A KNOWLEDGE-BASED SYSTEM AS A DECISION MAKING TOOL FOR EFFECTIVE MANAGEMENT OF VARIATIONS AND DESIGN IMPROVEMENT: LEVERAGING ON INFORMATION TECHNOLOGY APPLICATIONS

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SUMMARY**:** *In a perfect world, changes will be confined to the planning stages. However, late changes often occur during construction, and frequently cause serious disruption to the project. The integration of project knowledge and experience at the design phase provides the best opportunity to improve overall project performance. This paper presents a knowledge-based system (KBS) for management of variations in educational building projects in Singapore. The KBS consists of two main components, i.e., a knowledge-base and a controls selection shell. The KBS is developed by collecting data from the source documents of the 80 educational projects, questionnaire survey, literature review and in-depth interviews with the professionals.*
The system provides detailed information about variations in the educational building projects completed. This may assist the professionals in identifying the potential variations and their effective controls during the early stages of the construction projects. Furthermore, the KBS provides designers with information on what changes in design can cause to variations. The system is expected to assist in improving project designs because the most likely areas on which to focus to reduce variations can be identified during the design stage of the building projects. In short, the KBS is able to assist professionals by providing accurate and timely information for decision making, and a user-friendly tool for analyzing and selecting the suggested controls for variations in educational buildings. With further generic modification, the KBS will also be useful for the management of variations in other types of building projects, thus helping to raise the overall level of productivity in the construction industry.

KEYWORDS: *knowledge-based system, design improvements, variations, management, Singapore.*

1. INTRODUCTION

In a perfect world, changes will be confined to the planning stages. However, late changes often occur during construction, and frequently cause serious disruption to the project (Cameron et al, 2004). Great concern has been expressed in recent years regarding the adverse impact of variations to the construction projects. Project variations were identified as a major source of conflicts and disputes in the construction industries of many countries (Yates and Hardcastle, 2003). The need to make changes in a construction project is a matter of practical reality. Even the most thoughtfully planned project may necessitate changes due to various factors (O'Brien, 1998).

Variations are inevitable in any construction project (Mokhtar et al, 2000). Needs of the owner may change in the course of design or construction, market conditions may impose changes to the parameters of the project, and technological developments may alter the design and the choice of the engineer (Arain et al, 2004). The engineer's review of the design may bring about changes to improve or optimize the design and hence the operations of the project. Furthermore, errors and omissions in engineering or construction may force a change (Arain and Low, 2005a). All these factors and many others necessitate changes that are costly and generally un-welcomed by all parties.

Variations are common in all types of construction projects (CII, 1994a, Fisk, 1997, Ibbs, et al 2001). The nature and frequency of variations occurrence vary from one project to another depending on various factors (CII, 1986, Kaming, et al 1997). Variations in construction projects can cause substantial adjustment to the contract duration, total direct and indirect cost, or both (Ibbs, 1997a, Ibbs, et al 1998). Therefore, project management teams must have the ability to respond to variations effectively in order to minimize their adverse impact to the project.

As mentioned earlier, variations are frequent in construction projects and can cause considerable adjustment to the project time, cost and quality. The causes of variation orders are greatly varied, thus making the task of variation management difficult for most clients. However, the undesirable situation can be minimized as long as a mechanism for handling variations and making more informed decisions based on the past projects can be understood and built into project management.

Consideration must be given from the initial stages (inception) of the project until commissioning (Arain and Low, 2005a). Contractual provision is required to define the conduct of owner, consultant and contractor to participate in and manage variations. Systematic and proper procedures must be set in place to process a change from conceptual development until it materializes in the field. The reality is that an adverse environment exists among parties in the construction industry (Arian et al, 2004). Variations could be perceived as positive or negative to the preconceived goals of the professionals involved in a project. Therefore, a major variation must be managed and handled professionally in order to minimize its cost, schedule and consequential impacts that may divert the project away from its targeted goals.

Mendelsohn (1997) observed that probably 75% of the problems encountered on site were generated at the design phase. This is not to say that contractors do not create a slew of problems of their own but that these problems were often compounded by inherent design flaws. Kumaraswamy, et al (1998) studied claims for extension of time due to excusable delays in Hong Kong’s civil engineering projects. Their findings suggested that 15-20% time over run was mainly caused by inclement weather. 50% of the projects surveyed were delayed because of design variations.

Kaming, et al (1997) pointed out that the major factors influencing cost over run were material cost increase due to inflation, inaccurate material estimating and the degree of project complexity. In the case of time over run, the most important factors that caused delays were design changes, poor labor productivity, inadequate planning, and resource shortage.

Arain, et al (2004) argued that a majority of the most significant causes of discrepancies between design and construction of building construction projects was related to design phase. Furthermore, Arain and Low (2005a) identified the design phase as the most likely area on which to focus to reduce the variations in future educational projects. If one were to seriously consider ways to reduce problems on site, an obvious place to begin with is to focus on what the project team can do to eliminate these problems at the design phase.

Considering the hectic working environment of construction projects, decisions are being made under pressure and cost and time invariably dominate the decision making process (O’Brien, 1998). Most forms of contract for construction projects allow a process for variations. Even though there may be a process in place to deal with these late changes, cost and time invariably dominate the decision making process. If the change affects the design, it will impact on the construction process and, quite possibly, operation and maintenance as well (Cameron et al, 2004). To overcome the problems associated with changes to a project, the project team must be able to effectively analyze the variation and its immediate and downstream effects (CII, 1994a). To manage a variation means being able to anticipate its effects and to control, or at least monitor the associated cost and schedule impact (Hester et al, 1991). An effective analysis of variations and variation orders requires a comprehensive understanding of the root causes of variations and their potential downstream effects.

To identify and analyze potential variations that could happen in a project as early as possible can enhance the management of project (Arain and Low, 2005b). Learning from these variations is imperative because the professionals can improve and apply their experience in the future. In project management, variations in projects can cause substantial adjustments to the contract duration time, total direct and indirect cost, or both (Ibbs, et al 1998, Ibbs, et al 2001). Because variations are common in projects, it is critical for project managers to confront, embrace, adapt and use variations to impact positively the situations they face and to recognize variations as such (Ibbs, 1997). The variations and variation orders can be minimized when the problem is studied collectively as early as possible, since the problems can be identified and beneficial variations can be made (CII, 1994a). The variations and variation orders can be deleterious in any project, if not considered collectively by all participants. For successful project management, professionals should take advantage of lessons learned from past similar projects and apply their experiences during the design stages (Arain, 2005). This emphasizes the significance of design stage as the most potential area for reducing variations in the construction projects.

Decision making is a significant characteristic that occur in each phase of a project (Arain, 2005). In almost every stage, decision making is necessary. Often, these decisions will, or can affect the other tasks that will take place. To achieve an effective decision making process, project managers and the other personnel of one project need to have a general understanding of other related or similar past projects (CII, 1994). This underscores the importance of having a good communication and documentation system for better and prompt decision making during various project phases.

If professionals have a knowledge-base established on past similar projects, it would assist the professional team to plan effectively before starting a project, during the design phase as well as during the construction phase to minimize and control variations and their effects (Arain and Low, 2005c). The current technological progress does not allow the complete computerization of all the managerial functions or the creation of a tool capable of carrying out automatically all the required management decisions. To ensure the success of this important management function, it is believed that human involvement in this process remains essential. Thus the Decision Support System (DSS) approach for this kind of application seems to be the most natural idea (Miresco and Pomerol, 1995).

From the outset, project strategies and philosophies should take advantage of lessons learned from past similar projects (Ibbs et al, 2001). It signifies the importance of an organized knowledge-base of similar past projects. The importance of a knowledge-base for better project control was recommended by many researchers (Miresco and Pomerol, 1995, Mokhtar, et al 2000, Ibbs, et al 2001, Arain and Low, 2005b).

The integration of construction knowledge and experience at the early design phase provides the best opportunity to improve overall project performance in the construction industry (Arain and Low, 2003). To realize this integration, it is not only essential to provide a structured and systematic way to aid the transfer and utilization of construction knowledge and experience during the early design decision making process, but also to organize these knowledge and experience in a manageable format so that they can be inputted effectively and efficiently into the process.

Information technology has become strongly established as a supporting tool for many professional tasks in recent years (Arain and Low, 2005b). One application of information technology, namely the knowledge-base system, has attracted significant attention requiring further exploration as it has the potential to deliver the best solution in the management of variations, based on the expertise of the decision-makers (Miresco and Pomerol, 1995).

A knowledge-based system is a system that can undertake intelligent tasks in a specific domain that is normally performed by highly skilled people (Miresco and Pomerol, 1995). Typically, the success of such a system relies on the ability to represent the knowledge for a particular subject. Computerized decision support systems can be used by project participants to help make more informed decisions regarding the management of variation orders in projects by providing access to useful, organized and timely information. The objective of this study is therefore to develop a knowledge-based system for linking information to support decision making for effective management of variations in educational building projects in Singapore. The system would assist the designers in learning from past educational projects for reducing potential design variations in the educational building projects. Eventually, the system would assist in improving their designs for educational buildings.

2. SCOPE OF RESEARCH

This paper presents a knowledge-based system which is developed for educational building projects to provide information technology support in areas of design improvement, project management and control for better management of variations. The educational building projects under study are carried out under the major program of rebuilding and improving existing institutional buildings initiated by the government of Singapore. The number of completed educational projects is 80.

A total of about 290 educational buildings will be upgraded or rebuilt by a government agency over a period of seven years, at an estimated cost of S$4.46 billion from 1999 to 2005 (Note: at the time of writing, US$1 is about S$1.80.). The projects are of three types, namely, upgrade, rebuild and grass root (new) buildings under the major programme of rebuilding and improving. As mentioned earlier in the previous section, the construction of an educational building also poses similar risks as in the construction of any other large projects. Developing the knowledge-based system will contribute towards the improvement of designs, and better control of variations through prompt and more informed decisions. Hence, this research concentrated on the educational building projects under this major rebuilding and improvement programme in Singapore.

