As shown in Figure 7 (a), the shear walls and beams in the initial design are redistributed to form a semi-closed core at the building center in order to improve the overall building stiffness. Specifically, five shear walls and one beam are added to the structural system, which then interacts with the existing perimeter walls in the building to form the semi-closed core. This effectively mobilizes the rigidity of the perimeter walls to enhance the torsional resistance of the building and the overturning resistance against the wind load. As a result, the maximum lateral displacement at the topmost floor of the optimized design is substantially reduced, which is considerably smaller than that for the initial structural design. As Figure 7 (b) shows, the demand for construction materials (including concrete and steel reinforcement) as well as their corresponding embodied carbon are saved by up to 21%.

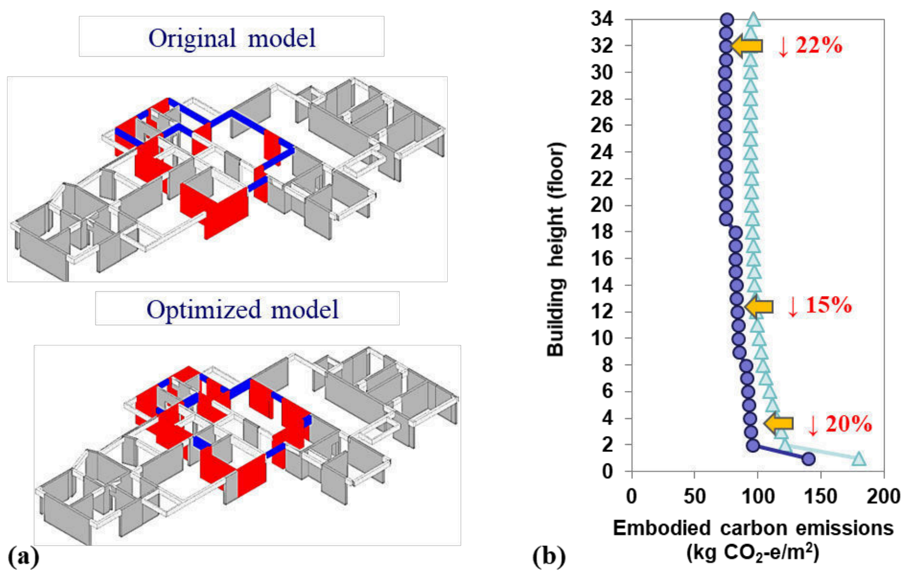

Figure 7. Optimization of (a) structural form and (b) embodied carbon.

CONCLUSIONS

This paper presents an integrated design optimization approach based on BIM for both architectural layout plan and structural form optimization, with the aim of minimizing both the operational and embodied carbon in buildings. A case study shows that the proposed approach saves around 30% of the carbon emissions from energy use during building operation as well as 21% of the carbon footprint from construction materials. In reality, designers can use better material designs, structural forms, and architectural solutions to reduce the embodied carbon, but such design changes may adversely impact the operational stage carbon emissions. Effort is still much needed to explore the potential trade-off relationship between embodied and operational carbon to reveal more insights on life cycle carbon emission reduction in buildings.

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Designing a Database Schema for Supporting Visual Management of Variable Parameters in BIM Models

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ABSTRACT

Recently there has been growing recognition of the value of facility management (FM) in the construction field. Nowadays, FM data can be extracted from parameters of BIM (building information modeling) models. Thus, it is increasingly important to manage parameters of BIM model elements in the operation and maintenance (O&M) stage. Currently, parameters in a BIM model are mostly treated as static (i.e. fixed information of a model element). In order to make BIM model more valuable in the O&M stage, variable parameters (operating information of a model element) should be considered in a BIM model to address the data management need in actual environment of a building, such as status of a building element (e.g. movable wall's status), IoT (Internet of things) data, etc. This paper presents an effort in designing a database schema for integrating both static and variable parameters of a BIM model into the database. The design considers the compatibility with COBie (construction operations building information exchange) and supports visual management of BIM model parameters, especially variable parameters. In addition, applications of the database with the proposed design are demonstrated through API implementation in Autodesk Forge.

