A BIM ASSISTED RULE BASED APPROACH FOR CHECKING OF GREEN BUILDING DESIGN

Yi-Wen Chen & Shang-Hsien Hsieh
Department of Civil Engineering, National Taiwan University, Taipei, Taiwan

ABSTRACT: *Since the publication of green building standards from the last decade, the designer of green buildings have often encountered the challenges of limited time but considerable complexity in the process of evaluating their design according to the rules specified in the standards. Also, the design process is usually an iterative one, which includes rule-checking tasks that are tedious and repetitive. With the advancement of technologies in Building Information Modeling (BIM), artificial intelligence, and Virtual Reality (VR), this research investigates and develops a BIM-assisted Rule-based approach for automating checking of green building design. The developed approach utilizes as much information available in a building's BIM model as possible to automate the design evaluation complied with green building standards. It also provides visual feedbacks through the BIM model to assist the designer in green building design. To evaluate and demonstrate this approach, an Application Programming Interface (API) tool has been developed in this research to extend the capability of BIM software for both automatic rule-checking of green building design and real-time visualization of feedbacks from the rule-checking. A rule base is used to manage the design rules specified in green building standards and facilitate the automation of rule checking. In addition, visualization of the rule-checking results (e.g. highlights of places in the design that do not satisfy the design requirements) is supported in a 3D VR environment of a building's BIM model.*

KEYWORDS: *Building Information Modeling, BIM, Rule Checking, Green Building Standards, Rule-based System, Application Programming Interface, Visualization.*

1. INTRODUCTION

To address the global warming crisis, many countries have started to incorporate their building designs with sustainable elements and developed their green building standards over the past decade. However, due to their differences in climate and natural environmental conditions, the standards developed may place focus on different environmental issues. Table 1 shows the top two categories in different green building standards. For example, the Green Mark of Singapore's Building and Construction Authority (BCA) focuses on Energy Efficient and Environmental Protection, which helps reduce both the potential impact on the environmental and energy consumption (Building and Construction Authority, 2013a, 2013b); while Leadership in Energy and Environmental Design (LEED) and Building Research Establishment's Environmental Assessment Method (BREEAM) mainly focus on Energy and Indoor Environmental Quality (Green Building Council, 2002; BRE Global Ltd, 2012). In Taiwan, to reduce the heat island effect and the carbon dioxide emission in the subtropical climate environment, the Green Building Evaluation Manual (EEWH), that is based on the Green Building Code in Taiwan, focuses on Energy Conservation and Ecology (Liu and Chen, 2011).

Table 1: Comparison of top two weighting subjects in green building standards

	LEED	BREEAM	BCA Green Mark	EEWH
Top two subjects	Energy & Atmosphere	Energy	Energy Efficient	Energy Conservation
	Indoor Environmental Quality	Health & Wellbeing	Environmental Protection	Ecology

To achieve green building design, the designer often needs to spend considerable effort and amount of time in the tedious process of evaluating their design against the rules specified in the standards. Usually the design process is an iterative one and therefore the rule-checking tasks for complying with the requirements specified in the

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standards need to be carried out repeatedly for many times. In a building project that is complex but has only limited design time, the quality of the green building design may be affected by the limited design iterations the designer can afford to have (Motawa and Carter, 2013). Therefore, with the advancement of computer technology and the emerging BIM (Building Information Modeling) technology (Eastman et al., 2011) for better building information modeling and management, some researchers (e.g. Wu and Chang, 2013; Sanguinetti et al., 2009; Chen et al., 2012) have developed systems or tools that are able to automatically calculate the energy conservation values to reduce manual calculation time and errors during the design process. In these systems, the calculation rules are implemented in the software program and cannot be easily modified or extended without recompilation of the program when the rules in the standards may be updated. Other researchers (e.g. Ding et al., 2006; Lee et al., 2010) have developed rule-based systems for checking the accessibility and fire safety rules in the design codes, showing the potential of applying rule-based systems to green building design. Moreover, a rule-based design checking system allows the designers to check their building design against different criteria in rules (Eastman et al., 2009).

