without physically visiting the space.

In the existing method, the data on the energy consumption of a building or facility and the IEQ per space are very limited. As a result, there is extremely insufficient evidence based on which the building occupants or facility manager could take action. Using the proposed intelligent facility management system, however, the building occupants or facility manager could use the various data (monitoring and diagnosis results) shown on the dashboard as the bases for their decision. Furthermore, it is expected to reduce the facility maintenance costs considering that with the proposed system, the building occupants or facility manager would not have to physically visit the site to obtain the information that they need. In the future, it is expected that a framework with which to consider facility management in advance in the integrated process, from the planning stage to the design, construction, and maintenance stages of a building, will be established by linking the proposed system to BIM.

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REFERENCES

[1] BP, "BP Statistical Review of World Energy 2019", 2019.

[2] Intergovernmental Panel on Climate Change, "the Fourth Assessment Report", 2007.

[3] B. Buckley, K. Logan, "The Business Value of BIM for Infrastructure 2017", 2017.

[4] M. Grieves, "Digital Twin: Manufacturing Excellence through Virtual Factory Replication", pp. 1–7, 2014.

[5] J. Haupert, X. Klinge, "CPS-Based Manufacturing with Semantic Object Memories and Service Orchestration for Industrie 4.0 Applications", Industrial Internet of Things: Cybermanufacturing Systems, pp. 203-229, 2016.

[6] EJ. Tuegel, AR. Ingraffea, "Reengineering Aircraft Structural Life Prediction Using a Digital Twin", International Journal of Aerospace Engineering. 2011, 2011.

[7] A. Parrott, W. Lane, "Industry 4.0 and the digital twin", 2017.

[8] R. Lu, I. Brilakis, "Digital Twinning of Existing Reinforced Concrete Bridges from Labelled Point Clusters", Automation in Construction, 2019.

[9] V. Gopinath, A. Srija, "Re-design of Smart Homes with Digital Twins", Journal of Physics Conference Series, 2019.

[10] Cupix, https://www.cupix.com/index.html , 2019.05.

[11] M. Park, "Current Status of the BIM-Based Augmented Reality Technology", KIBIM Annual Conference 2015, vol. 5, pp. 51-54, 2015.