INTRODUCTION

In the AEC (Architecture, Engineering, and Construction) industry, there has been a growing global trend in introducing Building Information Modeling (BIM), a rapidly emerging technology. In practice, different parties employ different BIM tools in respective areas or stages during a construction project. The remarkable advantage of BIM technology is that BIM model can accommodate plenty of information of constructed facilities including geometric and non-geometric data. Nowadays, Facility Management (FM) area had become increasingly important among researchers and commercial software companies (Aslam & Tarmizi, 2018), and more work has been done on adopting BIM in FM. Krukowski & Arsenijevic (2010) also find out that FM management with BIM has many potentials, including real-time access of data, monitoring environment fact, etc. According to the requirement of FM, the researchers and BIM stakeholders began to use COBie (Construction Operations Building Information Exchange) for facility management. COBie, originally developed by the US Army Corps of Engineers (NIBS, 2015), is an "*information exchange specification for the lifecycle capture and delivery of information needed by facility managers*" (East, 2010). Also, it can help capture and save the project data during the whole building life cycle. The COBie standard organizes building data in a series of related worksheets, which together form a database for describing a building's FM information set, such as facility information, product datasheet, warranties, spare parts list, preventive maintenance schedules, etc. (IFMA, 2013).

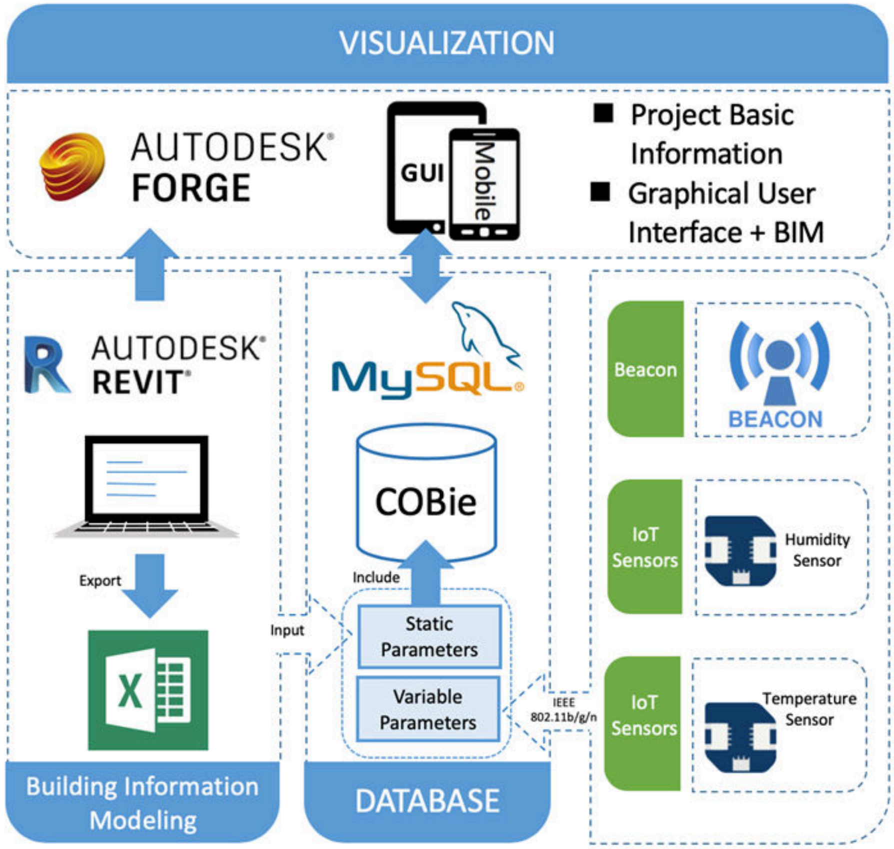


Fig. 1: Methodology for visual information management of BIM parameters

Generally, parametric modeling is composed of geometric components with non-geometric attributes, and the advantages of 3D product modeling are well documented. Goedert & Meadati (2008) discovered that the usage of BIM model diminishes rapidly after the preconstruction stage. Also, researchers rarely considered adding variable parameters in a BIM model for reflecting the actual conditions of a building space, e.g. collecting real-time temperature values and humidity values into the BIM model. In order to make the BIM model more valuable in the O&M (Operation & Maintenance) stage, Kuo et al. (2017) proposed that parameters in BIM model should include not only static parameters (i.e. size of components in building, location of facility) but also variable parameters (i.e. data collected by IOT sensors). Kirstein & Ruiz-Zafra (2018) also pointed out that current BIM models do not support IoT from the early design stage, because standards and specifications are not prepared to address smart environments with IoT which contain monitoring sensors and controlling devices. Therefore, based on Kuo et al. (2017), this research aims to design a database schema for integrating both static and variable parameters of a BIM model to accommodate the real-time sensor data into the database.