The objective of this paper is to take advantage of and integrate BIM, rule-based reasoning, and Virtual Reality (VR) technologies for helping the designers in automatic checking of green building design with real-time visualization of feedbacks from the rule-checking. To evaluate and demonstrate the approach, a prototype rule-based system for automatic checking of green building design, called Green Building Design Assistant (GBDA), has been developed to provide the designers with functionalities that show the differences between the current design results and the requirements in the standards. The current scope of the rule-checking implementation is on the ecology part of the Taiwan's green building design code, which uses the equivalent carbon dioxide amount reduced by plant greening as an index for evaluating the design of plant greening at the building site.

2. BIM TECHNOLOGY AND RULE-BASED APPROACH

BIM technology (Eastman et al., 2011) is the process of creating and managing parametric 3D digital models of a structure (or facility) during the structure's life cycle. It is an emerging technology that has the potential to revolutionize the business in the architecture, engineering, and construction (AEC) industry. The current design approach that is mainly based on the 2D CAD drawings will be replaced by the 3D BIM approach in the foreseeable future. Because a 3D BIM model of a building contains not only the geometric information of its components that correspond to physical building components in the real world, but also the attribute information (e.g. materials, color, etc.) of the components and the relationships among the components, it provides much information useful for automatic calculation and rule-checking in green building design. Also, it provides a very good platform for visualization of the calculation and rule-checking results.

A rule-based system (Hayes-Roth, 1985) is a system that can store knowledge or experiences in terms of rules and use them for making effective judgment in the real world situations. Generally speaking, the system consists of three main parts: working memory, inference engine, and knowledge base (rules), as shown in Fig. 1. The working memory passes facts to the inference engine to initiate the process of reasoning with the rules stored in the knowledge base. The result of the reasoning is then passed back to the working memory and may be displayed in the user interface. The rules in the knowledge base can be easily maintained (editing, adding, and deleting) without modifying any system software. This feature and its rule-based reasoning capability make it very suitable for managing design rules in codes or standards and performing design code checking for the designer.

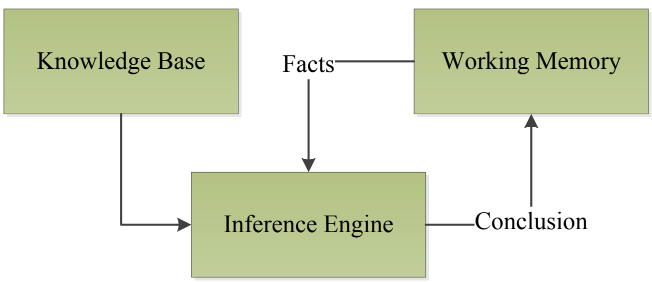


Fig. 1: Basic components of a rule-based system

3. THE PROTOTYPE DESIGN CHECKING SYSTEM: GBDA

The prototype rule-based system for automatic checking of green building design, named Green Building Design Assistant (GBDA), has been developed in this work using the Application Programming Interface (API) of Autodesk's Revit and the Neo4j NOSQL graph database. As shown in Fig. 2, GBDA includes three major components: Revit user interface, calculation and model control system, and rule engine system. The Revit user interface is written in .NET C# Windows Form, and allows designers to input the basic information of a building, as illustrated in the (a) part of Fig. 3. Another feature of the Revit user interface is the provision of the evaluation results, as shown in the (b) and (c) parts of Fig. 3. The calculation system contains all the evaluation formulas, which extracts the required information from a BIM model and calculates the value demanded by design codes. The model control system, on the other hand, is for retrieving the evaluation results from the rule engine and displaying the results in a BIM model with highlighted elements or auxiliary lines. Basically, the rule engine uses the calculation results (Facts) in the calculation system to perform automatic rule evaluation, and then sends the evaluation results to the model control system. The rule engine serves as the connection between the Revit API and the Neo4j database, and helps GBDA to perform real-time rule evaluations.

3.1 Calculation and model control system

The calculation and model control system shown in Fig. 4 consists of two parts: the calculation system and the model control system.

The calculation system implements the formulas in the Green Building Code with the help of the model extractor to extract needed data from the BIM model. In order to reduce the model preparation work in manually entering properties for rule evaluation, the calculation system uses categories and properties to identify the requiring data in a BIM model. Take tree-counting as an example, when a designer enables the rule evaluation function, GBDA starts comparing the names labeled in the tree elements of the BIM model to the names of the tree list stored in the database for tree identification as shown in Fig. 5(a). Also, the attributes of the tree objects, as shown in Fig. 5(b), are used to flag if the tree is an "original" one or not. This approach enables GBDA to reduce the complexity and time invested on manual rule evaluation and makes the rule evaluation more accurate and efficient.