3. KNOWLEDGE-BASED SYSTEM (KBS)

The issue of managing variations has received much attention in the literature. Despite many articles and much discussion in practice and academic literature, the issue of learning from the past projects for making timely and more informed decisions for effective management of variation orders was not much explored in the literature. Many researchers have proposed principles and theoretical models for managing variations (Mokhtar, et al 2000, Ibbs, et al 2001, Arain and Low, 2005b).

The fundamental idea of any management system is to anticipate, recognize, evaluate, resolve, control, document, and learn from past variations in ways that support the overall viability of the project (Ibbs, et al 2001, Arain and Low, 2005b). The professionals can improve and apply their experience in the future projects hence learning from the variations is imperative. This would help the professionals in taking proactive measures for reducing potential variations.

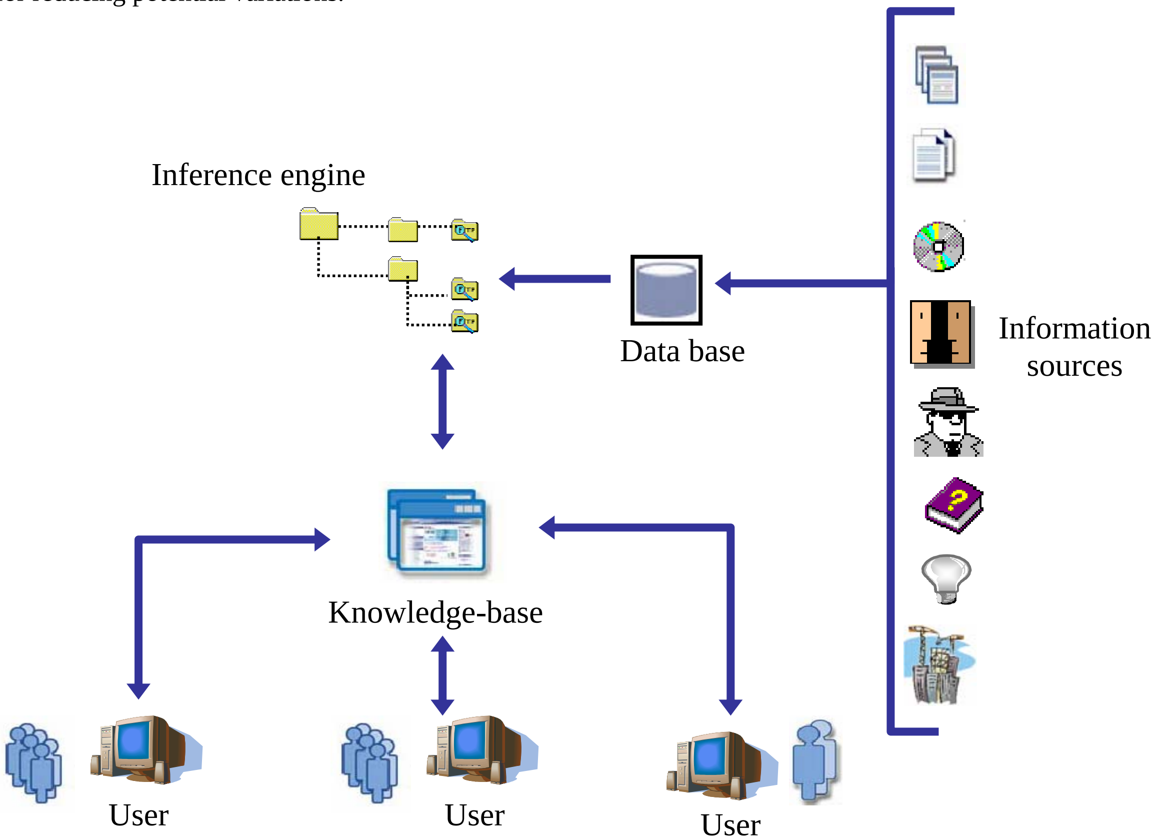


FIG. 1: The main components of a knowledge-based system (KBS)

Knowledge-based system can be used by project participants to help make more informed decisions regarding the management of variations in projects by providing access to pertinent and timely information. This would eventually assist professionals in improving designs for educational building projects because the variations can be identified at the early stage of design where the impact of variations is not severe. Here it is therefore important to understand that the knowledge-based system (KBS) is not designed to make decisions for users, but rather it provides pertinent information in an efficient and easy-to-access format that allows users to make more informed decisions. Although this system does not try to take over the role of the human experts or force them to accept the output of the system, it provides more relevant evidence and facts to facilitate the human experts in making well-informed final decisions. In providing a systematic way to manage variations through the KBS, the efficiency of the building project and the likelihood of project success would be enhanced.

The main components of the KBS are shown in Fig. 1. As presented in Fig. 1, the data was collected from various sources i.e., project documents, site data, interviews with experts, literature reviews and variation documents. This data was stored in a database. From the database, the data was sieved through an inference mechanism for developing the knowledge-base. The inference mechanism assisted in coding, filtering and categorizing the information based on certain given rules. Eventually, the knowledge-base provided decision support to the project teams for making more informed decisions for effective management of variations.

The architecture of the main components of the KBS is shown in Fig. 2. The KBS model contains two main components, i.e., a knowledge-base and a control selection shell, for selecting appropriate potential controls for variations in educational buildings. The database is developed through collecting data from source documents of the 80 educational projects completed, questionnaire survey, literature review and interview sessions with the professionals who were involved in these projects.

The knowledge-base was developed through initial sieving and organization of data, through an inference mechanism, from the database. The inference mechanism assisted in filtering the information based on certain rules and presented the coded and categorized information in the relevant layers accordingly. Furthermore, the knowledge-base was divided into three main segments namely, macro layer, micro layer, and effects and controls layer. The system contains one macro layer that consists of the major information gathered from source documents, and 80 micro layers that consist of detailed information pertinent to variations and variation orders for each project. Overall the system contains 155 layers of information (Note: a layer is a segment of the knowledge-base). The segment that contained information pertinent to possible effects and controls of the causes of variation orders for educational buildings was integrated with a controls selection shell. The controls selection shell contains 53 layers based on each of the causes of variations and their most effective controls. The controls selection shell provided decision support through a structured process consisting of building the hierarchy among the main criterions and the suggested controls, rating the controls, and analyzing the controls for selection through multiple analytical techniques.

The KBS is developed in the MS Excel environment using numerous macros for developing the user-interface that carry out stipulated functions. These are incorporated within a controls selection shell. The graphical user interface (GUI) assists users in interacting with the system on every level of the KBS. The user interface that is provided in the KBS allows the user to access, edit, modify, add and view the information on every layer available in the KBS. In addition, the GUI and inference mechanism maintain the compatibility between layers with in the knowledge-base and the control selection shell. The GUI and inference mechanism create interface between the macro layer and the micro layers to retrieve the pertinent information. Furthermore, the inference mechanism carries out all the stipulated functions required by the user and also provides comprehensive summaries of the information available on every layer of the KBS.

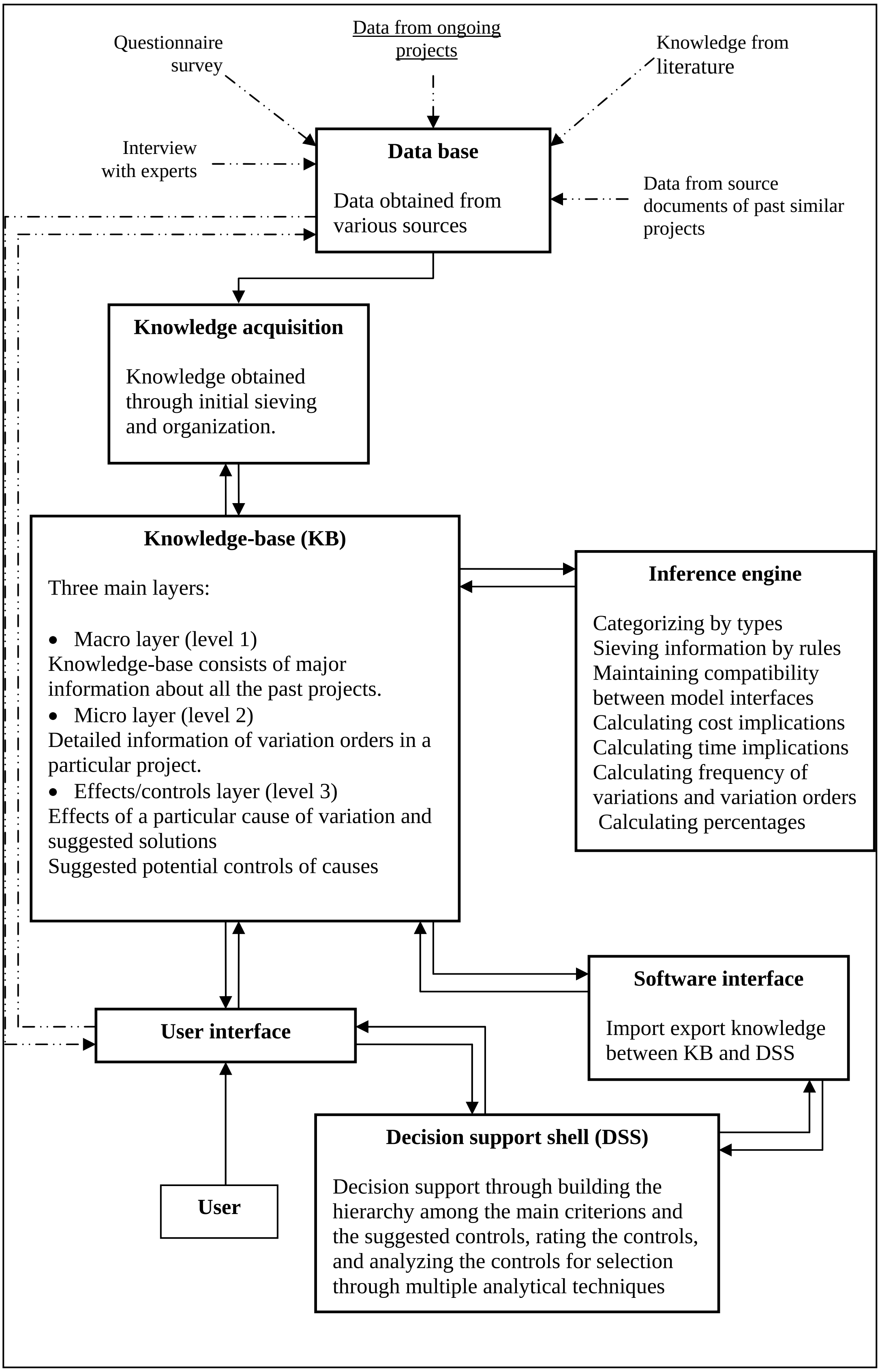


FIG: 2: Framework for knowledge-based system (KBS)