For reasons mentioned above, the design considers the compatibility with COBie and supports visual management of BIM model parameters, especially variable parameters. For the sake of storing variable parameters with BIM, this research also extended the database schema for variable parameters. In addition, applications of the database with the proposed design are demonstrated through API implementation in Autodesk Forge. In this paper, we employ the Civil Engineering Research Building at NTU in Taipei City as a case study.

METHODOLOGY

Figure 1 illustrates the system framework for visual information management of BIM parameters, which can be divided into four main parts. The first part is Building Information Modeling. In order to effectively manage building spaces and basic project information, BIM models were created by using Autodesk Revit. With BIM, it also allows us to visualize the project's progress in real-time. The second part is Database. The database in this research is an organized collection of data, including building information and sensors data. After we created the BIM model, we need to export from the model the COBie data which are treated as static data and stored in Excel spreadsheet (.xls) file format. The database also collects data from sensors that we set in the building, and we store these data in the system using variable parameters. The third part is IoT sensors. In this research we use temperature sensors and humidity sensors for monitoring environmental conditions. In order to record history values, the sensor's data are also transmitted to the database by Wi-Fi protocol. The final and fourth part is Visualization. In terms of visualization, the system applies colors and a graphic table for better visualization of building information. We also place sensor components in the BIM model to illustrate their locations, making it easier for a user to understand the environmental values of a specific zone. For example, the color of the floor may change according to the sensor's real-time value.

NORMALIZATION IN DATABASE FOR COBIE FORMAT

Database normalization is the process of restructuring and organizing data to minimize redundancy, and it is also a process to validate and improve a logical database design (Demba, 2013). A normalized database contained several advantages, such as it allows the system to perform tasks such as searching, sorting, and creating index faster since tables are now narrower, while more rows fit on a data page, and normalization is easier and more concise to maintain and change as data need to change. Therefore, normalization should be a part of the database design process. According to these reasons, COBie was employed as the database structure in this research. The database was then processed through First Normal Form (1NF) and Second Normal Form (2NF).

- First Normal Form (1NF): To remove multi valued attributes, and make every attribute value atomic.
- Second Normal Form (2NF): There should be no partial functional dependencies.

DESIGNING ENTITIES FOR VARIABLE PARAMETERS

This research extended the original COBie structure in the database for the sake of making BIM model more closely resemble a real-life situation (as shown in Fig.2). Basically, attribute worksheet in COBie is used to capture properties of any other COBie worksheet (as shown in Fig. 3(a)). However, it is not able to store real-time data, record a time stamp, and may be data redundant when lots of data are stored.