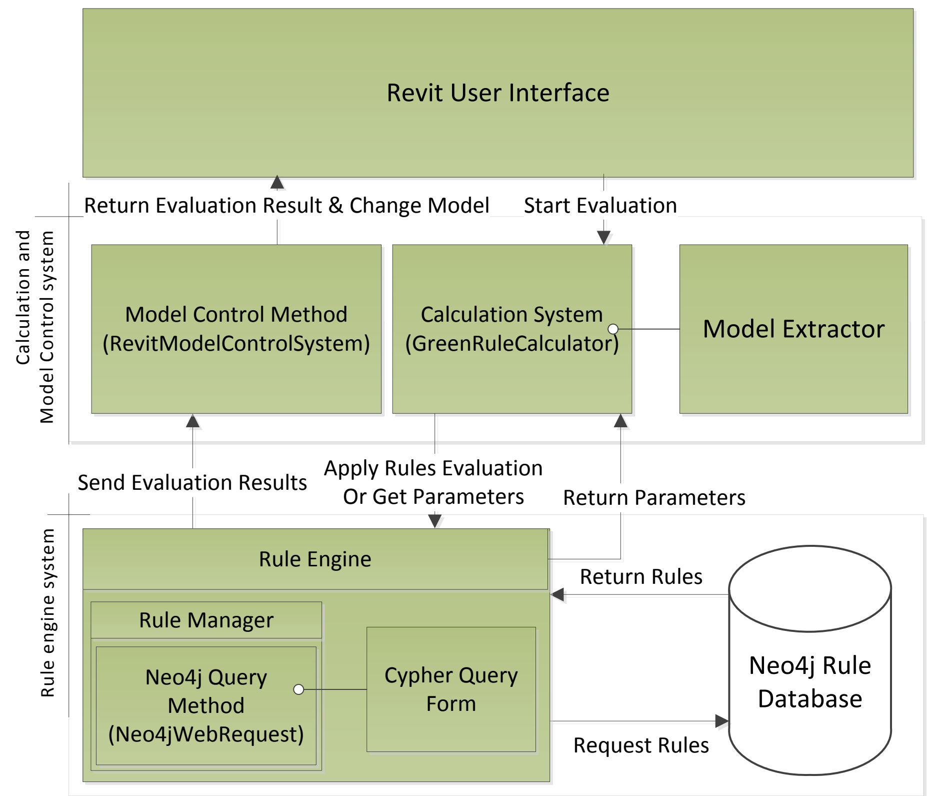


Fig. 2: System architecture of GBDA

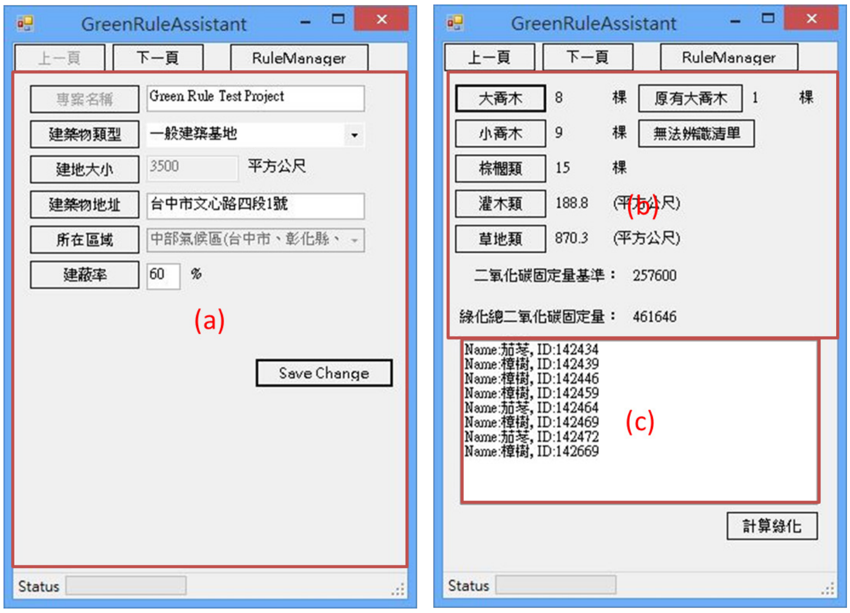


Fig. 3: GBDA's Revit User Interface: (a) building information, (b) evaluation result, and (c) object list display