4. KBS FOR MANAGEMENT OF VARIATIONS AND DESIGN IMPROVEMENT

The KBS provides an excellent opportunity to the designers and project managers to learn from past experiences. The KBS can be efficiently used to increase designers and project managers' understanding of the issues pertinent to variations. It may assist designers in learning about variance performance in the particular case studies reported (educational buildings in Singapore). The professionals will be able to analyze the causes, their effects and controls for variations based on the accurate and real knowledge provided in the KBS. The system would assist them in learning about the issues of designs, contracts, management and project variance through the wealth of information based on past educational projects provided in the KBS. Furthermore, the professionals would be able to apply numerous filters to the consolidated knowledge to analyze the various situations related to different projects.

The detailed information that is available on various layers of the KBS is briefly discussed below. The information and various filters that can be applied to the knowledge-base developed may assist the professionals in learning from past projects for improving future designs and enhancing management of variations in educational building projects.

4.1. Information available on the macro layer

As mentioned earlier, the macro layer is the first segment of the knowledge-base. It consists of the major information gathered from source documents of 80 educational projects and through interview sessions with the professionals. As shown in Figs. 3a, 3b and 3c, the macro layer contains the major information about the educational projects completed, i.e., project name, program phase, work scope, institutional level, date of commencement, project duration, date of completion, actual completion, schedule completion status, schedule difference, contract final sum, contingency sum percent, contingency sum, contingency sum used, total number of variation orders, total cost of variation orders, total time implication, total number of variations, frequency of variation orders, frequency of variations, main contractors and consultants.

A variety of filters are provided on the macro layer that assists in sieving information by certain rules. The user would be able to apply multiple filters for analyzing the information by certain rules, for instance, the user would be able to view the information about the educational projects that were completed behind schedule and among these projects, the projects with the highest frequency of variation orders, highest contingency sum used, highest number of variations, etc. This analysis assists the user in identifying the nature and frequency of variations in certain type of educational projects.

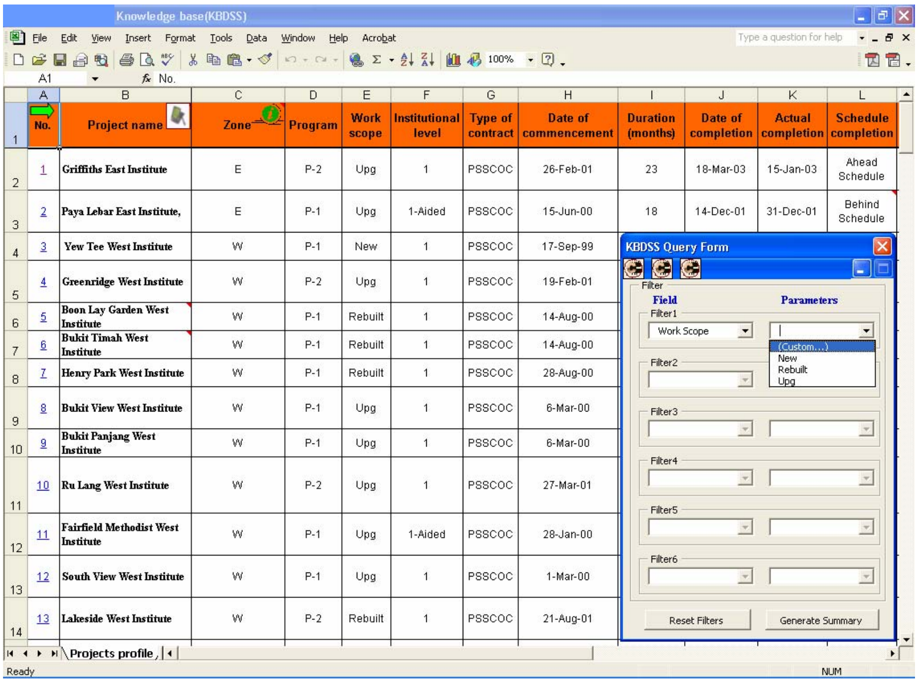
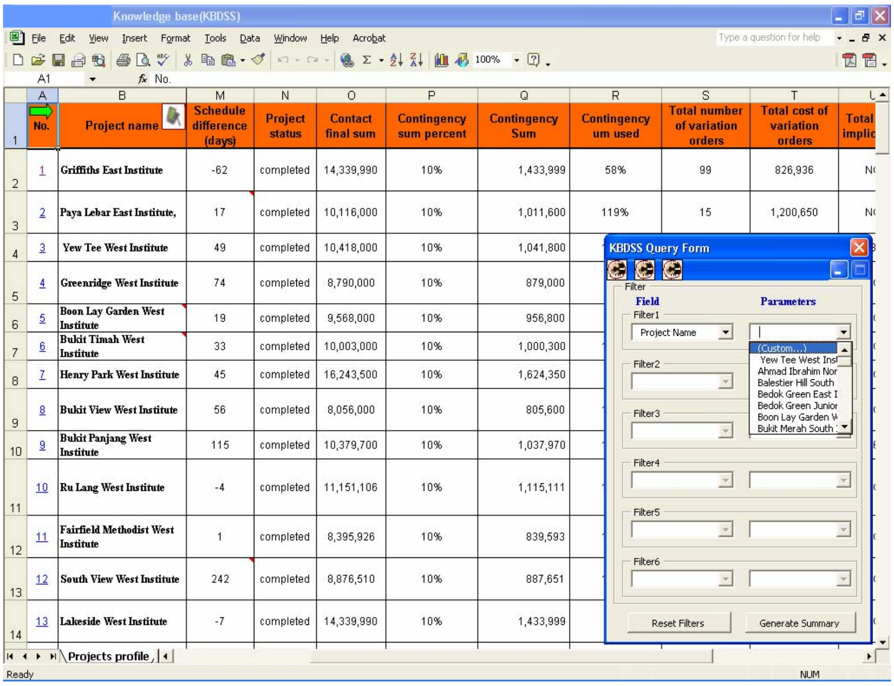
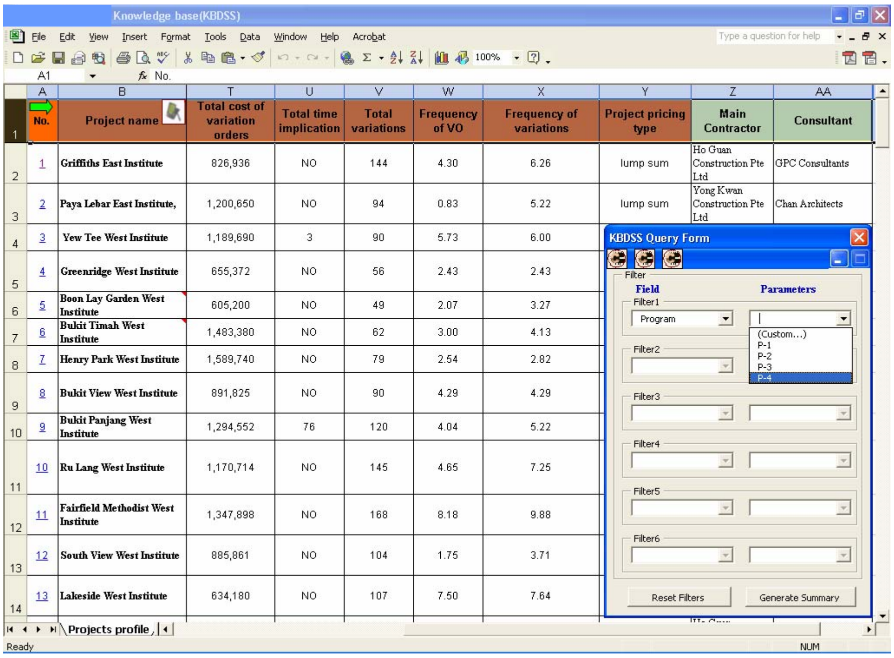


FIG. 3a: Macro layer of the knowledge-base that consists of the major information regarding educational building projects