According to this reason, we design BIM object entity as super type entity to store the common attributes of BIM objects (such as create time, element ID, etc.), and the two child entities are "Variable parameters" and "Static parameters". Moreover, every history data set in the database corresponds to one scenario for user analysis (e.g. energy record) or investigation (e.g. status of an object) in the future.

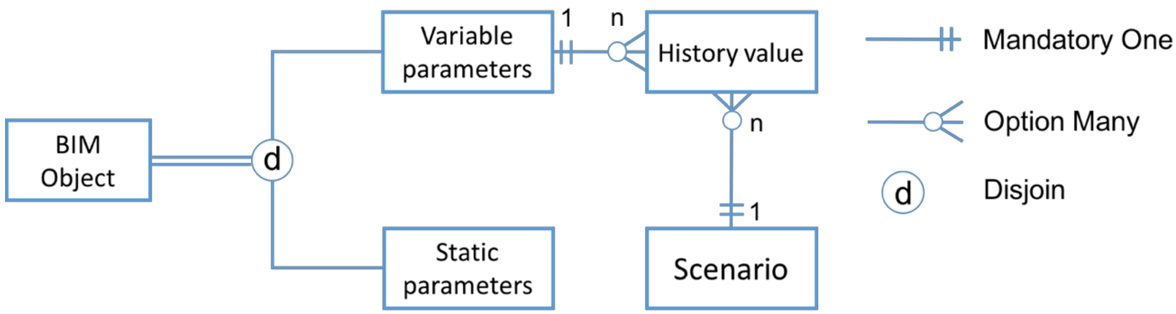
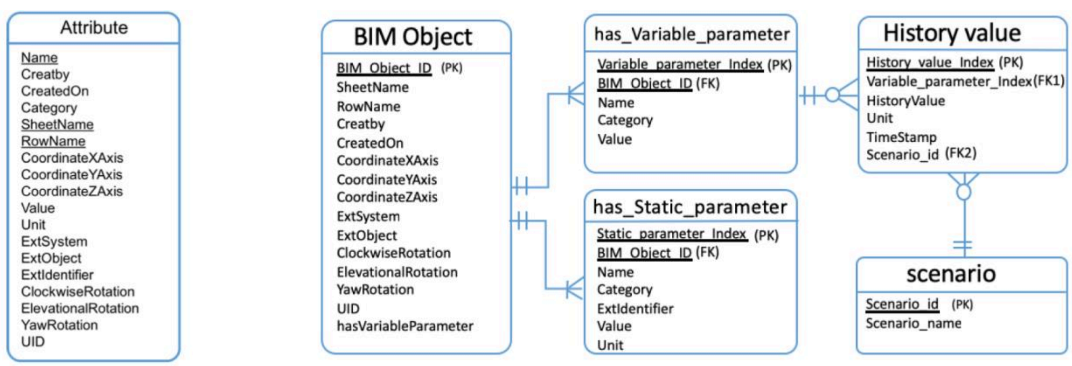


Fig. 2: Entities of BIM parameters

In order to extend and redesign Attribute entity, this research followed some rules of requirements to implement the database:

1. A BIM object must be either an object with "variable parameters" or "static parameters", but not both at the same time. This paper conceives every sensor in building as objects with "variable parameters", and the other objects in building as objects with" static parameters".
2. Each history record must belong to one sensor.
3. Every history data item needs a specific scenario (e.g. weekday, weekend, closing time).



(a) Attribute entity (b) Extended Entities in database

Fig. 3: Attribute relation

Explanation of each extended relations in the database is given below (as shown in Fig. 3(b)):

- BIM Object: This entity is used to capture BIM object basic information, such as create time, object position, contact information, UID, etc. Moreover, in order to distinguish whether the object includes variable parameters or not, we added "hasVariableParameter" column into this table, and it is a Boolean value. TRUE value means that the object has one or more variable parameters, and FALSE value means that the object has no variable parameter.
- has_Variable_parameter: This entity is used to store every attributes type of a BIM object. For example, sensor object attribute types include length, height, object type, etc.
- History value: Each data set measured by the sensor is stored in the database along with a time stamp.
- Scenario: Scenario entity is stored as information as well according to the any day of the week and several kinds of period during any day. (e.g. weekday, weekend, closing time).
- has_Static_parameter: this entity is used to store every attributes of a BIM object without

a variable parameter.

