



BIM-based idea bank for managing value engineering ideas

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Abstract

Value engineering is a proven management technique for generating benefits and improving the value of construction projects. However, due to kludgy and inconvenient past data and free-thinking techniques, idea generation during VE workshop is time-consuming and often relies on VE participants' experience. Although various studies have developed technical systems related to database management to overcome these limitations, the idea generation process is still recognized as an area to be improved. This study suggests a BIM-based VE Idea Bank to enable the systematic retrieval of past VE data, and efficient generation of new ideas. The system development includes: 1) Data model based on VE Idea Bank; 2) creating BIM objects; and 3) integrating BIM and VE Idea Bank. A prototype is developed and its effectiveness is assessed through system trials, interviews and questionnaires with 23 industry professionals. Interim results show that the proposed system has great potential to improve VE study efficiency.

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1. Introduction

Value engineering (VE) is one of the proven management techniques in the construction industry, which is applied to improve the function and eliminate unnecessary costs of projects. Since the construction industry has faced various challenges to reach project's high-value on time and within budget, VE has been applied in numerous countries around the world for half a century (Chen et al., 2010). VE has become an integral part in the development of many projects (Mao et al., 2009). According to Zhang et al. (2009), surveys reported that VE can save as much as 5–10% construction project cost. The VE study procedure, named a VE job plan, is a systematic problem-solving technique, comprised of the following phases: information, creativity, evaluation, devel-

opment, and proposal. Among these phases, the creativity phase followed by function analysis is the most crucial one to generate innovative ideas which requires existing information and experiential knowledge from past VE projects (Park, 1994).

However, a number of issues and problems exist during the creativity phase. Due to the lack of structured and well-managed VE databases from previous projects, the idea generation during VE study is inefficient (Shen et al., 2004). Furthermore, it is difficult to improve value, performance, and function of project through conventional free-thinking techniques such as Brainstorming Jung (2002) and much time is consumed to visually understand the essential functions of VE study areas and whole project through 2D-based work processes (Mao et al., 2009). To solve these issues, various studies have considered database management system development (Lee et al., 2009; Moon et al., 2011; Zhang et al., 2009) for retrieving and reusing the past VE data and providing group decision support system (Fan et al., 2007; Luo et al., 2011; Shen et al., 2004) during VE studies. However, despite these system developments, VE practitioners in

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the industry still mainly rely on their experience for improving idea generation.

Meanwhile, as construction projects have become larger and more complex, it has become increasingly challenging to manage whole project lifecycle. BIM has emerged as a powerful and robust approach, capable of dealing with essential design and data related to the project in digital format (Bryde et al., 2013). Especially, it has great potentials to integrate the existing data formats, improve design quality, and assist users to easily understand projects through parametric objects (Eastman et al., 2011). Thus, many studies attempted to integrate BIM and the existing 2D-based database and improve the current work procedure. Goedert and Meadati (2008) integrated construction documentation into BIM to collect practical 3D-based data and extend usability of the BIM software. Motamedi et al. (2014) developed a knowledge-assisted BIM-based visual analytics approach to provide visualization which allows users cognitive and perceptual reasoning for problem solving. However, no research has considered the development of a BIM-based system to systematically and visually organize past VE ideas. From this point of view, integrating BIM with VE idea database management can visually support VE idea retrieval and generation processes and thus enhance the effectiveness of VE studies.

With this regard, this study aims to develop a BIM-based VE Idea Bank system to enable the systematic retrieval, reuse, generation and storage of VE ideas. Using the system, the VE team can conveniently reuse and retrieve VE ideas from similar past projects through BIM objects and also efficiently generate high quality VE ideas based on BIM environments in a short-time. The proposed system will also allow the VE team to virtually modify BIM-based parametric objects in order to generate new VE ideas and support VE team members to collaboratively work with various engineering disciplines. The study hypothesizes that the proposed BIM-based VE Idea Bank would be usable, efficient and effective in enhancing the management of VE ideas. This paper discusses the creativity phase of the VE job plan, reviews the state of theory and practices regarding VE and BIM, and then highlights the current issues and limitations and addresses the necessity of a BIM-based VE Idea Bank. Next, this study proposes a BIM-based VE Idea Bank system, which includes the development of a data model, creation of BIM objects, and the integration of BIM with the VE Idea Bank. A system prototype is developed and its usefulness and effectiveness is assessed with system trials along with interviews with VE and BIM practitioners in the industry. Finally, the results and limitations of this study are discussed, and future research directions are suggested.

2. Literature review

2.1. Creativity phase in VE job plan

The main aim of creativity phase during VE studies is to compile and to generate innovative and creative ideas, which would contribute to achieving value in construction projects. Norton and McElligott (1995) explained a number of essential factors to conduct idea generation successfully. First of all, VE team members need to consider the basic principles for creativity

phase such as postponement of judgment, positive environment, large quantity of ideas, and hitchhiking of ideas before initiating idea generation. These factors can stimulate spontaneous idea generation, positive attitudes and prompt idea generation during the creativity phase. In this phase, the first task is usually a VE workshop in order to present VE study areas, client's demands, and projects, which were introduced during the information phase. During VE workshop, VE teams should collect and classify numerous data from past VE ideas, drawings, and specifications of materials etc., related to the current project. Shen and Liu (2003) emphasized that preparation of related information was one of Critical Success Factors (CSF) for successful VE studies. The past VE propositions can be utilized for apartment projects which have repeated and modularized plans for rapid idea generation. In addition, information from drawings and specifications can be used to support the generation of innovative and creative ideas for complicated projects. Afterwards, various creative thinking techniques such as Brainstorming, Delphi, Gordon Technique, and Synectics can be used to stimulate VE team's idea generation. At the end of this creative phase, some acceptable ideas can be recorded on VE idea chart lists for further study during the workshop and future VE studies since some ideas occur repeatedly in similar projects (Kim and Min, 2009).

2.2. Current issues of creativity phase

Several issues and problems regarding the creativity phase have been raised by researchers and practitioners, in particular, relating to data management and visualization are listed as follows:

1. Most of the data (past VE ideas, drawings, etc.) are accessed through unstructured and poorly managed databases during the creativity phase. In this case, even though the required data could be used well, it is difficult to retrieve and reuse efficiently (Kim and Min, 2009). For that reason, VE teams generally perform idea generation as a mere formality based on only their knowledge and experience. As a result, a lot of data cannot be retrieved and reused efficiently during creativity phase, even though valuable VE ideas are generated repeatedly in similar projects. According to Zhang et al. (2009), Choi et al. (2011), Park et al. (2014), one of the main causes of this problem was the lack of structured database management system, which could store, manage and accumulate past VE ideas systematically.
2. In certain cases, traditional creative thinking techniques such as Brainstorming are inefficient (Kim and Yang, 2006). During Brainstorming, lateral thinking and broader thoughts are necessary to generate better alternatives and offer better product to clients. However, it is difficult to achieve VE team's goals through the traditional approach, since it depends on the capacity of VE team members (Yang et al., 2014) and its main goal is just to gather as many various VE ideas as possible (Jung, 2002).
3. During the process of VE idea generation based on 2D data, tremendous time is consumed in trying to visually understand the essential functions of building elements and the VE areas discussed during information phase (Mao et al., 2009).

Considering this, some VE team members would participate in workshop without fully understanding required information due to limited time. Hence, such participants would refrain from presenting their alternatives during workshops because of shyness, pressure, and judgment when speaking without knowledge (Fan et al., 2007). Zhang et al. (2009) also emphasized that it is not easy to come up with innovative and creative VE ideas based on 2D data, especially in the case of inexperienced VE team members.

Although VE has been recognized as a useful technique and holistic approach to improve the value and generate benefits of projects in the construction industry, the implementation of its core phase, the creative idea generation, still remains very inefficient and ineffective due to the unstructured and ill-managed past data, unproductive conventional Brainstorming sessions, and 2D-based idea generation processes.

2.3. Need for BIM-based VE database

BIM has been defined as the process of collaboratively designing a building facility using a coherent system of computer models, which can manage practical data based on parametric objects (Bryde et al., 2013).

In order to address the limitations of 2D and paper based work processes, many studies have considered the application of BIM in the industry. Kim et al. (2013) developed a system framework to automate the generation of construction schedules using BIM. It demonstrated that it was possible to directly extract quantity, materials, and relational information of all building elements from the parametric objects by analyzing IFCXML file format. According to Liu and Issa (2012), required parameters from Revit models could be shared between multiple projects and Revit families based on ‘Shared Parameter’. In addition, required parameters could be exported to open databases such as ACCESS by ‘Shared Parameter’. Cha and Lee (2015) developed a structured pre-made BIM-based database structure for time and cost analysis throughout the project life-cycle and Motawa and Almarshad (2013) suggested an integrated knowledge-based BIM system which could enable retrieving information based on Case Based Reasoning (CBR). Lee et al. (2012) presented a space database which automatically organized and classified space objects within BIM to review building design.