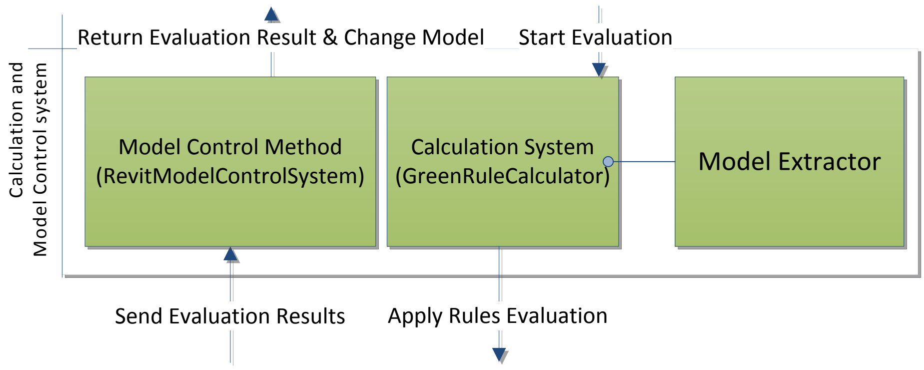


Fig. 4: Calculation and Model Control System

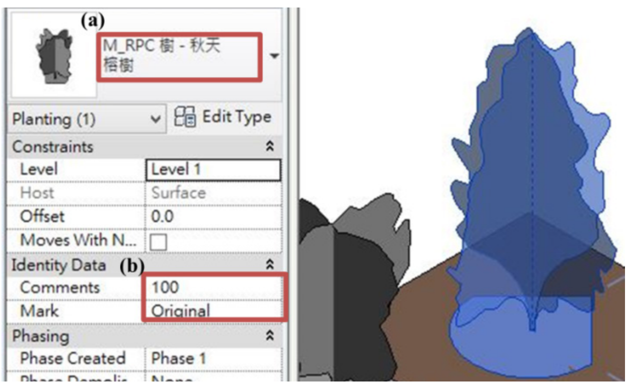
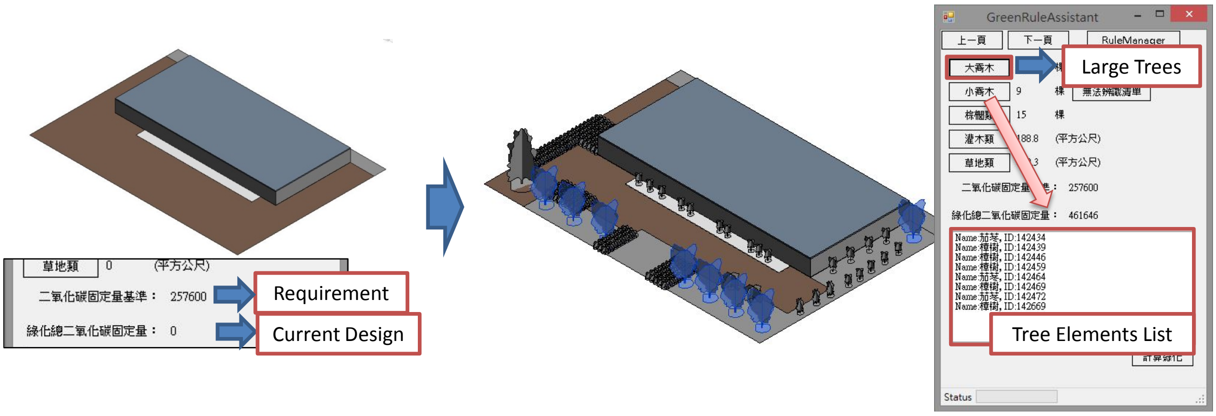