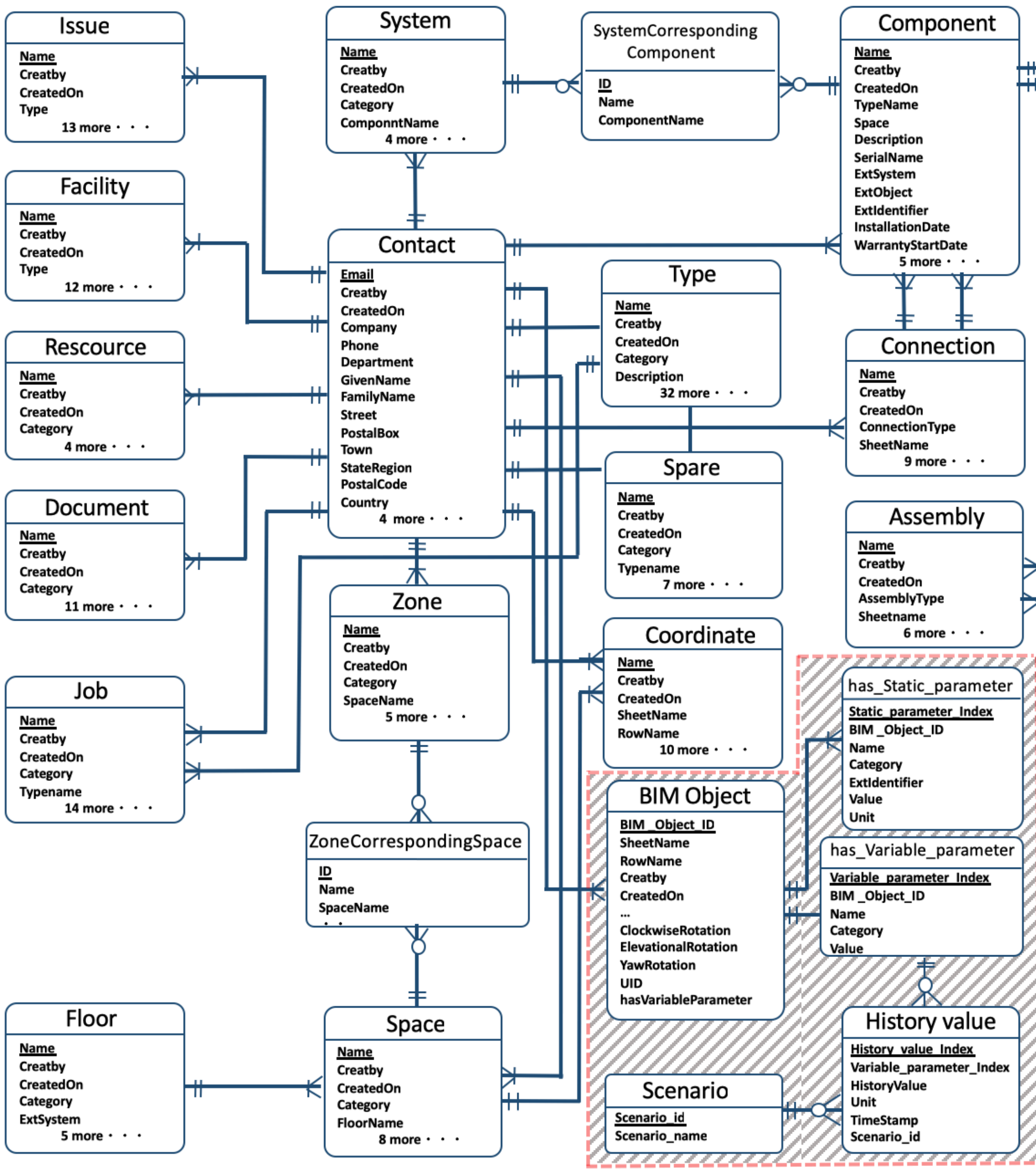


Fig. 4: Schema of the database designed in this paper

TESTING

In this case study, the BIM model of the Civil Engineering Research Building at National Taiwan University, Taipei is visualized through Autodesk Forge to showcase the practical application of the designed database scheme (as shown in Fig. 4). A few temperature and humidity sensors are allocated at various locations in the room and the real-time data collected by the sensors are then updated from time to time to the database. The temperature distribution of the room is then visualized in the BIM model for better monitoring purpose. As shown in Fig. 5, a real-time PMV distribution of the room and a real-time graph are plotted to display the latest and historical data collected by the sensors.

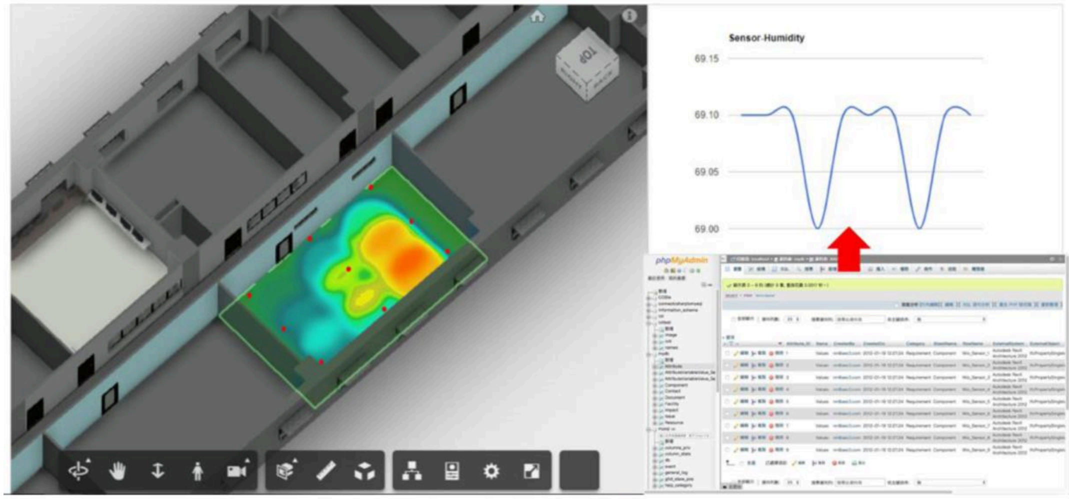


Fig. 5: Data visualization of humidity and temperature sensors

Visual Thermal Comfort Level

In order to further showcase the capability of the designed database scheme for visually managing the variable parameters, the thermal comfort level is presented as another option of the variable parameter. This also fully demonstrates the potential of this database because its application on variable parameters are not only on temperature but also other parameters like thermal comfort level.

An extended function is included as well to compute the thermal comfort level based on the Predicted Mean Vote (PMV) method. The real-time data of air temperature & relative humidity that are collected by the sensors are used to calculate the Thermal Comfort Level of different areas of the room. Other parameters such as dry bulb temperature, mean radiant temperature, air velocity, metabolic rate, and clothing insulation are assumed empirically in the condition of the indoor environment.