Many studies have attempted to integrate the existing external databases with parametric objects within BIM environments to efficiently retrieve and reuse the past data. However, literature reviews revealed that no research efforts have considered the development of a well-organized system to integrate BIM with VE studies. With this regard, this study proposes a BIM-based VE Idea Bank to support VE idea retrieval and idea generation processes.

2.4. BIM parametric object

Parametric object is a main function and terminology of BIM to understand the differences between traditional 2D and 3D modeling tools. Traditional tools such as Sketch Up, CAD, and 3D Max can provide only graphic visualizations and have

no object attributes. However, BIM parametric object contains geometric definitions, associated data, and attributes. Firstly, parametric object automatically modify associated geometries when changes are made to associated objects. The parametric objects which are shown in BIM environments have the ability to link, export, or broadcast attributes such as structural materials, energy data, acoustic data, and so on to other applications and models (Eastman et al., 2011). In addition, BIM allows users to improve design quality and assists users to better understand whole project through 3D visualization.

Thus, BIM parametric object has a potential to link the external structured database for creativity phase and then VE team can easily access the required data (2D drawings, attributes, specifications, etc.) through attributes and utilize past VE ideas in the BIM environment.

However, the existing parameters in BIM objects cannot be used to integrate BIM with the existing database due to the lack of relations which can connect both systems (Jeong et al., 2015). As such, it is necessary to categorize predefined construction classification such as Omniclass which can integrate BIM with VE Idea Bank as specific parameter into BIM objects. Afterwards, this study will apply an add-in to link BIM parametric objects (BIM) with VE ideas (VE Idea Bank) through specific search parameters (Omniclass).

3. BIM-based VE idea bank

The main aim of this section is to introduce the BIM-based VE Idea Bank. The following sections present the detailed system development by describing and illustrating a data model for the VE Idea Bank and BIM objects, and explaining the integration of BIM with VE Idea Bank. The system was developed using Revit Architecture, since it provides an Open API Platform which can develop add-in programs.

3.1. System structure

The structure of the BIM-based VE Idea bank is illustrated in Fig. 1. It comprises of following three steps: 1) Data model based VE Idea Bank, 2) creating BIM objects, and 3) integrating BIM and VE Idea Bank.

Firstly, – data model based VE Idea Bank – is designed to store, manage and update VE ideas, while the add-in is developed as a manipulation environment to support VE teams to reuse past ideas and generate new ideas based on BIM models within the VE Idea bank system. VE Idea Bank can be established by transferring the existing VE ideas into VE templates with the Omniclass classification. Cambridge Dictionary defines a template as something that is used as a pattern for producing other similar things and a system that helps you arrange information on a computer screen. The template which includes general information, graphical information and detailed information is designed to effectively store and manage VE ideas. Secondly, – creating BIM objects – creates BIM objects according to the Omniclass construction classification system. BIM objects is a terminology to group elements with common

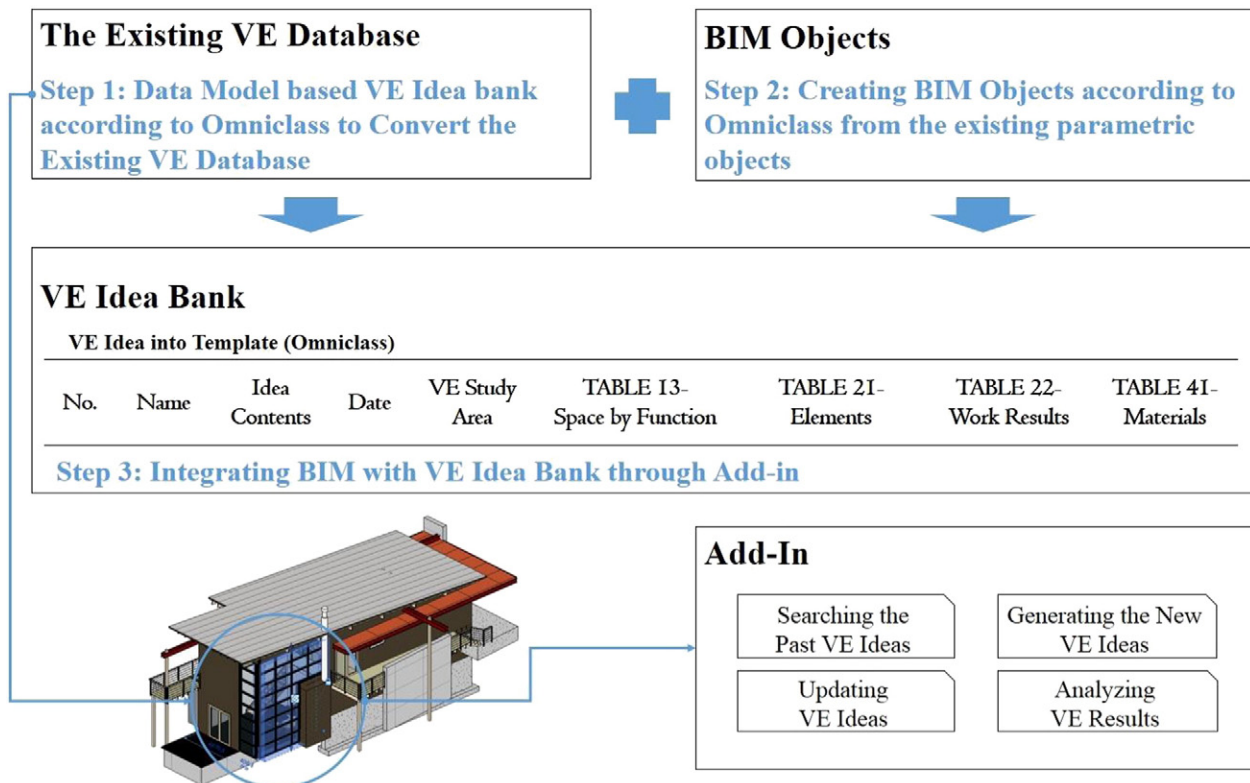


Fig. 1. System structure for BIM-based VE Idea Bank.

and specific parameters. To do this, it is necessary to classify and assign Omniclass tables into BIM objects respectively and then, the BIM objects would be created. It is noted that the BIM objects with Omniclass table can be reused for BIM models.

Finally, – integration of BIM and VE Idea Bank – the VE ideas are linked to BIM objects in BIM projects to support quick creation, search and reuse of VE ideas. In order to connect VE Idea Bank with BIM objects, an add-in which can expand the capability of BIM is developed (Lou and Goulding, 2008). The add-in comprises of four main functions including searching VE ideas, creating VE templates, updating VE ideas, and analyzing VE ideas. Every VE template which is linked to BIM objects through the add-in can be used to visualize VE ideas and support effective and efficient idea generation. The accepted VE ideas are updated into the VE Idea Bank through the add-in. In order to support convenient reuse and retrieval, new templates with new VE ideas are automatically categorized in the VE Idea Bank main server. Furthermore, these ideas can be exported from the VE Idea Bank to Excel files in order to analyze VE results and support clients' decision making.

3.2. Step 1: data model based VE idea bank

VE data model is structured to manage and save the VE ideas into VE template. It can support VE teams to reuse past VE ideas and generate new ideas based on BIM object attributes within the VE Idea Bank System. The VE template serves as a fundamental

building block in developing a VE Idea Bank for the effective retrieval, reuse and generation of VE ideas.

VE templates based on Omniclass classification are stored and managed in the VE Idea Bank. VE ideas from past projects are manually input into VE templates in order to create an initial database. The VE team reuse this initial database to generate new ideas in the template and also new templates are stored to enhance and systematically expand the VE Idea Bank. In comparison to traditional VE idea retrieval process, the VE template would allow the VE team to classify ideas based on element, work, space and material rather than solely by the idea name and date, as illustrated in Fig. 2. It demonstrates how the proposed VE template would support the development of clearly organized and categorized VE idea lists based on Omniclass. This function would assist the VE team in reducing the time required for VE idea retrieval and generation.

Based on this, a data model is developed to include the required information in the VE template. As illustrated Fig. 3, the data model of VE Idea Bank consists of a hierarchic organization with three levels. A VE idea (Level 1) contains general information (Level 2), graphical information (Level 2), and detailed information (Level 2). Their individual contents are described with sub-contents (Level 3) as follows:

1. General information: consists of general VE information including the idea number and name, date, idea contents, VE areas, as well as advantages and disadvantages. The general information provides VE team with an overview of past VE

The Existing VE Idea Lists

No.	Name	Idea Lists	Date	VE areas
1.	VE team 1	Adding window to the concrete wall in the living room	2003.08	Architecture (Apartment)
2.	VE team 2	Replace ART wall to a brick wall in the kitchen	2003.08	Architecture (Apartment)
⋮	⋮	⋮	⋮	⋮

No.	Name	Idea Lists	Date	VE areas	Element	Work Result	Space by Function	Materials
1.	VE team 1	Replace the door...	2003.08	Architecture (Apartment)	Wall	Concrete	Living Room	Binding Compounds
2.	VE team 2	Replace ART....	2003.08	Architecture (Apartment)	Wall	Interior Finishing	Kitchen	ART Wall
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Fig. 2. VE idea lists based on Omniclass.

ideas related to the current project. In addition, the VE team can create new templates to efficiently store, manage and evaluate new VE ideas.