No.	Project name	Schedule difference (days)	Project status	Contact final sum	Contingency sum percent	Contingency Sum	Contingency um used	Total number of variation orders	Total cost of variation orders	Total implic
1	Griffiths East Institute	-62	completed	14,339,990	10%	1,433,999	58%	99	826,936	N(
2	Paya Lebar East Institute,	17	completed	10,116,000	10%	1,011,600	119%	15	1,200,650	N(
3	Yew Tee West Institute	49	completed	10,418,000	10%	1,041,800				
4	Greenridge West Institute	74	completed	8,790,000	10%	879,000				
5	Boon Lay Garden West Institute	19	completed	9,568,000	10%	956,800				
6	Bukit Timah West Institute	33	completed	10,003,000	10%	1,000,300				
7	Henry Park West Institute	45	completed	16,243,500	10%	1,624,350				
8	Bukit View West Institute	56	completed	8,056,000	10%	805,600				
9	Bukit Panjang West Institute	115	completed	10,379,700	10%	1,037,970				
10	Ru Lang West Institute	-4	completed	11,151,106	10%	1,115,111				
11	Fairfield Methodist West Institute	1	completed	8,395,926	10%	839,593				
12	South View West Institute	242	completed	8,876,510	10%	887,651				
13	Lakeside West Institute	-7	completed	14,339,990	10%	1,433,999				

FIG. 3b: Macro layer of the knowledge-base (cont'd)



No.	Project name	Total cost of variation orders	Total time implication	Total variations	Frequency of VO	Frequency of variations	Project pricing type	Main Contractor	Consultant
1	Griffiths East Institute	826,936	NO	144	4.30	6.26	lump sum	Ho Guan Construction Pte Ltd	GPC Consultants
2	Paya Lebar East Institute,	1,200,650	NO	94	0.83	5.22	lump sum	Yong Kwan Construction Pte Ltd	Chan Architects
3	Yew Tee West Institute	1,189,690	3	90	5.73	6.00			
4	Greenridge West Institute	655,372	NO	56	2.43	2.43			
5	Boon Lay Garden West Institute	605,200	NO	49	2.07	3.27			
6	Bukit Timah West Institute	1,483,380	NO	62	3.00	4.13			
7	Henry Park West Institute	1,589,740	NO	79	2.54	2.82			
8	Bukit View West Institute	891,825	NO	90	4.29	4.29			
9	Bukit Panjang West Institute	1,294,552	76	120	4.04	5.22			
10	Ru Lang West Institute	1,170,714	NO	145	4.65	7.25			
11	Fairfield Methodist West Institute	1,347,898	NO	168	8.18	9.88			
12	South View West Institute	885,861	NO	104	1.75	3.71			
13	Lakeside West Institute	634,180	NO	107	7.50	7.64			

FIG. 3c: Macro layer of the knowledge-base (cont'd)

The inference mechanism provides a comprehensive summary of the information available on the macro layer. As shown in Fig. 4, the inference mechanism computes the total number of projects, subtotal (that assists in identifying the projects when multiple filters are applied), total number of projects based on program phases (P1, P2, P3), subtotal of projects based on program phases, total number of projects categorized according to work scope, subtotal of projects categorized according to work scope, total number of projects categorized based on institutional levels, subtotal of projects categorized based on institutional levels, total number of projects based on schedule completion status (ahead schedule, on schedule, behind schedule), subtotal of projects based on schedule completion status, total number of projects based on three levels of contingency sum usage, subtotal of projects based on three levels of contingency sum usage, total number projects categorized based on time implications, and subtotal of projects based on time implications. Furthermore, the inference mechanism also computes the percentages for each category mentioned above and shown in Fig. 4. This assists the user in analyzing and identifying the nature and frequency of variation orders in certain type of educational projects.

The information available on the macro layer would assist the designers in identifying the potential tendency of encountering more variations in certain type of educational projects. By applying multiple filters that are provided on the macro layer, the professionals would be able to evaluate the overall project variance performance. Furthermore, the wealth of knowledge available on the macro layer may assist in reducing design variations for instance, if the designers are developing a design for Level-1 institute they may evaluate the project performance based on the information available on the macro layer i.e., project cost, total number of variations, contingency sum usage, frequency of variations and variation orders in the Level-1 institutes. These analyses at the design stage would assist the professionals in developing better designs with due diligence.

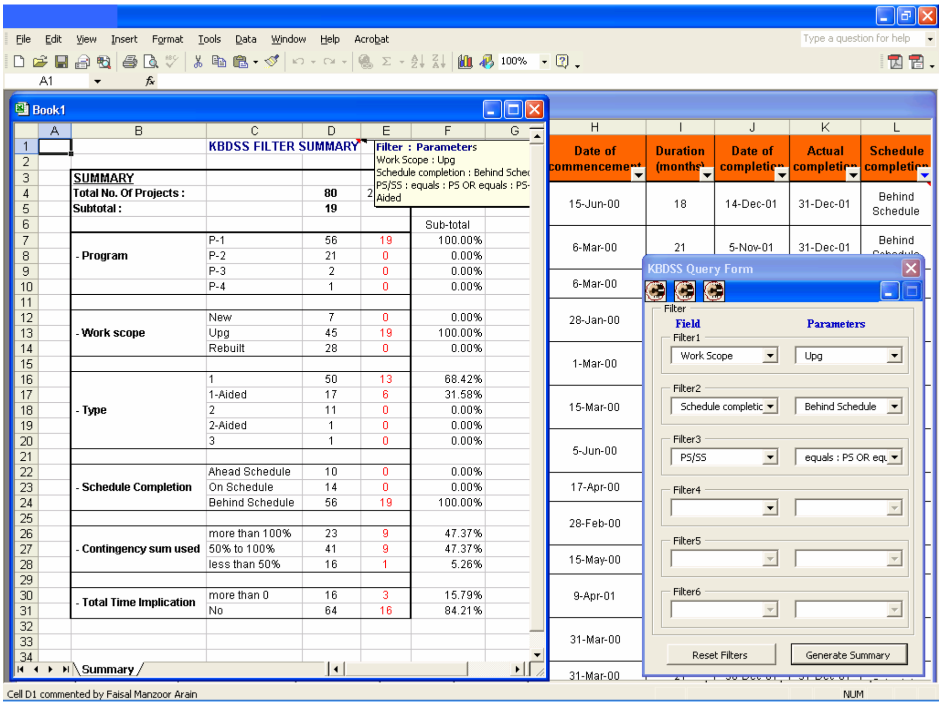


FIG. 4: Summary section displaying the results of the filters applied on the macro layer

4.2. Information available on the micro layer

The micro layer is the second segment of the knowledge-base that contains 80 sub-layers based on the 80 educational projects respectively. As shown in Figs. 5a and 5b, the micro layer contains the detailed information regarding variations and variation orders for the educational project. The detailed information includes the variation order code that assists in sieving information, detailed description of particular variation collected from source documents, reason for carrying out the particular variation provided by the consultant, root cause of variation, type of variation, cost implication, time implication, approving authority, and endorsing authority. Here, the information regarding the description of particular variation, reason, type of variation, cost implication, time implication, approving authority, and endorsing authority were obtained from the source documents of the 80 educational projects. The root causes were determined based on the description of variations, reasons given by the consultants, and the project source documents and were verified later through the in-depth interview sessions with the professionals who were involved in these projects.