Fig. 5: (a) Category and name of the tree, (b) Labels embedded in the attributes

Through the model control system, the evaluation result can be illustrated in both the BIM model and data tables for assisting sustainable building design. Let us continue to use the example of greening with trees. The GBDA user interfaces provide both the detailed information about each type of trees (including total numbers, names with ID numbers, locations in the BIM model, etc.), as shown on the right side of Fig. 6, and the calculated result of the code requirement and the evaluated value for the current design, as shown on the left bottom side of Fig. 6. Furthermore, the user interface can interact with the BIM model in Revit to generate real-time visualization for the trees listed in the object list display area. When the designer clicks on either the tree type buttons or the trees on the list, the tree objects (or elements) in the model get highlighted. In this way, not only can the designer know the current design value, but also have a good idea about the contributions among different greening strategies depicted in the BIM model.



(a) Real-time evaluation (b) Selection by tree type and interaction with Model

Fig. 6: Feedback visualization of interactive design evaluation

3.2 Rule engine system

Fig. 7 shows the implementation of the rule-based system (as previously shown in Fig. 1) in GBDA. The calculated results are sent as facts from the calculation system and the evaluation with rules contained in Neo4j rule database is conducted in the rule engine system. Then, the evaluation result is sent as a conclusion to the model control system for visualization.

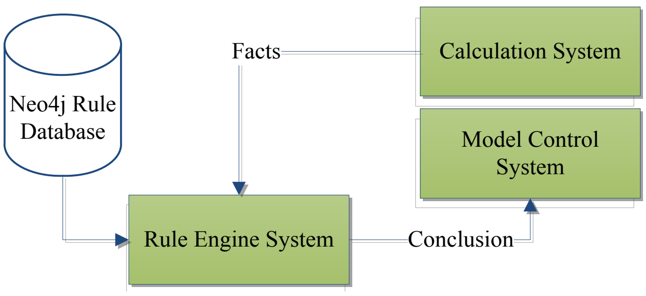


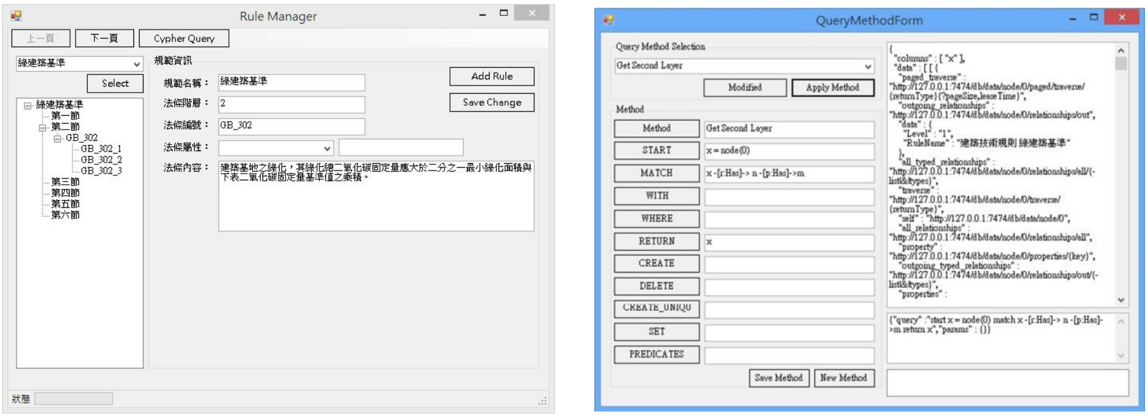
Fig. 7: Rule Engine System data flow

3.2.1 Rule engine control interfaces

To facilitate the management of rules, an interface called Rule Manger is designed for GBDA. The Rule Manger, as shown in Fig. 8(a) displays the tree structure of all rules in the rule base on the left side and the attributes of the selected rule on the right side. It also provides functions for adding new rules and modifying the properties of existing rules. Moreover, a Query Method Form is implemented (see Fig. 8(b)) to provide a user interface for defining the query methods that the rule engine can follow the defined paths to get access to the rules created by the users (usually the rule managers) in the rule database. As shown in Fig. 8(b), the query methods are stored in the XML format.