- Graphical information: includes a box which can depict 2D drawings and 3D models to aid the VE team in visualizing and understanding ideas from past projects. With this graphical information section in the template, the team can conveniently refer to past ideas, compare them and generate new alternatives. In order to illustrate new ideas, the VE team can conveniently upload 2D drawings and extract 3D elements from a BIM models.
- Detailed information: allows users to input detailed search parameters based on the Omniclass classification (elements,

work results, space by function, and materials) according to BIM objects, as illustrated Fig. 3. Through this, the VE team can search and find past ideas related to the specific parameters of the current project being considered. This process would significantly reduce the time and effort required in sorting past ideas and cataloging new ideas.

The proposed data model would be useful for efficiently recording and effectively reusing VE ideas during the creativity phase of VE studies. This would yield more benefits for the VE team in terms of time-savings and quality idea generation, in comparison with the existing unstructured and ill-managed systems.

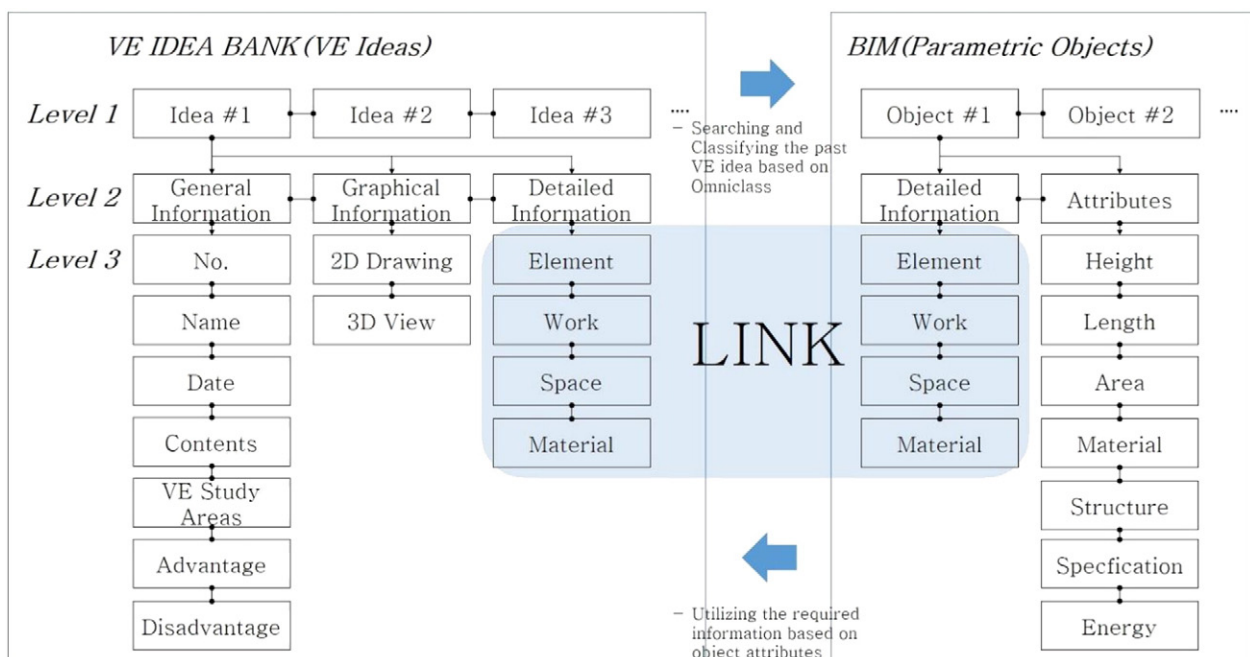


Fig. 3. Data structure between VE Idea Bank and BIM.

3.3. Step 2: creating BIM objects

In order to assign the Omniclass classification to BIM objects, commercial Revit software was used in this research. Even though, the commercial Revit software provides Omniclass classification into the system, it is only Table 23—Products. Thus, it has a limitation to classify and assign Omniclass in the parametric objects following specific parameters such as work, element, space, and materials by Revit itself. As such, it is necessary to categorize predefined Omniclass which can integrate BIM with VE Idea Bank as specific parameters into BIM objects.

As illustrated in Fig. 4, “Table 21—Elements” was created as a “Shared Parameter” which can be shared between multiple projects and BIM objects into attributes (Liu and Issa, 2012). It was divided into type parameter (which can control all elements of same type per group) and instance parameter (which can control selected elements). In addition, Table 21—Elements was stored and managed as a “text” data format into property. Through this, other Omniclass parameters (Table 13—Space by function, Table 22—Work results, and Table 41—Materials) can also be added to categorize specific parameter into BIM objects.

By using “Family Editor”, BIM objects which contain specific parameters are created and duplicated from the existing BIM objects to automatically assign the Omniclass into attributes (Montaser and Moselhi, 2015).

As illustrated in Fig. 5, (1) “###Generic-Concrete made by Contil Lab” BIM object was duplicated, and (2) specific parameters such as Interior Wall Space “Table 13—Space by function” (Canada and Institute, 2012a), Wall Finishes “Table 21—Elements” (Canada and Institute, 2012b), Concrete “Table 22—Work results” (Canada and Insitute, 2012c), Binding Compounds “Table 41—Materials” (Canada and Institute, 2012d) were assigned in attributes of BIM objects. Through this, (3) when the BIM object would be newly duplicated, the predefined Omniclass classification could be automatically assigned into attributes. This BIM object can be used repeatedly without having to recreate and reduplicate for different projects or tasks. The following section describes how to integrate BIM and the VE Idea Bank, which serves as the backbone of the proposed system.

3.4. Step 3: integration of BIM and VE idea bank

The next step in the development of the proposed system is the integration of BIM and the aforementioned VE Idea Bank through an add-in. This step is essential to enable efficient searching and retrieval of VE ideas based on the Omniclass search parameters (space, element, work and material) specified for BIM objects.

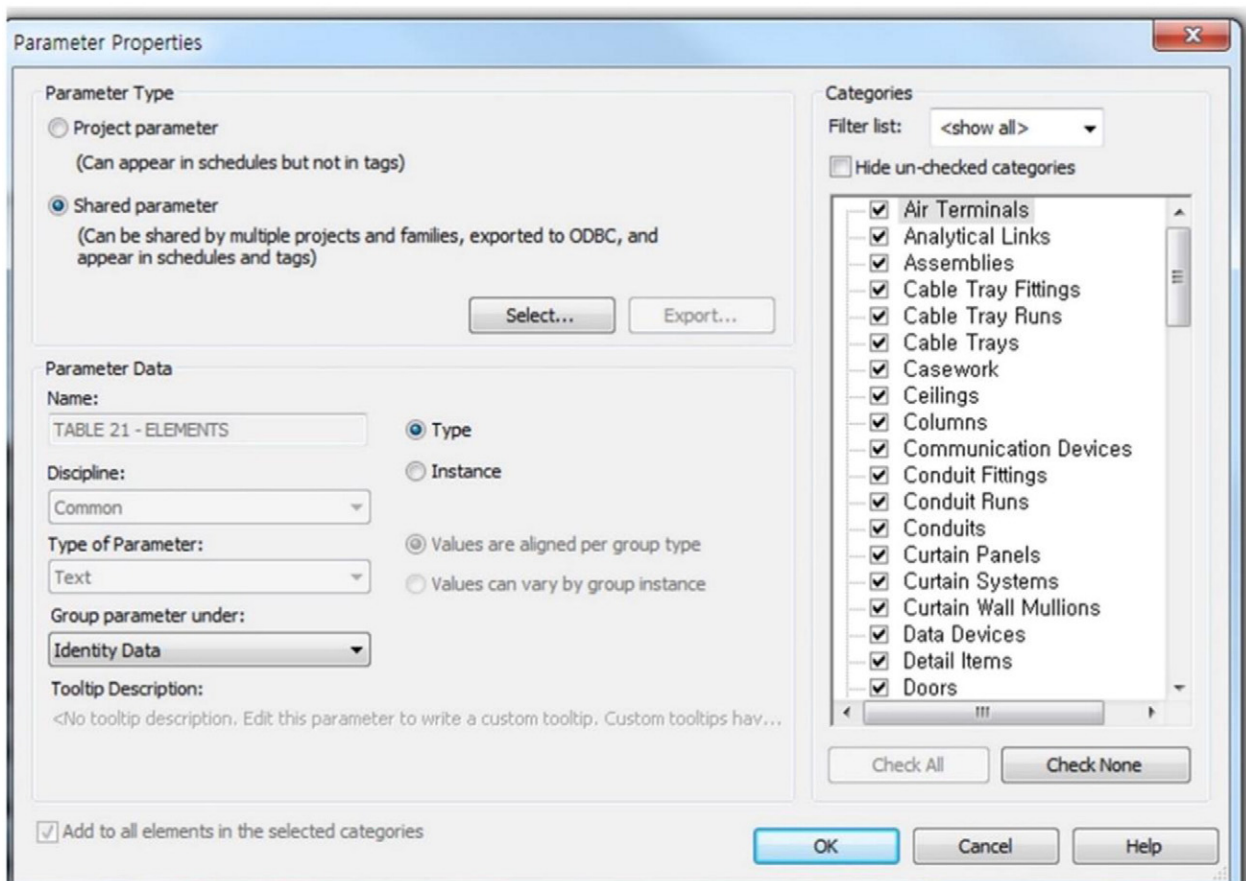


Fig. 4. Creating specific parameter based on Omniclass.