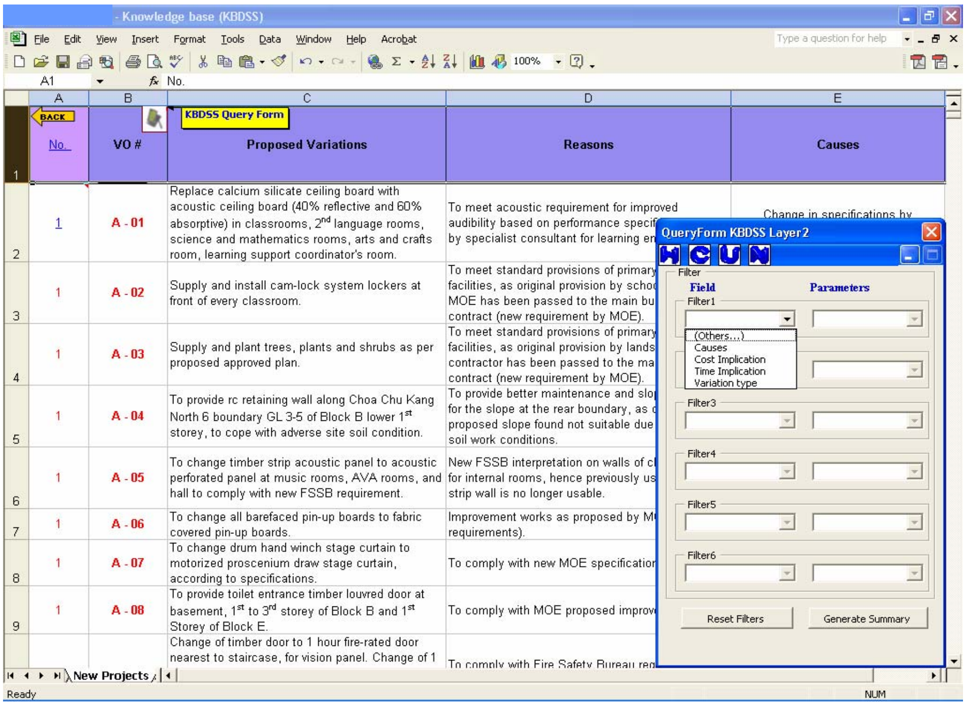


FIG. 5a: Micro layer of the knowledge-base

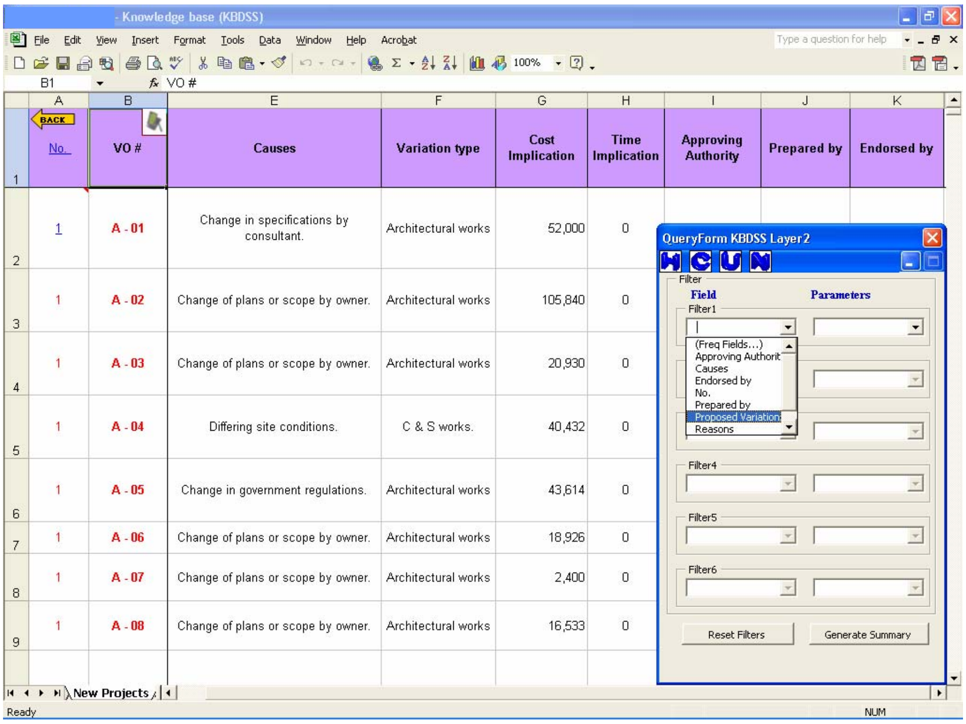


FIG. 5b: Micro layer of the knowledge-base (cont'd)

In addition to computing the abovementioned information, the inference mechanism also computes and enumerates the number of variations according to various types of variations as shown in Fig. 6. The inference mechanism also assists in computing the actual contingency sum by deducting the cost of variations requested and funded by the institution or other sources. This may assist in identifying the actual usage of contingency sum based on the project cost.

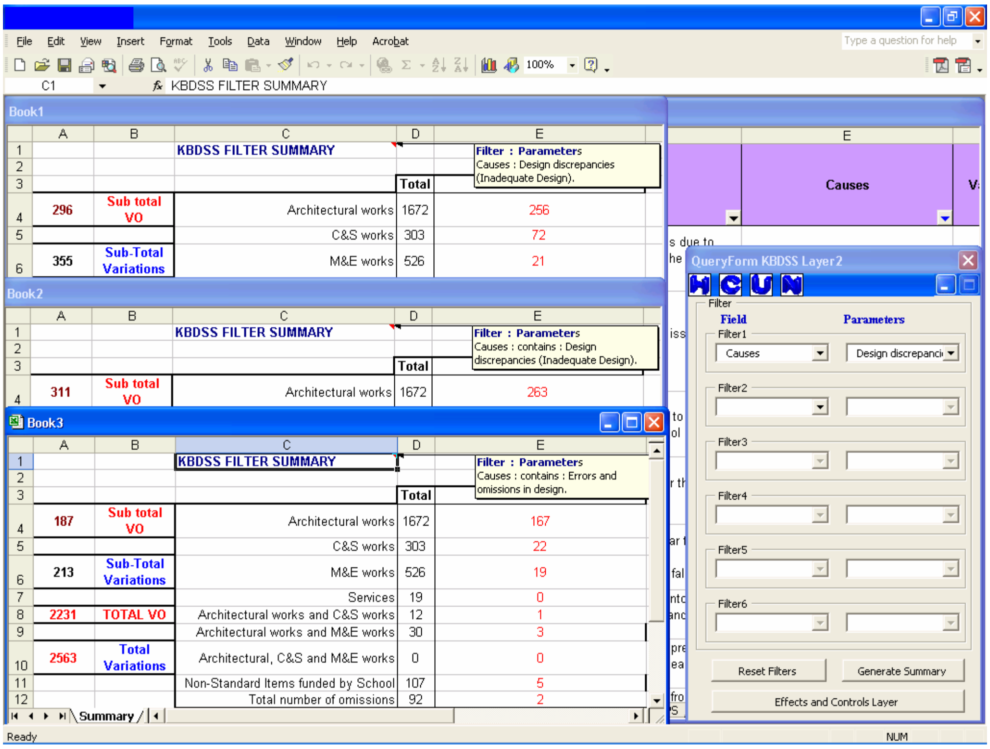


FIG. 6: Multiple summary sections displaying the results of the filters applied on the micro layer

The information can be sieved by certain rules through a variety of filters provided in the micro layer. The professionals would be able to apply multiple filters for finding out the most frequent causes of variations, most frequent types of variations, and variations with most significant cost implication and time implication. The multiple summaries that can be generated by apply filters and using the query form is presented in Fig. 6. The summary section of the micro layer can be saved for future reference. This feature of the KBS assists in carrying out comparative analyses of the information provided in all the layers of the KBS. The inference mechanism integrates the summary section with the filter applications that assist in indicating the multiple filters' application results in the summary section. The results in the summary section assist the user in determining the most important causes of variations in each project. However, the micro layer also provides detailed information (as mentioned above) about all the 80 educational projects for a comprehensive analysis.

The professionals would be able to analyze the most potential variations in educational building projects. The information available on the micro layers would assist in pinpointing the design errors and discrepancies in the past educational projects. As shown in Fig. 6, the KBS provides comprehensive summaries based on the filters applied, for instance, the professionals would be able to evaluate variations categorized according to the cause of variations. These analyses assist in identifying the potential areas on which to focus to reduce variations in future projects. Furthermore, the KBS provides brief description about each variation implemented in the past educational projects documented. This may assist in finding the actual variations and the reasons for carrying out these variations. Based on these analyses, the professionals would be able to pinpoint the major variations that were initiated due to design errors, design discrepancies, and non compliance of design with certain regulations, etc. Hence, during the early stages of construction projects i.e., the design stage, the KBS would assist in improving designs through identifying the potential frequent errors and discrepancies in designs.

When the professionals select any specific cause of variations, for instance, as shown in Fig. 7 they selected design discrepancies, the effect and control tab appears in the query form that creates the interface between the micro layers and the effect and control layers of the KBS. Furthermore, the information available on the micro layer will also be filtered according to the filter applied. The layers and the query forms are dynamic; therefore the user may interact or browse the layers which are activated. This assists in thorough analysis of the information. The professionals may apply custom filters i.e., the filter can be defined to retrieve a particular information available on the micro layer. This feature of the KBS is very useful and user friendly because the professionals can define any combination of information required. During the design stage, the professionals may retrieve all the design related information available in the micro layer that may assist them in improving design and accommodating potential variations, which can affect the projects adversely, at an early stage where the impact of the variations would be less severe than during the construction phase.

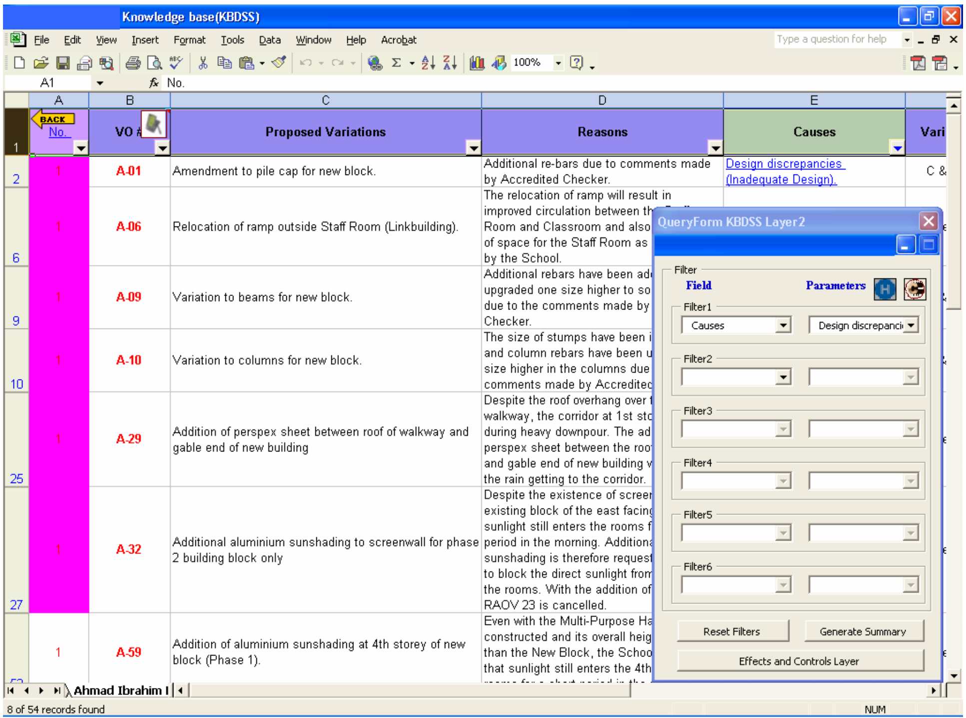


FIG. 7: Query form showing the effects and controls layer tab that connects the micro layer with the effect and controls layer of the knowledge-base

4.3. Effects and controls for potential cause of variations

The third layer of the KBS contains 53 sub-layers based on the potential causes of variations and 10 sub-layers of most important causes combined (Note: the 53 causes were identified from the literature review, analysis of information given in the source documents and in-depth interviews with the developers, consultants and contractors (Arain and Low, 2005a)). The 53 causes can be modified in the event that new ones are discovered or emerged over time. The numerous filters provided in the macro, micro, and effects and controls layers will be updated automatically with every new project added. As shown in Fig. 8, the graphical presentation of the 5 most important effects and 5 most effective controls for the cause of variations was presented. The upper part of the graphical presentation displayed the potential effects of the cause of variations. The lower part presented the most effective controls for the cause of variations. Here the effects and controls for variation orders were tabulated according to the survey results. As shown in Fig. 8, the CDP form is provided in the effects and controls layer, which enabled the user to switch among the effects and controls layer, micro layer and the macro layer that contains major information about all the 80 projects. The names of the projects can be selected in the CDP form that links with the corresponding micro layers.