3.2.2 Rule interpretation

The rules in a green building code are usually expressed in natural language and tables. To convert the rules into a database, we need to extract the conditions and properties from the rules and distinguish all properties contained in the rules. Let us take the rule No. 302 in Taiwan's Green Building Code as an example Fig. 9 shows that the interpreted rule includes basic information such as "RuleName" representing the rule number and properties. Properties with different requirements will be stored in different sub-nodes of the node GB_302 and relationships between the node β and the sub-nodes are represented as conditions. This approach allows us to



(a)Rule Manager (b) Query Method Form

Fig. 8: Rule engine control interfaces

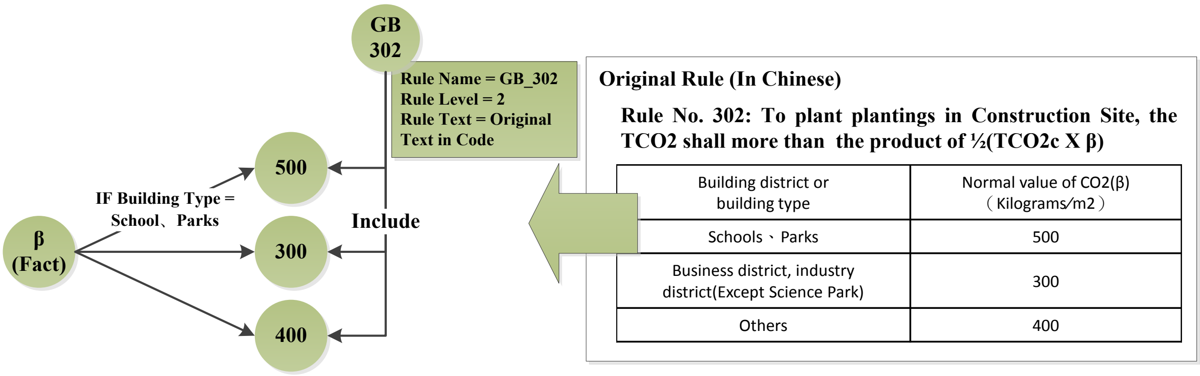


Fig. 9: Translating natural language rules into a database

translate the natural langrage rules into a NOSQL database object, which is used later for automatic rule evaluation

3.2.3 NOSQL rule database

For the flexibility in the rule management and rule base extensibility, rules in GBDA are stored in a NOSQL database. With this type of database, three major parts of a rule-engine: facts, conditions and actions, are represented by nodes of facts, relationships between nodes, and the directions of relationships, respectively, as illustrated in Fig. 10. By using the nodes to represent facts, the system can easily store non-structured data and extend the properties of nodes when there is a need to modify current rules or implement new ones. Using relationships to connect nodes for forming paths with different conditions allows for flexible formulation of rules. The direction of a relationship represents the action of reasoning and the process of a complete path of the nodes represents the evaluation of a corresponding rule in the rule base.