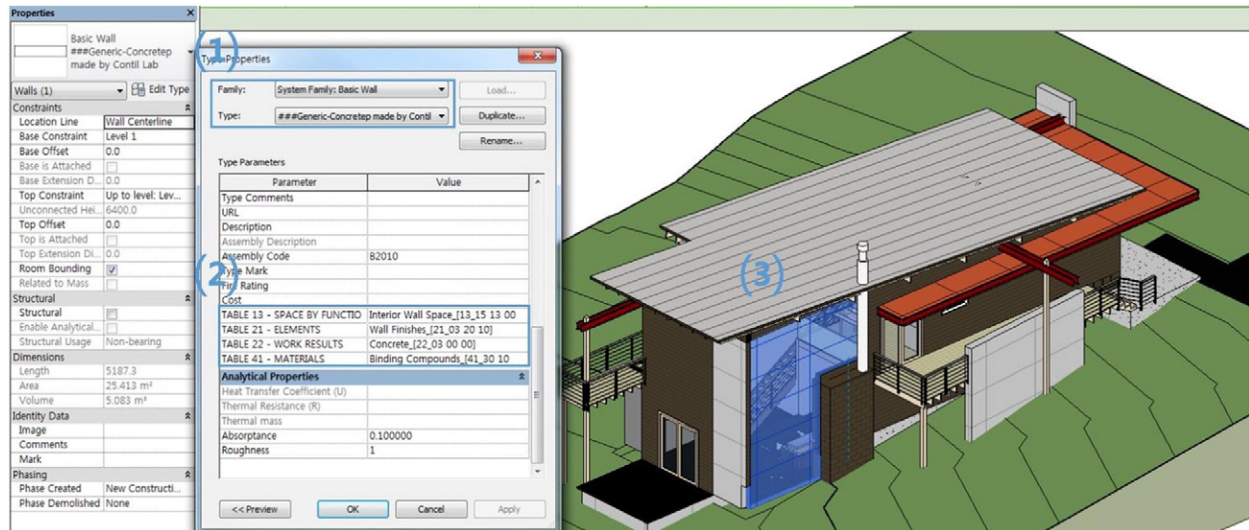


Fig. 5. Duplicating BIM object from the existing BIM object.

Firstly, VE ideas in the templates of the VE Idea Bank were classified according to Omniclass's space, element, work and material classification. Next, in order to assign the Omniclass classification to BIM objects, commercial Revit software was used.

Initially, BIM object was used to manually assign Omniclass (space, element, work and material) in previous Section 3.3.

Through the development and application of an add-in, these classified BIM objects can then be linked to the VE Idea Bank, as illustrated in Fig. 6.

Through the add-in, a classified BIM object is picked to get parameters from attributes including Omniclass which had been predefined. It is necessary to classify general parameters and specific parameters to extract Omniclass information in order to

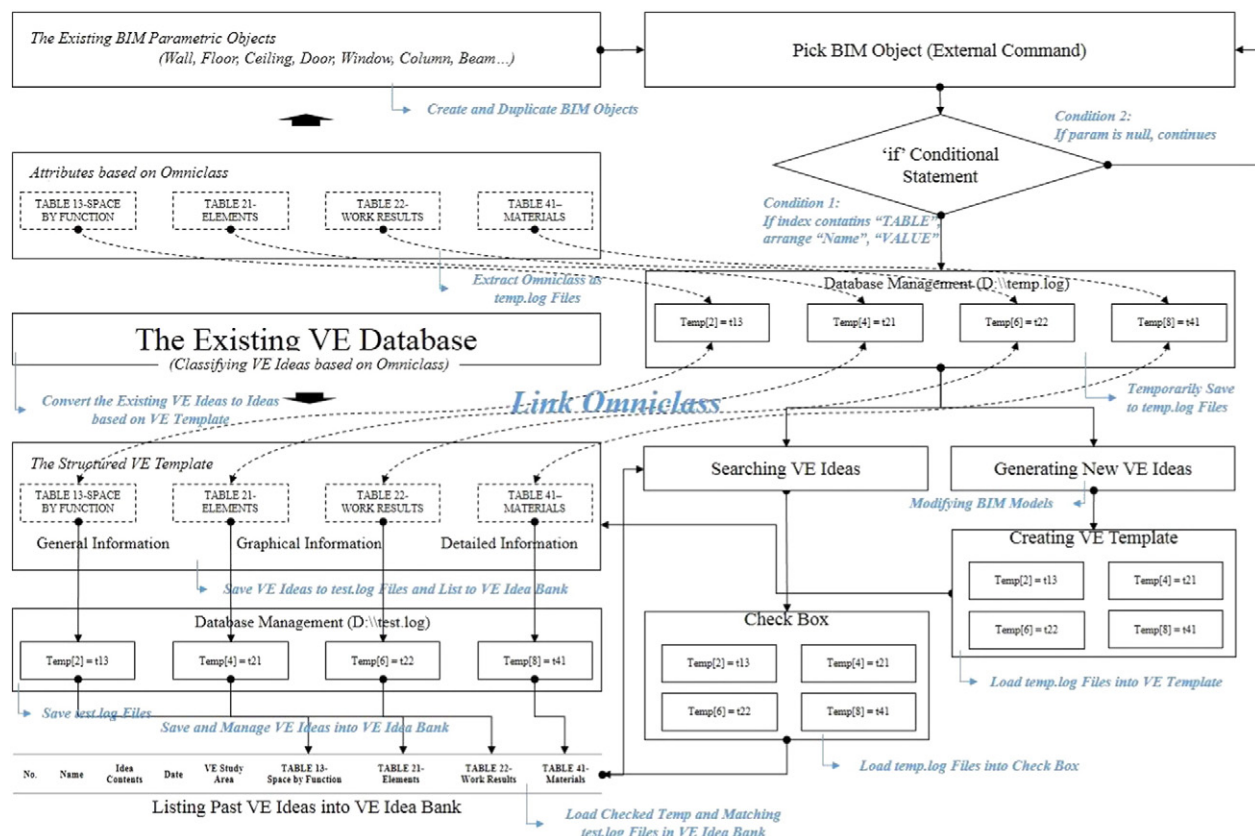


Fig. 6. Integration process for BIM and VE Idea Bank.

make search parameters. To distinguish between general and specific parameters, an “if” conditional statement which can evaluate conditions as true or false is applied. The conditions are defined as “if a parameter contains ‘TABLE’, arrange ‘NAME’ and ‘VALUE’ in the window” and “if parameter is null, continue the operation”. The parameter which contains ‘TABLE (Omniclass)’ displays its ‘NAME (Table 13—Space by function)’ and ‘VALUE (Interior Wall Space_[13_15 13 00])’ in the window. The NAME and VALUE parameters are temporarily saved in a Temp storage, as log files (D:\\temp.log). All pre-defined Omniclass parameters in the attributes of BIM object that users pick are automatically loaded into the VE template and a Check Box which can adjust level of detail for searching VE ideas from the Temp of temp.log files. The created VE template is saved as a test.log file in the system and is listed in VE Idea Bank system for efficient idea retrieval. In the case of the Check Box, the checked Temp is transferred to the idea list of the VE Idea Bank. Afterwards, the checked Temp is matched with the listed VE ideas which are loaded from the test.log files within the VE Idea Bank. Through this procedure, VE idea lists from the VE Idea Bank can be linked with BIM objects based on the selected Omniclass search parameters in the Check Box, as illustrated in Fig. 6.

Using this system, the VE team can search for VE ideas and create VE templates. Figs. 7 and 8 illustrate one example to depict this work process.