As shown in Fig. 8, the frequent effects and effective controls for design discrepancies are displayed. An understanding of the effects of variations would be helpful for the professionals in assessing variations. A clearer view of the impacts on the projects will enable the project team to take advantage of beneficial variations when the opportunity arises. Eventually, a clearer and comprehensive view of the potential effects of variations will result in informed decisions for effective management of variations. It is suggested that variations can be reduced with due diligence during the design stages. Furthermore, the suggested controls would assist professionals in taking proactive measures for reducing variation orders for educational building projects. As mentioned earlier about the design stage, it is recommended that the controls be implemented as early as possible. As shown in Fig. 8, the controls selection tab is provided in the CDP form. This feature assisted in linking the knowledge-base with the control selection shell. This is required because the professionals may not be able to implement all the suggested controls. Therefore, the controls selection shell assists them in selecting the most appropriate controls based on their own criterions.

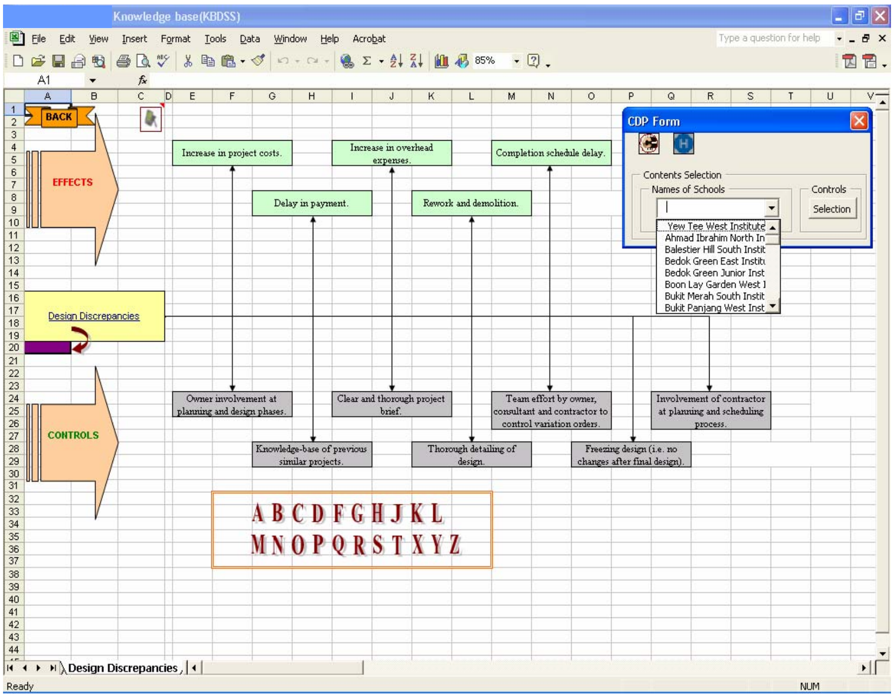


FIG. 8: The most important effects and controls for the cause (design discrepancies) of variations displayed in the effects and controls layer of the knowledge-base

4.4. Controls selection shell

The control selection shell is integrated with the knowledge-base to assist the user in selecting the appropriate controls of variations. As mentioned in the previous section, the 5 most effective controls for the cause of variations were presented on the effects and controls layer, and the layer was linked with the controls selection shell. The control selection shell provides decision support through a structured process consisting of building the hierarchy among the main criterions and the suggested controls, rating the controls, and analyzing the controls for selection through multiple analytical techniques, for instance, the analytical hierarchy process, multi-attribute rating technique, and direct trade-offs. The control selection shell used in this system was a commercially available decision support shell i.e., Criterium Decision Plus (CDP, InfoHarvest$^{\mathrm{TM}}$). The controls selection shell contained four layers that were based on the structured process of decision making, namely, control selection criterions, building the hierarchy between criterions and controls, rating the controls, selecting the best controls based on the given criterions.

4.4.1 Control selection criterions

As shown in Fig. 9, the main criterions for selecting the most effective controls for design discrepancies are the time, cost and quality. This layer of the controls selection shell contains the suggested controls for the cause of variation selected in the controls and effects layer of the KBS. Hence, the controls selection shell contains 53 layers based on the each cause of variations and their most effective controls. Here the goal was to select the controlling strategies and the main criterions were time, cost and quality. The suggested controls would be evaluated based on the given criterions. In this layer, the professionals may add any suggested controls that are considered to be important. Furthermore, the professionals may specify their own contemporary criterions for selecting the controls. The provision of the facility for adding more controls and criterions would assist them in evaluating the suggested controls according to the project stages and needs. For instance, during the design stage the professionals may assign more weights for the controls that may be implemented during the early stage of the construction projects. This may assist them in selecting and implementing the appropriate controls at appropriate time.

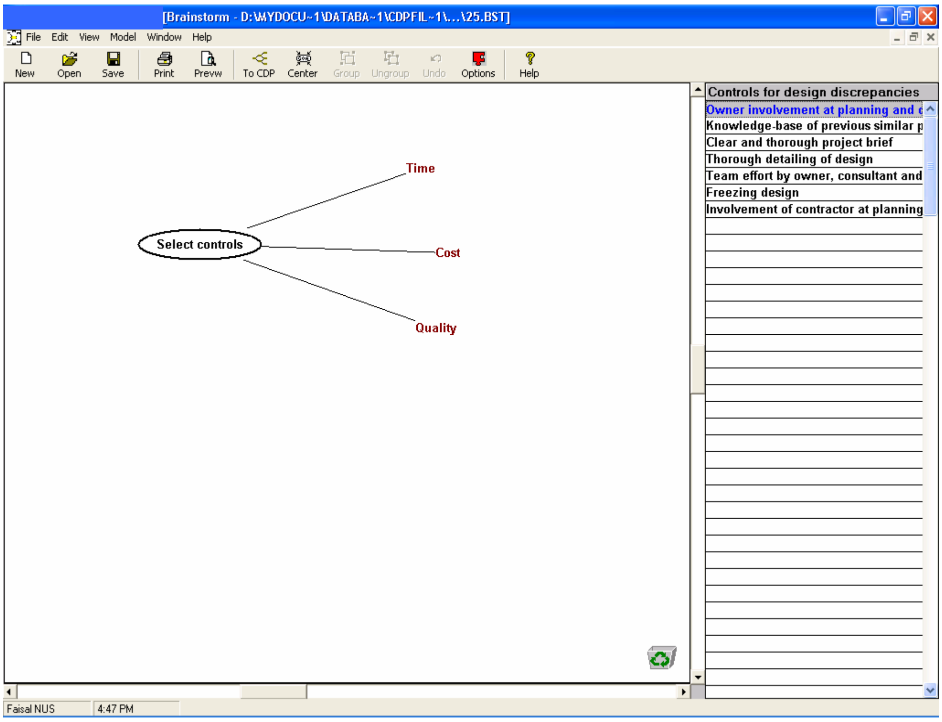


FIG. 9: *Control selection shell contains the goal, main criterions and the most effective controls for variations*

4.4.2 Building the hierarchy between criterions and controls

The main objective of this layer is to generate the hierarchy between the main criterions and the suggested controls for variations. The shell generates hierarchy among the goal, the criterions and the suggested controls as shown in Fig. 10. The hierarchy assists in rating all the suggested controls.

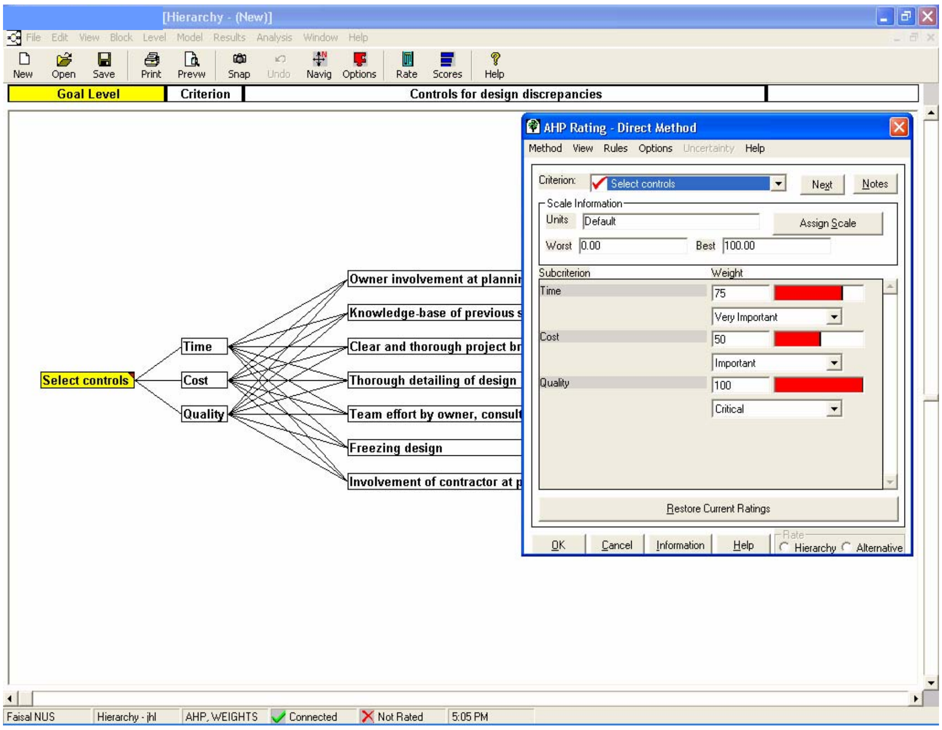


FIG. 10: *Building the hierarchy among the goal, main criterions and controls for variations and rating the main criterions using the direct method*

4.4.3 Rating the suggested controls

The rating process includes four main activities i.e., choosing a rating method, selecting rating scale views, assigning rating scales and entering weights or scores. This layer provides analytical hierarchy process (AHP) as a rating technique. This is because the decision will be based on purely qualitative assessments of the suggested controls. There are three rating methods available, i.e., direct comparison, full pair-wise comparison, and abbreviated pair-wise comparison.