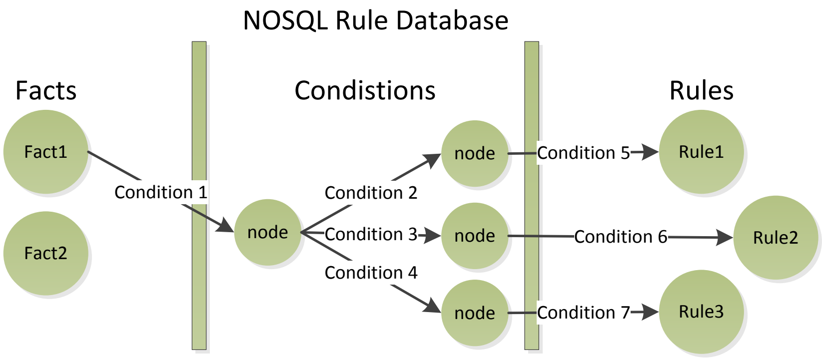
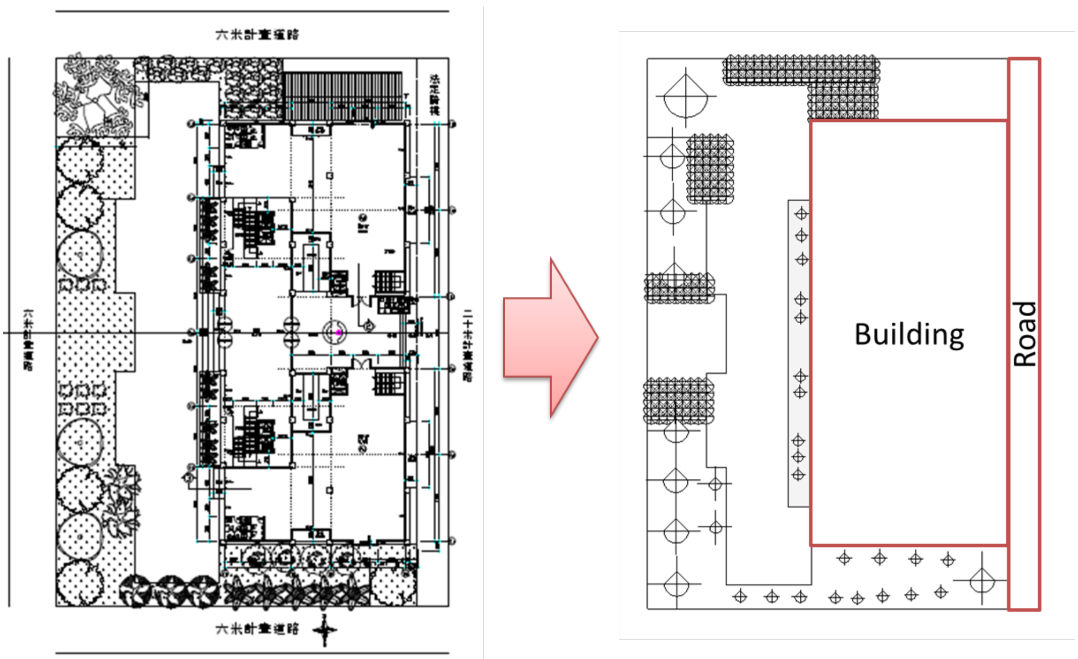


Fig. 10: NOSQL rule base structure

4. A CASE STUDY

In order to demonstrate and verify the proposed approach, this research uses a sample project documented in Taiwan's Green Building Code as a case study. The design plan in the Code is used to establish a BIM model of the same layout and the same tree types as shown in Fig. 11, and then the GBDA rule evaluation is applied to this model. Finally the results calculated by GBDA are compared with those provided in the sample project.



(a) Sample case in the Code (b) Plan view of the corresponding BIM model

Fig. 11: Sample project documented in Taiwan's Green Building Code

Because GBDA counts every trees in the BIM model and identifies tree type based on the tree database built in the system and the attributes of the tree objects in the model, its calculation on the number of each type of trees matches accurately with the result of the sample in the Code. Moreover, with GBDA, the designer can easily adjust the plant greening design, quickly obtain all the needed calculation associated with the adjusted design, and clearly visualize the adjusted design in the 3D BIM model as well as the numerical results in text-based user interfaces. For example, Fig. 12 shows a modified green design on the sample project and the corresponding updated results of rule evaluation.

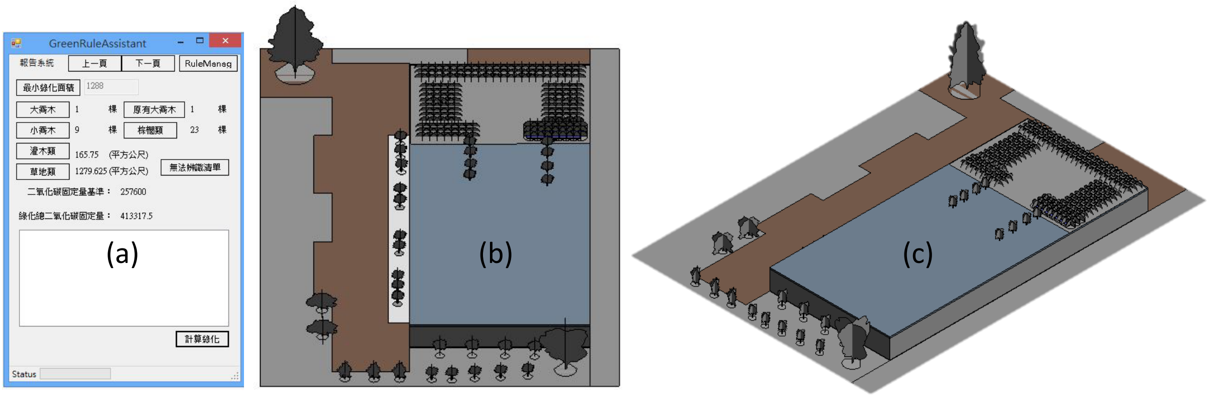


Fig. 12: Rule evaluation during design iteration: (a) Evaluation result, (b) BIM model top side view and (c) BIM model 3D view