(1) Firstly, when searching through past ideas in the VE Idea Bank, VE team members can click on the “Searching VE IDEA” option in the External Tools tab (top left corner of Fig. 7). (2) A generic concrete wall which was related to VE study area being considered was selected, in order to improve value and function of the project. After selecting the wall object, the space, element, work and material search parameters could be checked/selected to adjust level of detail and classification for

retrieving related VE study areas. (3) In this case, only one search parameter i.e. element was checked since the VE team wanted to keep their search broad and collect as many various VE ideas as possible. Through this, (4) the past VE ideas related to Wall Finishes (Element) were linked from the VE database. Alternatively, if the team wanted to find more specific and closely related ideas, every search parameter would have been checked. Consequently, (5) a “VE IDEA LIST” box which is automatically linked from the VE database opens up with various VE ideas. Among the listed ideas, the VE team selected one VE idea and opened a VE template, which included general, graphical, and detailed information).

After referring to the past VE ideas, the VE team could virtually implement alternative VE ideas by modifying the BIM model. After generation, it was necessary to fill out VE contents including General Information, Graphical Information, and Detailed Information in the ‘VE IDEA TEMPLATE’. Most of the blanks for General Information should be manually input, while No., and Date were automatically input in VE template. Graphical Information consisted of both Drawings and 3D View, which were acquired through BIM software. Detailed Information such as Exterior Windows (Element), Exterior Wall Space (Space by Function), Openings (Work Results), and Glass (Materials) was automatically assigned in the VE template, as illustrated in Fig. 8. The following section provides further details regarding implementation process of the BIM-based VE Idea Bank for the creativity phase.

4. System implementation during creativity phase

The BIM-based VE Idea Bank system proposed in this paper is developed to support the effective and efficient retrieval, generation, and management of VE ideas. This

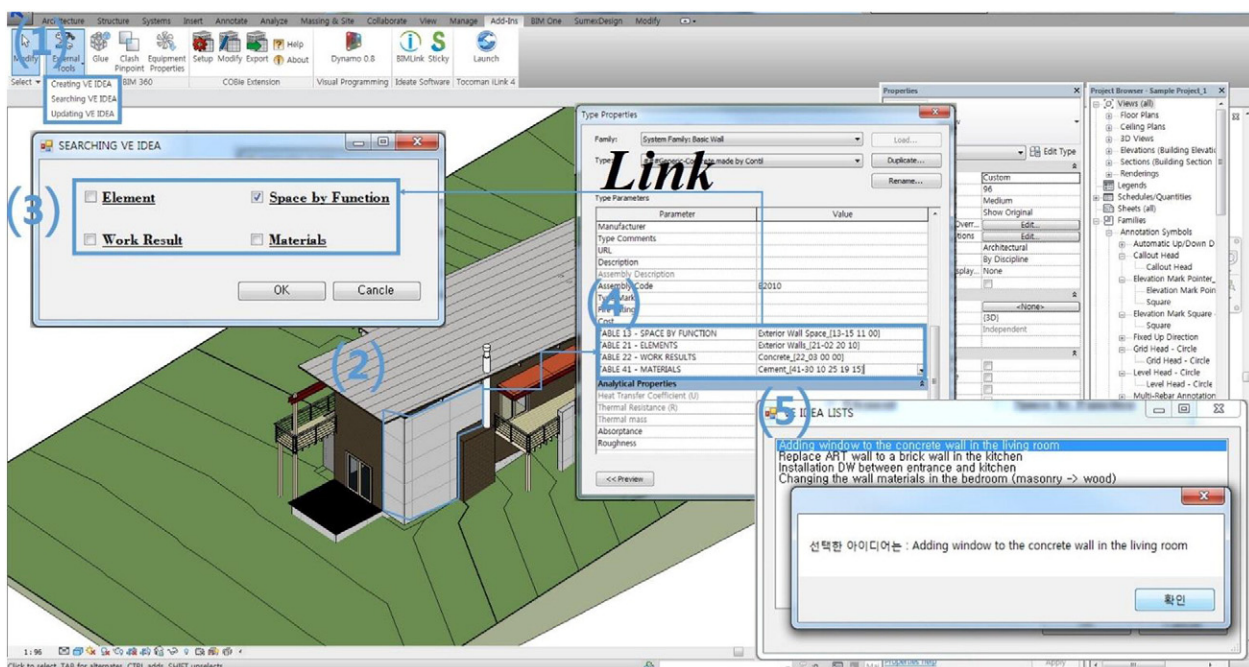


Fig. 7. Searching past VE Ideas through add-in.

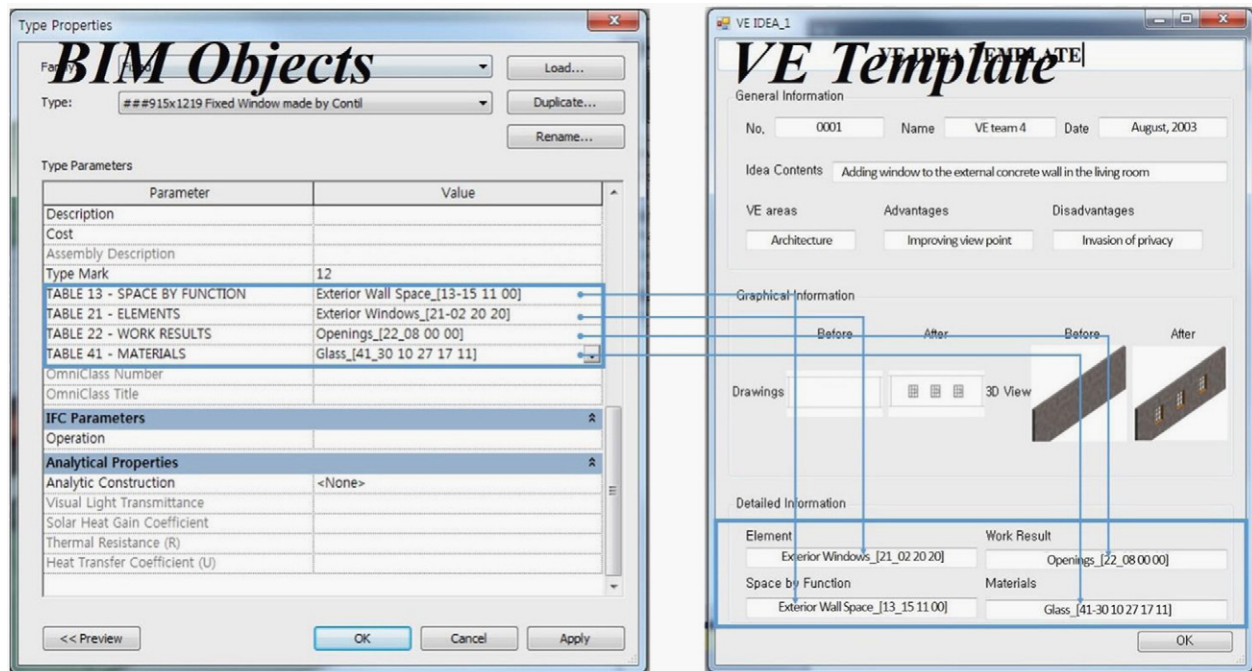


Fig. 8. Creating alternative idea in VE template.

section demonstrates the BIM-based VE Idea Bank implementation with a sample two floor residential building. The previous VE idea lists for apartment project, as shown Table 1, are converted and transferred from documents into the VE Idea Bank. For the case study, ideas are assumed to have been generated in August, 2003. Afterwards, this study suggests two approaches for idea generation.

As illustrated Fig. 9, Reusing VE Idea (Type 1) comprises of three steps including Searching, Reusing, and Proposal in order to rapidly generate VE ideas for projects which have similar and modularized plans such as apartments and residential building.

Based on this type, Case 1, ‘Adding window (915 × 1219) to the external concrete wall in the living room’, is generated to improve amenity, viewpoint, and ventilation by referring to past VE ideas, as illustrated in Fig. 10. This idea can be easily generated by modifying the BIM model without traditional creative thinking techniques during creativity phase. In this regard, the BIM-based VE Idea Bank system is useful to reduce

the work time, when VE team reuse past VE ideas and access the structured database.

Improving VE Idea (Type 2) supports creative and innovative idea generation for complicated and intricate projects by using BIM functions such as visualization and attributes. As illustrated in Fig. 11, VE team can visually recognize the required improvement parts in the BIM model. Furthermore, they can utilize information such as drawings, specifications, and analytic data to improve the quality and value of VE study areas from attributes.

Based on Type 2, the suggested VE idea cases are the following: Case 2: ‘Adding guardrail to the corridor in second floor’, Case 3: ‘Replacing single-glazing window to triple-glazing window in the living room’.

