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ESTABLISHING A KNOWLEDGE BASE SYSTEM (KBS) FOR POST-CONSTRUCTION BUILDING FACILITY MAINTENANCE

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Abstract

With the increasing need for energy efficient occupant comfort, the maintenance process becomes a key factor. Aspects including failure response time, maintenance treatment time and maintainability have a great influence on the building occupant comfort. Normally, the efficiency and effectiveness of maintenance process largely rely on the knowledge the maintenance workers have and the right notifications. However, occupants are not generally skilled in such field, and they most likely send the wrong information while failing to find the right person in charge. That will cause the longer response time. In this regards, this study intends to develop a building facility maintenance Knowledge Base (KB) more visually. Particularly, OpenGL was used to make the process of case-based reasoning directly perceived through senses. Meanwhile, using Building Information Models (BIM) simplified the process of developing a 3D Knowledge-Based System (KBS). Moreover, Microsoft Access database was set up to provide search and update functions for the KB. The efficiency and effectiveness of the proposed system was examined by this paper. However, the proposed Knowledge-Based System is limited to the complexity in facility manufacturers, protocol used and discreteness in hardware. Moreover, the operation conditions of building facilities vary in different projects. Therefore, the accuracy and volume of the KB should be further optimized. In futuristic research, more real-world buildings will be applied on to validate and improve the proposed system.

Keywords: *Knowledge Base System (KBS), Building Information Models (BIM), Facility Maintenance, Post-Construction Lifecycle*

1. Introduction

There is evidence that energy efficiency retrofit has emerged as a significant solution to fuel poverty and climate change [1]. However, one of the obstacles of promoting energy conservation comes from the trade-off with occupant comfort [2]. Uncomfortable living and working environment can lead to the inaccessibility [3], low working efficiency [4], bad moods [5], even disease [6, 7]. For satisfying both from a facility completion standpoint, an efficient Facility Maintenance (FM) process becomes a pivotal role in lifecycle perspective [8]. A primary concern of failure response time, maintenance treatment time and maintainability have a great influence on energy efficient occupant comfort [9]. Post-construction facility maintenance and management activities account the highest proportion of the building lifecycle while those activities cost the largest expense in the property sustainment budget [10]. However, the amount of FM-related data has a serious effect on the efficiency and effectiveness of facility maintenance. Such data are normally maintained as either handwritten record books or repair records (Chen, Hou et al. 2013). On the other hand, the successful facility operation and maintenance are also limited by the knowledge of the maintenance workers. Occupants are not generally skilled in such field, and they are most likely to send the wrong information while failing to find the right person in charge. Longer response time will be caused. The efficiency and effectiveness can be adversely affected under certain conditions.

While some researchers and companies have carried out on developing building facility maintenance and management system based on information technology (IT), such as AkitaBox [11] and MEX [12]. Such platform is not intuitive enough for particular data, such as maintenance tutorial and real-time facility usability information. Few 3D-based building management systems have been established such as IESVE [13]. Most of the studies in this field have only focused on the visualization of building entities, have made it too complex for a non-skilled staff to use [14]. Honeywell has attempted to achieve energy efficient occupant comfort with a 3D visualized system. However, no current documents are found to show their maintenance reasoning concern.

There are two primary aims of this study: 1. To investigate the significance of proposing a more visual building facility knowledge-based system in energy efficient occupant comfort perspective. 2. To ascertain the feasibility of using current techniques to satisfy the requirements of the proposed system.

2. Literature Review

As an artificial intelligence (AI) approach Case-Based Reasoning (CBR) is developed for reasoning and learning from past experiences [15]. CBR was first defined in Schank's research at Yale University in the early 1980s. Schank's model [16] of dynamic memory was the rudiment of CBR systems. The earliest CBR systems are Janet Kolodner's CYRUS [17] and Michael Lebowitz's IPP [18]. During 1980-1990, numbers of AI and expert systems were established, including KB-Reducer (KBR) [19], the "M" directory [20], the Rule Checking Program (RCP) for the ONCOCIN expert system [21], CHECK, ARC, and EVA5, Rob Acksyn's and Don McCracken's Knowledge Management System (KMS) [22].