Three types of scale views are provided for entering weights, i.e., numerical, verbal and graphical. These three types are provided for a user-friendly interface, any of the scale views provided can be used to input the weights for the criterions.

The direct method is the default rating method and is used for entering weights for this decision process. As shown in Fig. 10, the first step for rating the controls was to assign weight to the criterions, i.e., time, cost and quality. The main criterion for assigning weight to the sub criterions, i.e., time, cost and quality, was selecting the controls. This assisted in indicting the importance of each criterion in selecting the controls for the cause of variations. The professionals should rate each criterion based on the project phases. This is because during the early stages of the construction projects, normally the implementation cost of suggested controls is not significant. More emphasis should be given on the available resources at the present stage of the construction projects.

The second step was to rate the suggested controls with respect to quality. This was because quality was rated critical as shown in Fig. 11. The rating priority is based on hierarchy of the main criterions rated earlier in the first step. Here the professionals should assign more weight to the controls that may enhance the project quality. The third step was to rate the suggested controls with respect to time. Here the professional should rate the controls, which may require less time for implementation, as high. The user rated all the suggested controls and assigned weights to each alternative (control) as shown in Fig. 12. Lastly, the fourth step was to rate the suggested controls with respect to cost. Here the professionals should select more weights for the controls that are not costly. The user rated all the suggested controls and assigned weights to each alternative (control) as shown in Fig. 13.

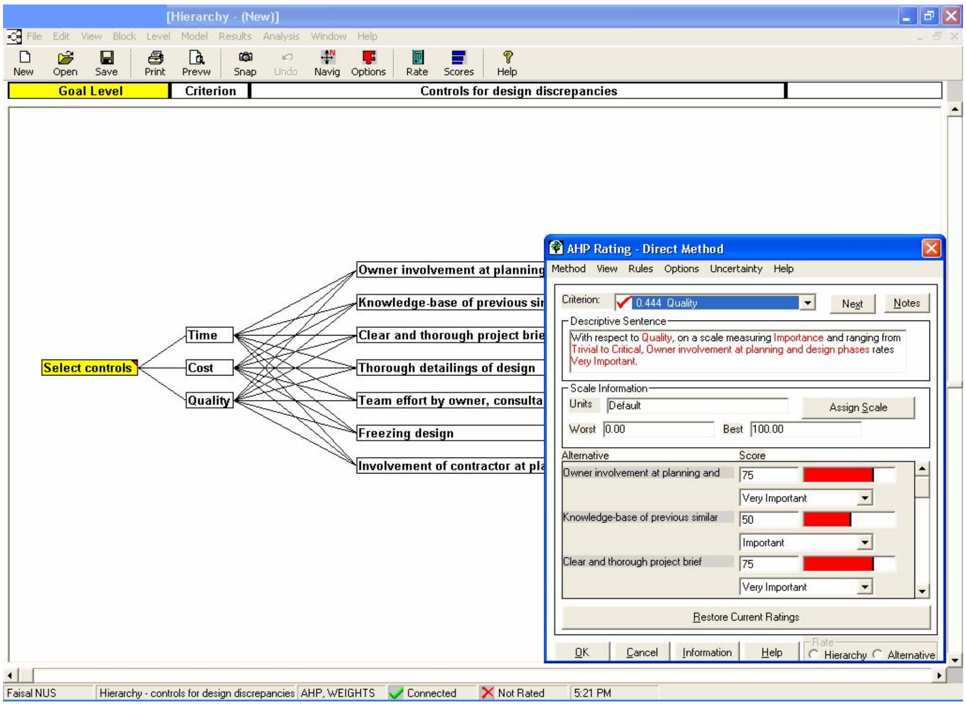


FIG. 11: Rating the controls for variations with respect to quality (Note: the rating priority is based on the hierarchy of the main criterions rated earlier)

The abovementioned steps are dependent on the number of criterions, for instance, the user may add sub-criterions to the given three main criterions. Depending on the number of sub-criterions, the steps of assigning weights will be increased accordingly. The shell does not let the user miss a rating. Once the rated is completed the shell prompts the user about the rating process completion. Overall, the rating of the suggested controls may vary according to the project phases. For instance, the controls may be implemented only in the design phase or in the construction phase of the construction projects. Hence, the KBS would assist the professionals in selecting the appropriate controls for variations according to the present stage of the building project.

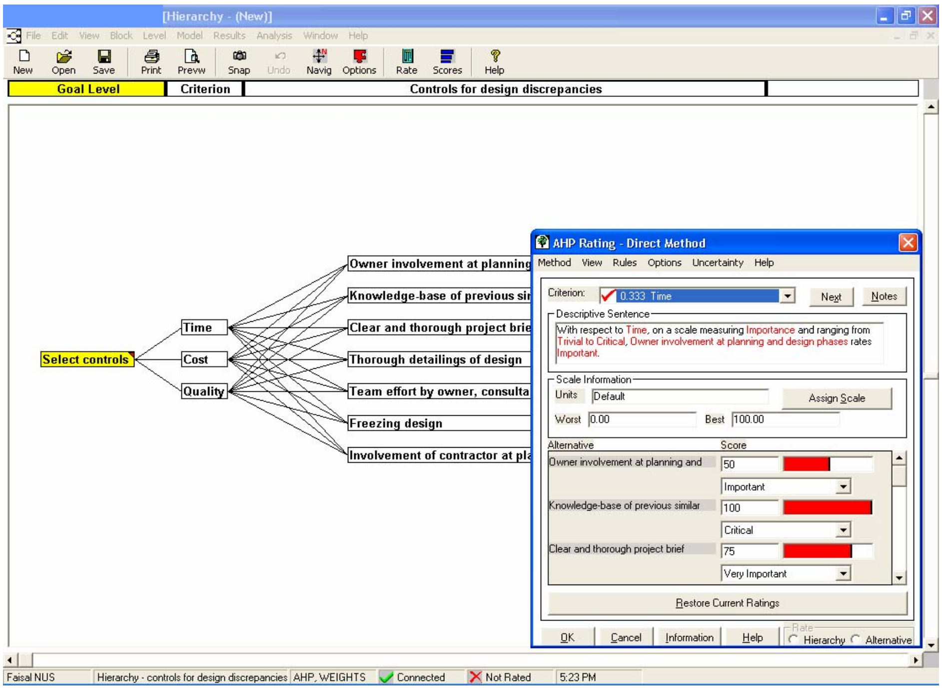


FIG. 12: Rating the controls for variations with respect to time

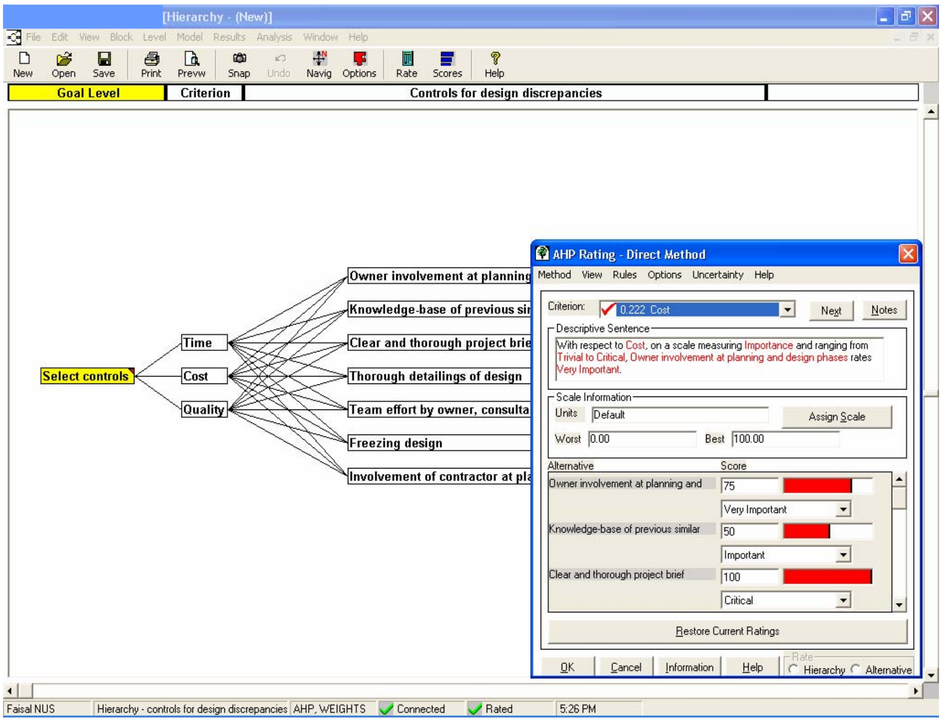


FIG. 13: Rating the controls for variations with respect to cost

4.4.4 Selecting the best controls based on the given criterions

The controls selection shell calculates the decision scores based on the rating process and displays a graphical presentation of the results as shown in Fig. 14. The decision scores can be sorted according to ascending or descending orders, which assist in viewing the comprehensive scenario. The suggested controls for design discrepancies were displayed with their corresponding decision score and its graphical presentation as shown in Fig. 14. The professionals can easily select the best controls based on the decision scores. Furthermore, the results can be analyzed according to various contributions by criterions as shown in Fig. 15. The graphical presentation of the results is shown in Fig. 15 according to the contributions by criterions. The professionals may analyze the suggested controls by selecting any one of the criterions. For further analysis, various analysis modes are also provided, i.e., sensitivity by weights, data scatter plots, and trade-offs of lowest criterions. All these modes assist in analyzing and presenting the decision. Furthermore, the shell also presents various other options for displaying the results, i.e., decision score sheet, pie charts, stacked bars, stacked horizontal bars, and trend. The graphical presentations of the results not only assist in selecting the most appropriate controls but also help in presenting the results to the project participants.