As shown in Fig. 12, guardrail installation was omitted for the open space in the second floor. Even though it might lead to a falling accident hazard, it is difficult to recognize this problem statement through the existing idea generation due to 2D-based work processes. (See Fig. 13.)

Table 1
The existing VE Idea lists for apartment project.

No.	VE team member	Contents	Date	VE study area
1.	000	Adding window to the external concrete wall in the living room	August 2003	Residential units (Architecture)
2.	000	Replacing brick wall to ART wall in the kitchen	August 2003	Residential units (Architecture)
3.	000	Installation DW between entrance and kitchen	August 2003	Residential units (Architecture)
4.	000	Changing the wall materials in the bedroom (masonry → wood)	August 2003	Residential units (Architecture)
5.	000	Changing the external wall materials in the bedroom (concrete → masonry)	August 2003	Residential units (Architecture)
6.	000	Replace the door to sliding type door in the balcony 4	August 2003	Residential units (Architecture)
7.	000	Reducing the external retaining wall in the entrance	August 2003	Residential units (Architecture)
8.	000	Installing the door screen in the entrance	August 2003	Residential units (Architecture)
9.	000	Moving the refrigerator in the kitchen	August 2003	Residential units (Architecture)
10.	000	Moving boiler to the balcony of bedroom 2	August 2003	Residential units (Architecture)

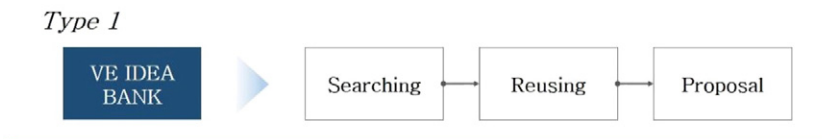


Fig. 9. Type 1: reusing VE idea.

However, by using this system, VE team can easily recognize the required improvement parts related to safety, design, and omitted objects through the visualization function of BIM. After adding a guardrail object in the BIM model which has Omniclass, VE team can generate a new idea (Case 2) in the VE template by implementing the add-in program.

In order to improve functionality of space, material, work, and element during creativity phase, attributes information in BIM environment can be utilized. In sample two floor residential building, a single-glazing window was installed to the external wall in the living room. However, the energy efficiency of single-glazing windows is too low due to Solar Heat Gain Coefficient (0.86) and Thermal Resistance (0.1743) by checking attributes of window object. To improve energy efficiency, a new idea (Case 3) to replace to the triple-glazing window is suggested, as illustrated Fig. 14. Through attributes of triple-glazing window, VE team can recognize that energy efficiency of triple-glazing window is higher than single, because Solar Heat Gain Coefficient is 0.61 and Thermal Resistance is 0.6523. Therefore, the result showed that triple-glazing window can block external heat during summer and the building insulated during winter. It is useful to utilize the required information to generate new VE ideas without lots of 2D documents.

After a VE team member submitted the generated VE ideas, the VE team leader will choose one optimal VE idea. (1) Five

different VE ideas were reported in ‘PROPOSED IDEA BOX’, as illustrated in Fig. 15.

Among these VE alternatives, the VE team leader accepted the most optimal VE idea by checking it in ‘PROPOSED IDEA BOX’. The accepted VE idea would be automatically updated and managed in the system server for convenient future retrieval and reuse.

For post-creativity work, the listed VE ideas would be exported to Excel files in order to analyze the final results. The Excel Sheet contents include no., name, idea contents, date, ve areas, element, work result, space by function, and materials.

As shown in Fig. 16, the VE team can classify, review, compare and analyze accepted VE ideas by using Excels built-in functions. Accordingly, the VE ideas generated from the creativity phase can be systematically accumulated and managed in database server for searching, retrieving, and reusing VE ideas.

5. Evaluation

In order to assess the usefulness and effectiveness of the BIM-based VE Idea Bank, a preliminary evaluation was carried out through interviews and questionnaires with 23 participants, and system trials with a few VE experts in Korea. Participants comprised of three groups including VE facilitators, VE experts, and BIM engineers. VE facilitators are personnel who have work

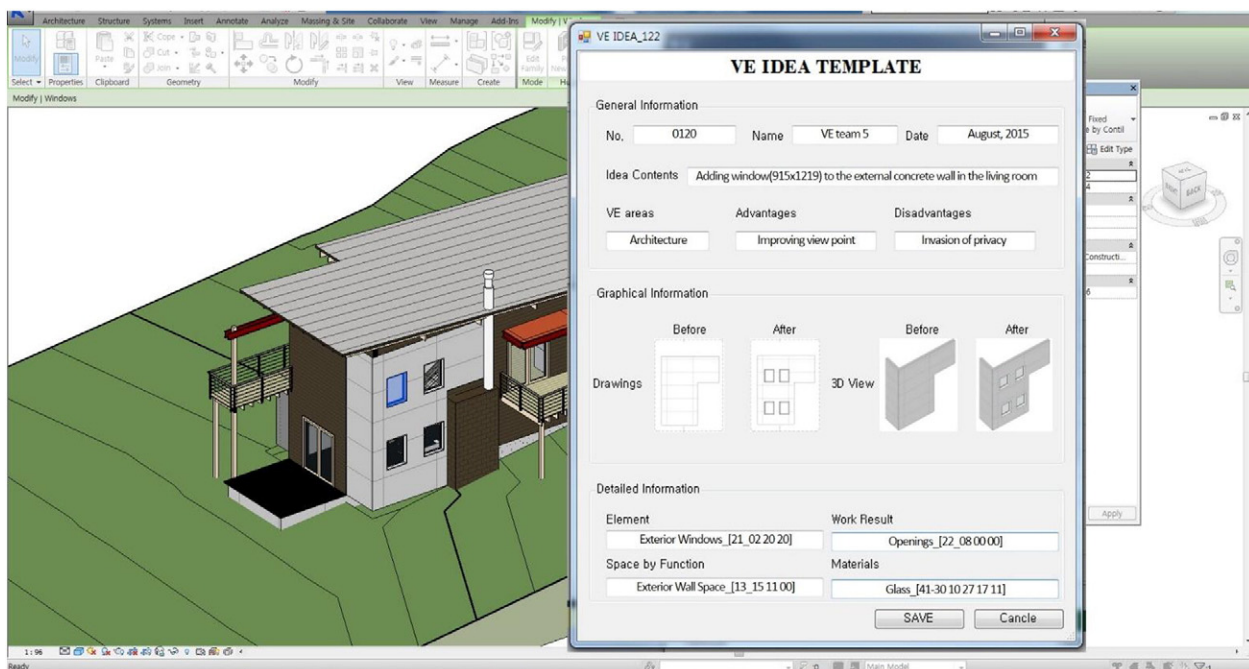


Fig. 10. Case 1: Adding window (915 × 1219) to the external concrete wall in the living room.

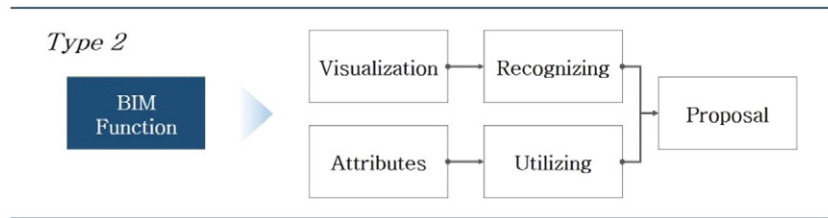


Fig. 11. Type 2: Improving VE idea.

experiences relating to VE however they are non-licensed, while VE experts are professionals who have licenses such as CVS, CVA, KCVS and KVMP, and lastly, BIM Engineers are professionals who make BIM models and manage the BIM technology in construction site.

Participants filled out a 5-point Likert scale from strongly disagree (1) to strongly agree (5). The evaluation participants were given a brief introduction about the development of the BIM based VE idea bank System. Surveys were conducted online through Google sheets, while preliminary system trials were carried out in the Construction Technology Innovation Laboratory of Chung Ang University, Seoul, South Korea. The evaluation criteria for the system effectiveness were divided into the following three categories: Usability, Time Saving, and Quality.

- 1) Usability: represents usability of the proposed system prototype in the industry and contains three questions including applicability of BIM to integrate existing VE ideas, validity of system structure, and the necessity of 3D visualization during idea generation.
- 2) Time Saving: is associated with reducing work time during creativity phase. This category considered the abilities of the system to efficiently support the collecting and screening of past data (Sik-wah Fong et al., 2001), and quick idea generation.
- 3) Quality: measures the performance of a VE study, a main indicator is high-quality of the outcome (Lin et al., 2011). The quality of the outcome could be improved by stimulating VE

team's the problem-solving ability (Maurer, 1996), better understanding of idea's effect and VE study area (Stewart, 2004).