Referring to Thomas's research [22], Knowledge management (KM) was first defined in 1991. In 1994, the International Knowledge Management Network (IKMN) was released online [22]. In 1995, KMS received increasing attention when the European Community began offering funding for KM-related projects [22]. In 2004, feature construction methodology was proposed facing new attributes in the KBS [23]. This methodology significantly simplifies data dimensionality and promote prediction performance. Researchers develop KMSs in a wide field such as railway scheduling [24], manufacturing [25], maintenance planning, space transportation [26], health sciences [27], and AEC/FM industry [28]. In 2015, searchers developed a knowledge-based expert system to assess the building sustainable performance[29].

3. Research Methods

Framework Formation: This research adopted principles of axiomatic design [30] to develop the nD BIM-IKBMS framework. Axiomatic design provides a scientific base for system research and development that supports the creativity of designers. Additionally, it reduces the random searching process, shortens the iterative process of trial and error, clarifies the assessment principles of design, and endows the computer with the capacity to create [31].

Functional Modelling: Next, the study conducted a comprehensive functional modeling for the proposed system using Integrated Computer-Aided Manufacturing

DEFinition for Function Modeling (IDEF0) diagrams. This was done based on independence axiom, information axiom and their inferences for axiomatic design. IDEF0 is a function modeling methodology that consists of a hierarchical series of diagrams, text, and glossary cross-referenced to each other [32] (See **Figure 1**).

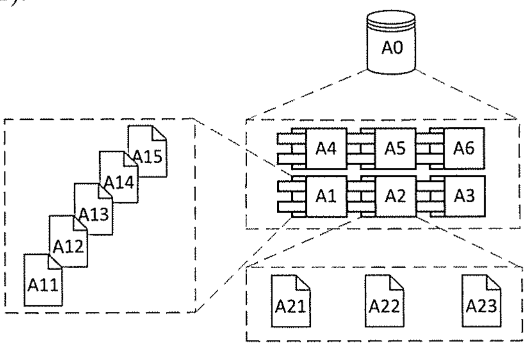
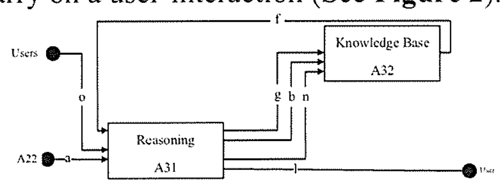


Figure 1 Hierarchy for All Context Diagrams for nD BIM-IKBMS

4. Analysis & Results

As the establishment of the proposed KBS is a part of our research nD Building Information Model Integrated Knowledge-Based Building Management System (BIM-IKBMS), the index for KBS module is defined as A3 among the six modules. The proposed KBS includes two parts: Reasoning (A31) and Knowledge Base (A32). Firstly, reasoning is about to find the solution and to update the records as well. Secondly, Knowledge Base (KB) is the database for the maintenance case, maintenance tutorials, maintenance records sequenced by the User-Perceived Quality (UPQ) scores. The proposed module can carry on a user-interaction (See **Figure 2**).



(A22: Fault Diagnosis and Detection Module; a: Diagnostic result; b: User Input.; c: Similarity function; d: Class identification; e: New cases/final UPQ scores; f: Matching cases; g: Perceived quality (UPQ) scores)

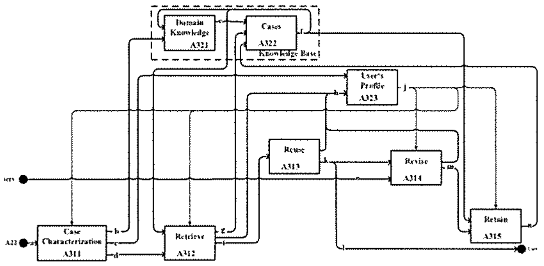
Figure 2 The Proposed Framework for KBS.