As shown in Figs. 14 and 15, the KBS would assist in identifying the effective controls that may ideally be implemented during design stage. Hence the system may assist in improving the overall design of the educational building projects. The system developed and the findings from this study would be valuable for designers because it may assist them in developing educational building designs with less number of discrepancies and errors.

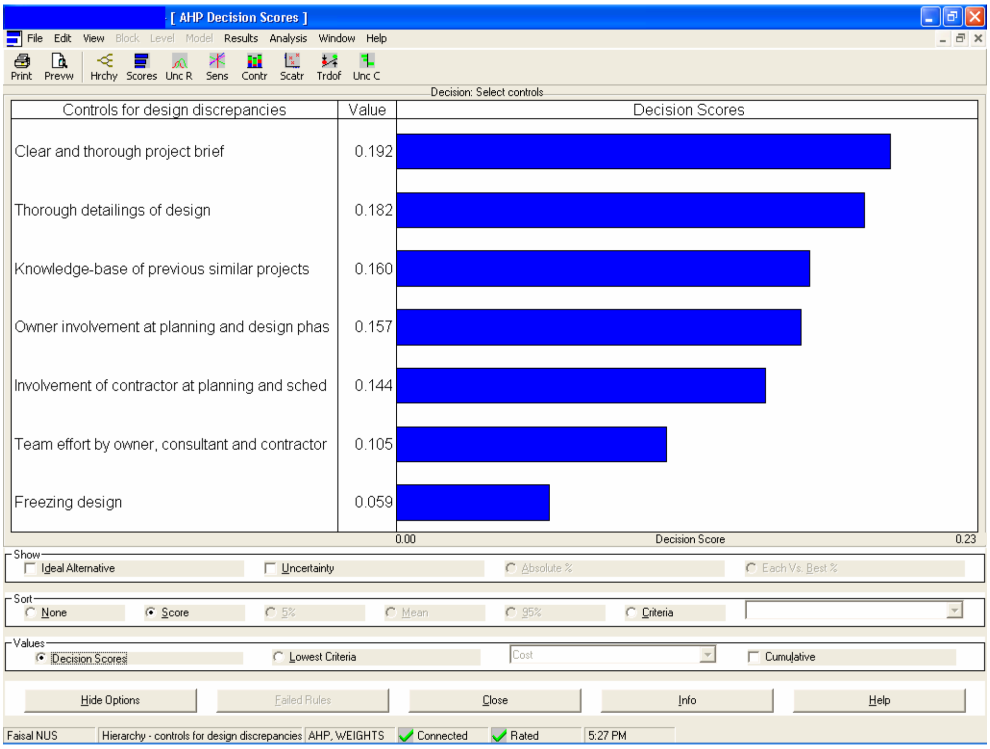


FIG. 14: The controls selection shell calculates and displays the decision scores based on the rating process

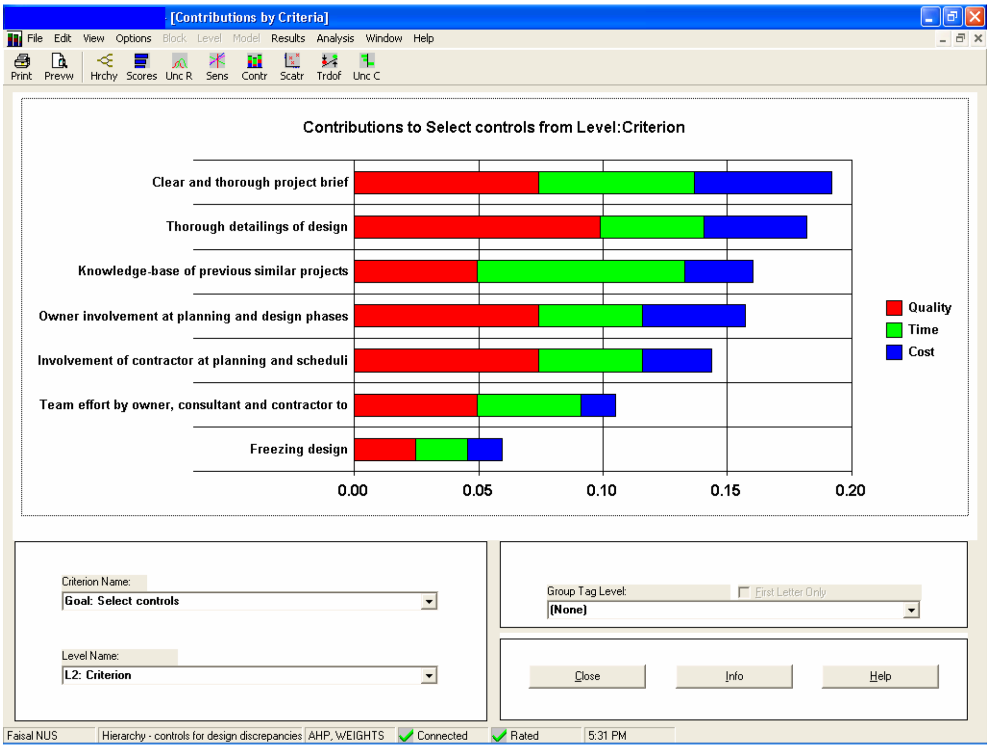


FIG. 15: The suggested controls sorted according to contributions by criterions

5. CONCLUSIONS

This paper presents the development of a knowledge-based system (KBS) for effective management of variations in educational building projects in Singapore. The KBS is a unique system developed specially for the effective management of variations in educational building projects under the rebuilding and improvement programme for the first time. This is a timely study as the programme of rebuilding and improving existing educational buildings is currently underway in Singapore; it provides the best opportunity to address the contemporary issues relevant to the management of variations. The KBS would assist professionals in analyzing variations and selecting the most appropriate controls for minimizing variations in educational building projects. The study is valuable for all the professionals involved with developing the educational projects. The system developed may assist in improving designs of educational projects.

Knowledge acquisition was the major component for developing this system. The KBS was developed based on the data collected from the 80 educational buildings. The KBS consists of two main components, i.e., a knowledge-base and a controls selection shell for selecting appropriate controls. The database is developed by collecting data from the source documents of these 80 educational building projects, questionnaire survey, literature review and in-depth interviews with the professionals who were involved in these projects. The KBS provides a fast response to queries relating to the causes, effects and controls for variations. The KBS is capable of displaying variations and their relevant in-depth details, a variety of filtered knowledge, and various analyses of the knowledge available. This would eventually lead the decision maker to the suggested controls for specific variations and assist the decision maker to select the most appropriate controls for managing the variations timely.

Although every construction project has its own specific condition, professionals can still obtain certain useful information from past experience. This information will enable building professionals to better ensure that their project goes smoothly without making unwarranted mistakes, and it should be helpful to improving the performance of the project. Furthermore, it is imperative to realize which variations will produce significantly more cost variation effect for a construction project.

The KBS developed based on the information gathered from the source documents of the completed educational projects and in-depth interviews with the professionals, would help decision makers in taking proactive measures for reducing potential variations. The system provides detailed information about variations in the educational building projects completed. This may assist the professionals in identifying the potential variations during the early stage of the construction projects. The KBS provides designers with information on what changes in design can cause to variations. It can extend from the inception right up to the building stage. The KBS provides such information so that designers will know what to avoid. Furthermore, the system assists in pinpointing the suggested controls that can ideally be implemented during the early stages of the building projects. Hence, the system would assist in improving the designs for educational building projects because the most likely areas on which to focus can be identified during the design stage of the educational building projects. In short, the KBS is able to assist project managers by providing accurate and timely information for decision making, and a user-friendly tool for analyzing and selecting the suggested controls for variations in educational buildings in Singapore.

The KBS provides an excellent opportunity to the professionals to learn from past experiences. It is important to note that this system for the management of variations is not designed to make decisions for users, but rather it provides pertinent information in an efficient and easy-to-access format that allows users to make more informed decisions and judgments. Although this system does not try to take over the role of the human experts or force them to accept the output of the system, it provides more relevant evidence and facts to facilitate the human experts in making well-informed final decisions. The KBS should be applied in the early stages (design stages) of the construction projects. In providing a systematic way to manage variations through the KBS, the efficiency of the building project and the likelihood of project success can be enhanced.

The knowledge consolidation process of the past experience will allow such knowledge to reside within organization rather than residing within individual staff that may leave over time. Furthermore, the KBS systematically consolidates all the decisions that have been made for numerous projects over time so that individuals, especially new staff, would be able to learn from the collective experience and knowledge of everyone. Hence, the KBS should be used during the early stages of the construction projects to achieve optimal results. The professionals will be able to explore the details of all previous actions and decisions taken by other staff involved with the educational projects. This would assist them in learning from the past decisions and making more informed decisions for effective management of variations. Eventually, this assists them in developing improved designs with fewer discrepancies and errors that may assist in increasing the overall level of project performance.

With further generic enhancement and modification, the KBS will also be useful for the management of variations in other types of building projects, thus helping to raise the overall level of productivity in the construction industry. The KBS efficiently assists the professionals in learning from past experiences. It is recommended that the system should ideally be used during the design stages of construction projects. The system developed and the findings from this study would also be valuable for all building professionals in general.

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