As shown in Table 2, the results indicated that means of all evaluation criteria ranged from 3.73 to 4.52. Namely, most of the participants seemed to be in favor of the proposed system. Especially, three criteria including efficiency of systematically accessing database (4.34), stimulating VE team's the problem solving ability (4.17), better understanding of idea's effect and VE study area (4.52) got the high means over 4 points. Participants who tried using the system mentioned that the structured VE template with the Omniclass classification for cataloging ideas in the VE Idea Bank was efficient and systematic. In addition, the system user interface was found easy to use and operate. Furthermore, the visual representation of alternatives through parametric objects in BIM was considered beneficial for stimulating VE team's problem solving ability. Also, participants found the process of referring to past VE ideas from the VE Idea Bank more convenient than in the conventional idea generation process. Furthermore, the 3D visualization of BIM was considered effective and expected to be useful in assisting VE team members in understanding the effects of ideas.

These preliminary results suggest that the proposed system could have great potential to enhance the productivity of idea generation process during creativity phase and address the limitations of conventional idea generation and management

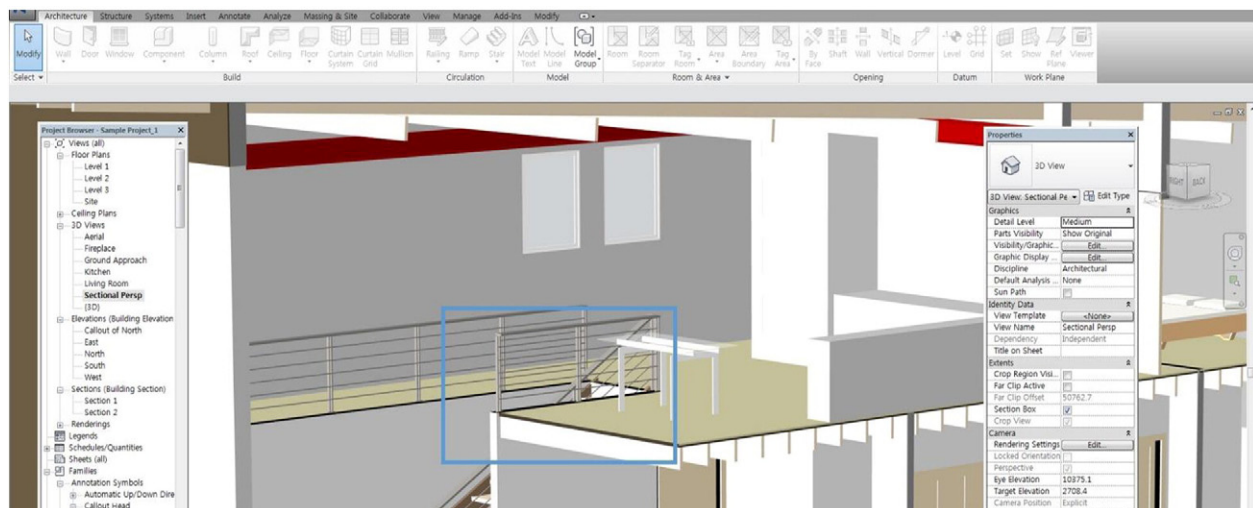


Fig. 12. Internal 3D view in the residential building.

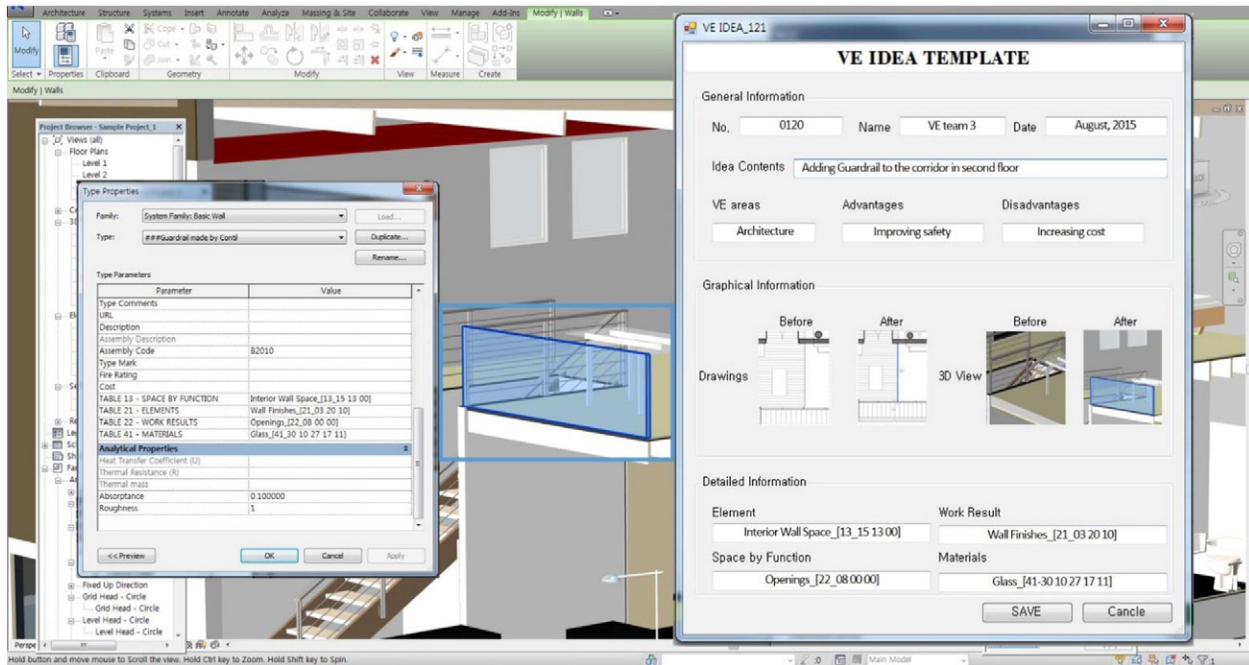


Fig. 13. Case 2: Adding guardrail to the corridor in second floor.

processes. The VE Idea Bank could systematically structure existing data, enhance the idea generation process and as such, improve the results of VE studies.

6. Discussion

This study developed a BIM-based VE Idea bank to efficiently reuse and retrieve past VE ideas and effectively generate new alternatives and VE ideas. In order to assess the usefulness and

effectiveness of this system, interviews and questionnaire were conducted with 23 practitioners working in VE and BIM departments, and preliminary trials were conducted with a few experts. The results indicated that the VE Idea Bank can be one of the useful tools to better understand idea's effects and VE study areas, stimulate VE team's the problem solving ability, and efficiently provide systematic access to VE data.

In spite of these potential benefits, a few concerns and limitations were noted. Firstly, the Idea Bank presented in this

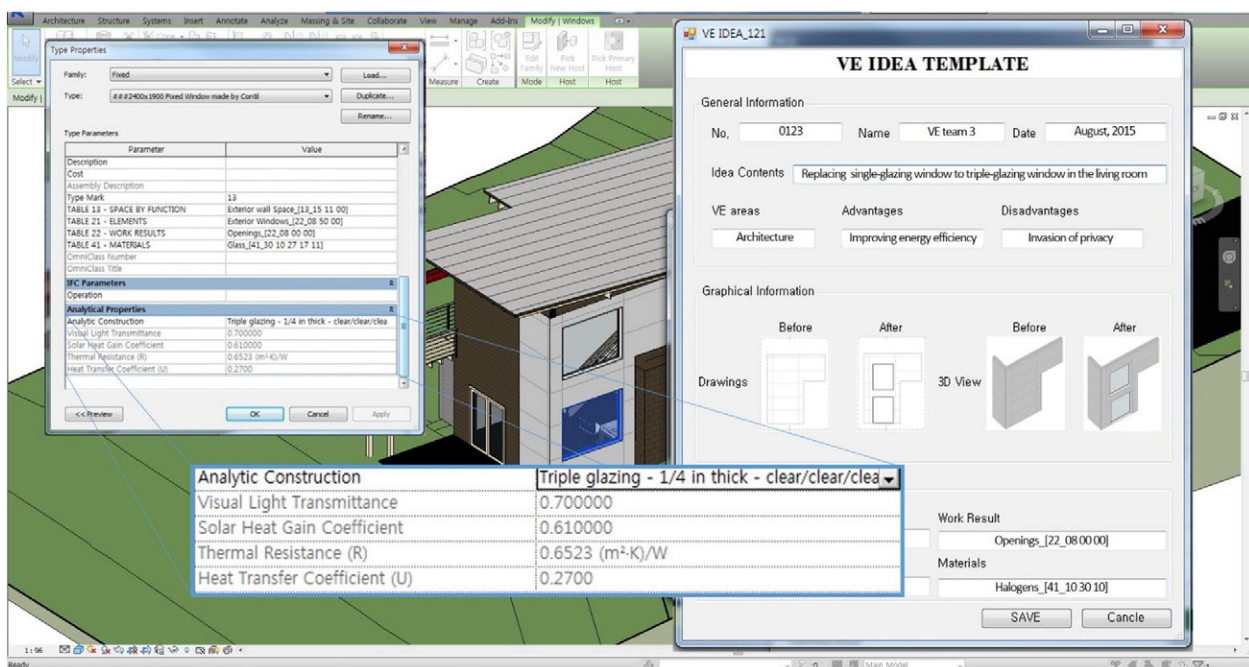


Fig. 14. Case 3: Replacing single-glazing window to triple-glazing window in the living room.