5. CONCLUSIONS

A BIM-assisted Rule-based approach for automating checking of green building design has been presented in this paper. A prototype system that integrates BIM tool, NOSQL rule base, and rule-based engine has been successfully developed and tested to show the feasibility of the proposed approach. The automatic calculation and rule-checking features relieve the designer from the tedious, repetitive and error-prone manual operations in the iterative process of green building design. The application of 3D BIM model for real-time visualization of feedbacks from the rule-checking greatly facilitates the designer's decision-making and communications with his or her clients.

6. ACKNOWLEDGEMENT

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7. REFERENCES

Lin H. T., Chuang H. W., Chang C. Y. & Chen C. N. (2012). Green Building Evaluation Manual – Basic Version (EEWH-BC). Architecture and Building Research Institute, Ministry of the Interior, Taiwan, 163 pages (in Chinese).

Building and Construction Authority (2013a). BCA Green Mark [Online], Available: http://www.greenmark.sg/index.html.

Building and Construction Authority (2013b). BCA Green Mark for New Residential Buildings, Singapore.

Green Building Council (2002). Green Building Rating System for New Construction & Major Renovations (LEED-NC), Version 2.1, U.S.A., 67 pages.

BRE Global Ltd. (2012). BREEAM Refurbishment. Domestic Buildings Technical Manual, SD5072-2012-1.0.2, United Kingdom, 325 pages.

Chen P.-H., Chuang P.-C. & Kan M.-S. (2012). Study on Integration of Building Information Modeling (BIM) and Taiwan's Green Building Standard - Taking Building Envelope for Example. Proceeding of the Twenty-fifth KKCNN Symposium on Civil Engineering, October 22-24, 2012, Busan, Korea.

Ding L., Drogemuller R., Rosenman M., Marchant D. & Gero J. (2006). Automating Code Checking for Building Designs - Design Check. In: Brown K., Hampson K. & Brandon P. (eds.) Clients Driving Construction Innovation: Moving Ideas into Practice, Brisbane, Australia: CRC for Construction Innovation, 113-126.

Eastman C., Lee J. M., Jeong Y. S. & Lee J. K. (2009). Automatic Rule-based Checking of Building Designs. Automation in Construction, 18, 1011-1033.

Eastman C., Teicholz P., Sacks R. & Liston K. (2011). BIM Handbook : A Guide to Building Information Modeling for Ownwes, Managers, Architects, Engineers, Contractors, and Fabricators, John Wiley and Sons, Inc.

Hayes-Roth F. (1985), Rule-based systems, Communications of the ACM, 28(9), 921-932, New York, NY, USA: Assoclation for Computing Machinery.

Lee J.-k., Eastman C. M., Lee J., Kannalaô M. & Jeong Y.-S. (2010). Computing Walking Distances within Buildings Using the Universal Circulation Network, Planning and Design, 37(4), 628-645.

Liu T. F. & Chen C. N. (2011). Comparison of Green Building Rating System between Taiwan and other Countries. Sinitech Engineering Journal, 113, 87-94. (in Chinese).

Motawa I. & Carter K. (2013). Sustainable BIM-based Evaluation of Buildings, Procedia - Social and Behavioral Sciences, 74, 116-125.

Sanguinetti P., Eastman C. & Augenbroe G. (2009). Courthouse Energy Evaluation: BIM and Simulation Model Interopreability in Concept Design, Proceeding of Building Simulation, July 27-30, 2009, Glasgow, Scotland. 1922-1929.

Wu I. C. & Chang S. (2013). Visual Req Calculation Tool for Green Building Evaluation in Taiwan, Automation in Construction, http://dx.doi.org/10.1016/j.autcon.2013.01.006.