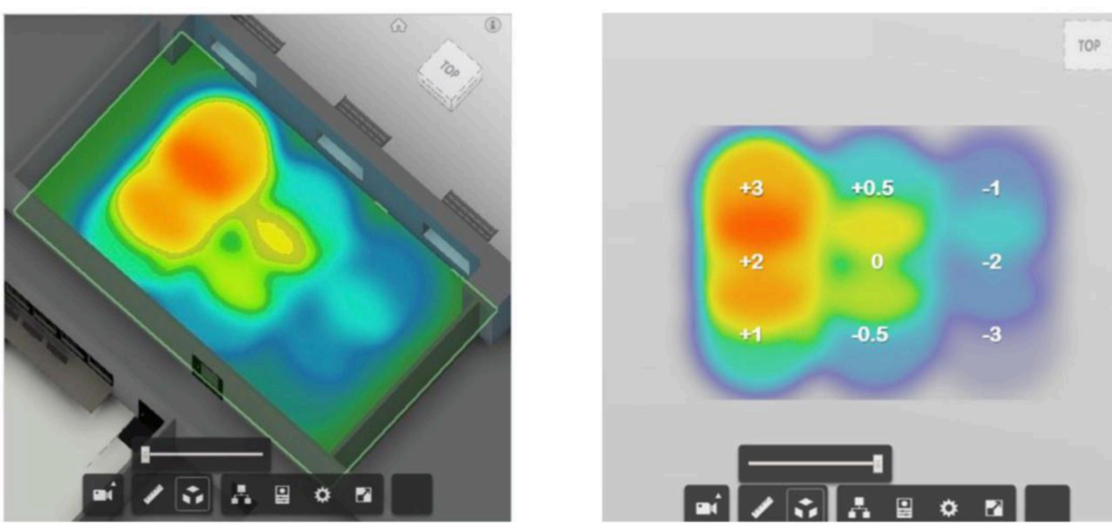


Fig. 6: Color Scheme that represents the scale of PMV (-3 to +3).

CONCLUSION

The introduction of variable parameters can enrich the use a BIM model in the O&M stage and enable more flexible and representative simulations of O&M scenarios. To support the introduction of variable parameters in BIM, this paper presents an effort in designing a database schema for integrating both static and variable parameters of a BIM model into the database. A normalized COBie database schema is redesigned and extended for storing real-time sensor data as well as other time-dependent data.

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Automated Mining of Construction Schedules for Easy and Quick Assembly of 4D BIM Simulations

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ABSTRACT

Over the past two decades, hundreds of studies have been published that demonstrate the benefits of 4D building information modeling (BIM) for optimizing construction planning and scheduling. Nonetheless to date, 4D BIM has only been adopted by 35–40% of top engineering news-record (ENR) companies and only used on a small fraction of their projects. The longevity of using 4D BIM also rarely outlasts the pre-construction phase. While the value associated with using 4D BIMs during the construction phase is well documented, the level of effort required to create them has significantly impacted perceptions about their return of investment (ROI) and limited their adoption. To address these inefficiencies, this paper presents a new method—comprised of text mining and machine learning (ML) techniques. Our method parses the description of construction schedule activities, assembles a breakdown structure of work locations/areas, and maps each activity to its corresponding 3D BIM element. Our method also labels each activity to a project phase such that these activities can be animated with different visual cues. Experiment results on 10 real-world construction projects show that the method achieved 89% accuracy in the parsing task. The benefits of the proposed method are discussed in detail.

INTRODUCTION

The contributions of 4D BIM modeling to the AEC industry have unlocked the possibility of exploring new construction sequences and methods to meet client requirements and margin goals (Fischer & Kunz, 2004; Gao et al., 2005). Hundreds of case studies and articles have been published that demonstrate the benefits of 4D BIM simulation in achieving optimization of the construction schedule and streamlining project controls by exposing details such as out-of-sequence work, scheduling conflicts among multiple trades, and enabling what-if analysis of scenarios and macro-level and micro-level construction phasing (Akbas, Fischer, & Kunz, 2001; Kassem, Brogden, & Dawood, 2012; Koo & Fischer, 1999). The value associated with using 4D BIMs during the construction phase is highly regarded, however the effort required to create them - particularly at the production level - has negatively impacted perceptions about their ROIs