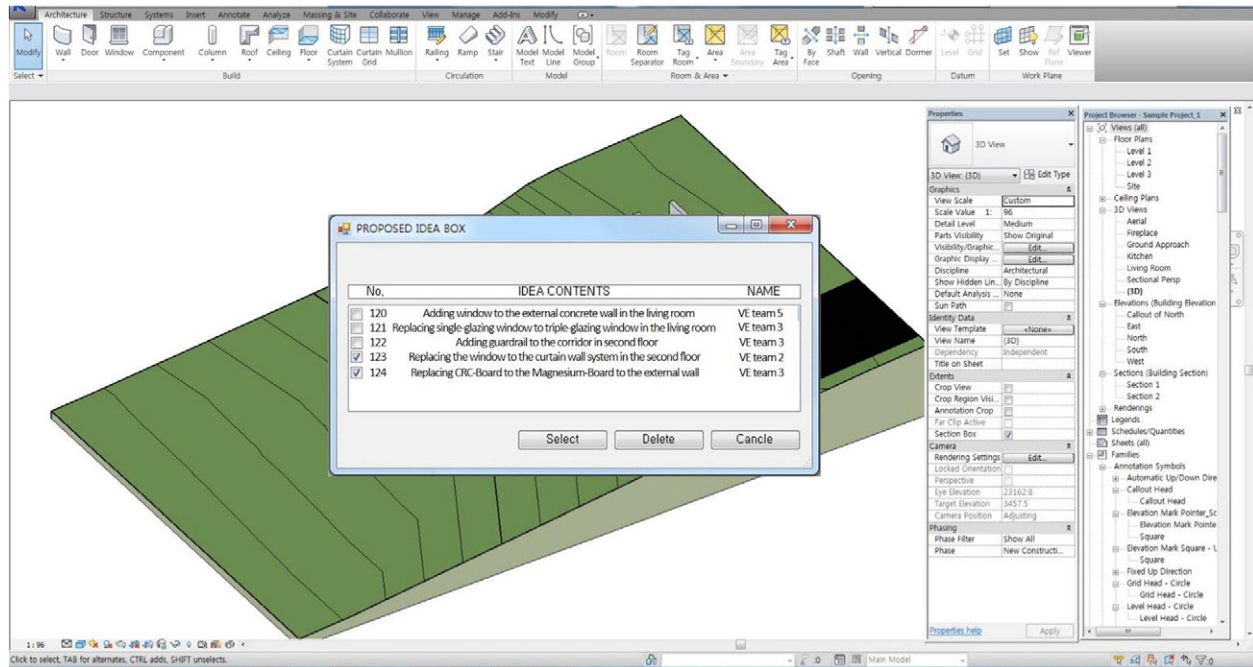


Fig. 15. Updating the accepted VE idea in the VE Idea Bank.

paper does not include functions for removing ideas. To address this, future developments of the idea bank will implement ontology software with reasoning techniques for managing duplicated ideas. Secondly, the system cannot group VE ideas according to importance and recommend optimal alternatives. In other words, the VE teams should make a decision by themselves to suggest the alternative VE ideas, since this system was implemented only considering systematic access to past VE ideas from similar project environments (e.g. work, space, element, and material) based on BIM. In order to recommend the optimal VE ideas, the system should estimate the importance by various specific factors such as cost, function, value and so on. However, this study was focusing on the only creativity phase. Thus, future research would extend the system applicability to the whole VE job plan. For example, in the previous phase (information phase), VE team would analyze

the function based on the facility level, space level, or element level within whole project to depict hierarchy of functions and FAST diagram. The analyzed functions should then be considered to deduce function and value based on system rules. In the case of the subsequent phase (evaluation phase), one of the most important criteria when assessing generated VE ideas is cost. With this regard, if the system can be connected within the whole VE job plan, it can be a useful tool to automatically suggest optimal VE ideas by considering various factors including cost, function, and value.

Furthermore, up to this point, this study has carried out a predominantly subjective evaluation of the system. Future research will implement a more objective evaluation procedure in order to quantitatively ascertain the effectiveness and efficiency of the system. The objective evaluation procedure

No.	Name	Idea Contents	Date	VE areas
1	ooo	Adding window to the external concrete wall in the living room	August.2003	Architecture(residential units)
2	ooo	Replacing brick wall to ART wall in the kitchen	August.2003	Architecture(residential units)
3	ooo	Installation DW Between entrance and kitchen	August.2003	Architecture(residential units)
4	ooo	Changing the wall materials in the bedroom (masonry -> wood)	August.2003	Architecture(residential units)
5	ooo	Changing the external wall materials in the bedroom (concrete -> masonry)	August.2003	Architecture(residential units)
6	ooo	Replace the door to sliding type door in the balcony 4	August.2003	Architecture(residential units)
7	ooo	Reducing the external retaining wall in the entrance	August.2003	Architecture(residential units)
8	ooo	Installing the door screen in the entrance	August.2003	Architecture(residential units)
9	ooo	Moving the refrigerator in the kitchen	August.2003	Architecture(residential units)
10	ooo	Moving boiler to the balcony of bedroom 2	August.2003	Architecture(residential units)
11	ooo	Adding window(915x1219) to the external concrete wall in the living room	August.2015	Architecture(residential units)
12	ooo	Replacing single-glazing window to triple-glazing window in the living room	August.2015	Architecture(residential units)
13	ooo	Adding Guardrail to the corridor in second floor	August.2015	Architecture(residential units)
14	ooo	Replacing the window to the curtain wall system in second floor	August.2015	Architecture(residential units)
15	ooo	Replacing CRC-Board to the Magnesium-Board to the external wall	August.2015	Architecture(residential units)

Fig. 16. Exporting VE idea list to the Excel files.

Table 2
Results of evaluation for BIM-based VE Idea Bank.

	Evaluation criteria	Means
Usability	Applicability of BIM to integrate the existing VE ideas	3.73
	Validity of system structure	3.91
	The necessity of 3D visualization	3.73
Time saving	Efficiency of systematically accessing database	4.34
	Screening of VE ideas	3.73
	Quick idea generation	3.73
Quality	Stimulating VE team's problem solving ability	4.17
	Better understanding of idea's effect and VE study area	4.52

will include: 1) the application of the BIM-based VE Idea Bank by a VE team during the creativity phase of a VE study for a real ongoing project; and 2) the application of conventional VE techniques and tools by another VE team during the creativity phase of the same project; 3) a comparison of the performance of the VE teams in terms of a) number of ideas generated b) quality of ideas generated and c) the time required in generating ideas using both approaches; 4) and lastly statistical t-tests would also be implemented to validate the significance of differences between results from the two approaches.

7. Conclusion

Construction personnel consistently faces various challenges in delivering high quality projects on time and within budget. Value engineering has been established as a systematic and structured management approach that can significantly improve the function and value of projects, and also eliminate unnecessary costs. This paper developed a BIM-based VE Idea Bank in order to enable the systematic storage, retrieval and reuse of past VE data, as well as the efficient generation of new ideas. The proposed system was developed using the C# programming language within the Autodesk API platform. The detailed system development and implementations including data model based VE Idea Bank, BIM objects, the integration of BIM and VE Idea Bank, and system implementation for creativity phase were described and illustrated. Afterwards, in order to assess the systems potential usefulness and effectiveness, system trials were conducted, along with interviews and questionnaires of VE and BIM professionals in the construction industry. Interim results show that the proposed system has great potential to improve the efficiency of systematically accessing databases, retrieving and reusing past ideas as well as stimulating idea generation.

Further studies would be worthwhile to expand the functionalities of the BIM based VE Idea Bank, and implement it on real projects. This paper forms part of an ongoing research which will also consider how to connect the proposed VE Idea Bank in the creativity phase with the previous phase (information) and the following phase (evaluation) within BIM environments. Function analysis is one of the essential activities during the information phase while cost is one of the most important criteria for assessing alternatives and ideas during the evaluation phase. Subsequent research efforts will consider how data from function analysis can be managed and reused based on the functional types of facilities from past projects and linked with the BIM-based VE idea bank; as

well as how BIM could allow users to automatically assess the costs of new VE ideas and alternatives in the evaluation phase.

Conflict of interest

The authors of this paper certify that they have no affiliations with or involvement in any organization or entity with financial or non-financial interests in the subject matter or materials discussed in this manuscript.

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