Taking KBS on board, the proposed system can accurately locate the fault facility from OpenGL based visual building entities and obtain the solutions from past case by effective reasoning. The fault will be described in the Fault Diagnosis and Detection (FDD) process, and the descriptions will act as key clues for searching similar building maintenance cases in the KB and get the solutions. Motawa and Almarshad [28] showed that the KBS could provide a good collection of past cases, operation and maintenance records, maintenance tutorials for the building facilities so that the maintenance staff can get response to the operational faults more efficiently. Hence, solutions can be selected in maintenance scheduling. Highlights of the fixed case will also be kept in the KB for future use. Furthermore, based on Sampaio's works [33], UPQ scores are used in the KB. Fixed cases include highlights of an operational fault, successful solutions, and the UPQ scores. The process is depicted in Gu's works [34], including a reasoning cycle consisting five sub-modules of Retrieval, Reuse, User's profiles, Revise, and Retain. (See **Figure 3**) In this cycle, maintenance staff can easily find similar solutions through the KB. Meanwhile, solutions can be reused for future cases. In addition, UPQ scores should be updated according to the users' feedback. Such scores coupled with its case will be retained in KB.

Following the rules above, the proposed KBS is working as an AI controller that can undertake continuously self-update. From the KB, operation and maintenance staff can classify features from the operational fault and reasoning solutions easily. When a solution is nominated, the UPQ scores will be updated based on feedbacks. In case no solutions satisfy the requirements, users will have to find solutions as usual. Then, such new case coupled with respective solutions will be stored into the KB with a dedicated new UPQ score.

In order to make the process of CBR directly perceived through senses, OpenGL, known as a graphical application programming interface (API) [35], is used for reconstructing 3D entities. OpenGL is widely used in 2D/3D graphical operating system development [36].

Furthermore, Building Information Models (BIM) has been imported into the system to facilitate the graphic reconstruction process. Such models have integrated multidimensional building facility information and largely shorten the work volume of establishing the proposed system. In addition, Microsoft Access database is used to maintain and update the KB. Such database can be linked with the BIM, which will update building information in real time.



(A22: Fault Diagnosis and Detection Module; a: Diagnostic result; b: Class identification; c: User's profile identification; d: Case's attribute weights; e: Catalog; f: Matching cases; g: Similarity function; h: Update; i: Similar cases; j: User's profile; k: Actual scores; l: Perceived quality (UPQ) scores; m: Adjustment of UPQ scores; n: New cases/final UPQ scores; o: User Input.)

Figure 3 The process of reasoning by using UPQ scores.

5. Discussion & Conclusion

With the increasing operational faults, maintenance staff always cannot the response the failures in time [37]. This study was set out to establish a visualized KBS to facilitate the energy efficiency occupant comfort. Although the proposed system may not be capable of addressing the whole failures, it considerably reduces the repetitive works for the maintenance staff. This study has shown that the visualized KBS is essential in facilitating proactive maintenance decisions by the resourceful solution retrieving. Providing a visualized KBS can largely promote the efficiency of maintenance and occupant service [38]. It also stops similar failures from early stage [8]. Particularly, the proposed system plays a significant part in standardizing maintenance process and avoiding inevitable human errors. Additionally, by using the KB, the proposed system can raise the possibility of finding the right solution robustly and significantly decrease the unfruitful information.

However, the proposed KBS is limited to the complexity in facility manufacturers, protocol used and discreteness in hardware. Moreover, the operation conditions of building facilities vary in different projects. Therefore, the accuracy and volume of the KB should be further optimized. The reader should bear in mind that the study is based on the ND BIM-IKBMS. It is beyond the scope of this study to examine the effectiveness of the proposed system in case of projects with other existing BMS, multiple BMSs and no BMS respectively. In futuristic research, more real-world buildings will be applied onto validating and improve the proposed system.

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