Development of A Knowledge-based System for Strategic Cost Planning of Construction Projects in Hong Kong

Dr. Tin Wah William Leung, Mr. Sik Wah Fong and Dr. Qi Ping Geoffrey Shen
Department of Building and Real Estate,
The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Abstract

Cost estimation of construction projects is a difficult and complex task especially in preliminary stage of design. For many years, construction costs have been estimated by experienced personnels, such as quantity surveyors or cost engineers. However, underestimation and overestimation do occur. With the lack of detailed information on the construction site and building itself, a precise cost estimate for a construction project is hardly achieved. Hong Kong has significant construction activities. A fast and accurate knowledge-based system that can give expert knowledge during the initial cost planning stage would increase its competitiveness. In the new era of information technology, many research projects in information technology and knowledge-based applications for construction industry have been established. The authors investigate the use of knowledge-based approach to perform cost estimation on construction projects at early conceptual stage. Knowledge for Hong Kong situation has been established in practical terms by collaborating with several quantity surveying firms or departments locally. The proposed system could be used for training fresh graduates and undergraduate students about construction cost estimation in Hong Kong.

Introduction

Building construction is a complex task where multidisciplinary professionals are involved. This includes architectural, structural, building engineering, etc. The presence of quantity surveying is a unification of all disciplines to quantify and integrate the cost of construction. Since the quantification is a complex and enormous task, a large amount of quantity surveying manpower and time are required. In recent decades, fast development in computing technology and vast establishment in information technology can benefit the construction industry. Even building cost can be appraised by using a computer system [1] through the mathematical modeling of building cost [2,3]. Li et al [4] investigated the use of a neural network approach, taken into account factors interrelated in a complex and unpredictable manners, for predicting accuracy in estimating construction cost. The drawback of the network approach is the lack of expertise's knowledge. The successfulness of the network depends on the training set of data and requiring a long training period. Ng et al [5] took a research on the impact of knowledge-based system on construction industry because a knowledge-based system can assist users in making decision or solving problems that require human reasoning. Many knowledge-based systems are developed in different subjects relating to the construction industry. Ng et al[6] established an expert system for construction scheduling in construction of modular multi-storey buildings. Rules were set up for a particular case of residential buildings with a reinforced concrete skeleton. Mathur et al[7] explored the possibility of using expert systems to control the conceptual design process of buildings to mimic human professionals during the inception stage. Stathopoulos [8] researched on an expert system for estimation of the wind loading on low building of various roof geometry's for envelope design. Gowri et al [9] used a knowledge-based approach to have code compliance checking for building designs. Demirkan et al[10] built production rules in space planning of houses. In recent years, Brandon [11] developed an application expert system for quantity surveying. However, the domains are in England context and there are major differences between the construction and building industries in Hong Kong and England.

This paper presents a feasibility study on the development of a knowledge-based approach for predicting costs on Hong Kong construction projects at the early design stage. In order to obtain precise estimation, several quantity-surveying firms are invited to involve in the design and development phases, giving their expertises on establishing the inference nets. The system consists of databases of geotechnical information, knowledge of building design criteria, ratios and factors and cost data for commercial buildings. With the use of the traditional deterministic cost model, the system requests answers of a few questions related to site situation, functionality and appearance of a building without the need of an in-depth construction knowledge. The inference engine consists of forward and backward reasoning which have been used to minimise the number of questions, implement the required codes and regulations for commercial buildings, judge by the complexity of the construction and decide types of costs to be taken into account. The system is being developed by using a knowledge-based development package with good interfaces and simplicity of the system make it suitable not only for cost estimation but also for the teaching of undergraduate students in construction related disciplines.

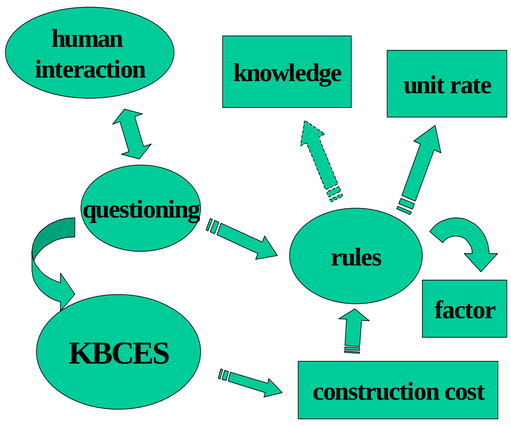
System Domain

For the design of a multimedia KBS cost estimation system, several assumptions have been made:

- the building is designed for commercial purpose,
- unique floor plan shape and usage,
- the system is designed for non-technical personnel and undergraduates.

System Structure

The knowledge-based cost estimation system (KBCES) consists of six main sections (Fig.1): questioning, rules, knowledge base, factors, cost estimation and human interaction. The expertise knowledge of construction cost forms the key element (knowledge base) of the system. This knowledge base includes the methods of construction cost estimates and building design. The 'unit rate' files, that are supplied by several collaborating Hong Kong quantity surveying firms, contains material unit costs and 'factor' files consists of factors and ratios for the building design. The system estimates costs of a construction project by asking a number of questions which related to the site situation, functionality and appearance of the building. The questioning is one of the rule sets. The given answers direct the inference nets to search for next question. With the knowledge in the database, the inference net forms a complete structure of the building and construction cost will be calculated. The questioning set will be explained in detail in the later section.



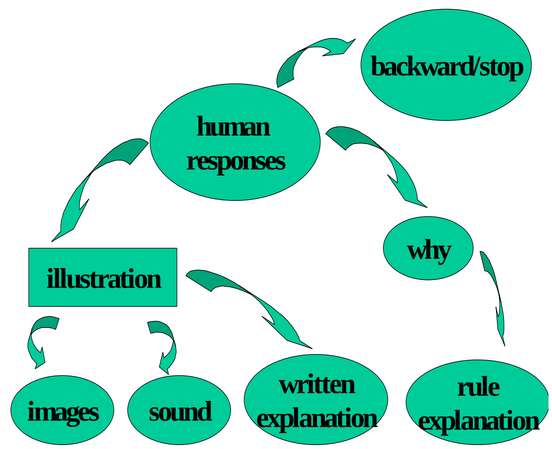


Fig. 1. The system structure of KBCES.

Fig. 2. The human interaction in KBCES

Human Interaction

As seen in Fig.2, a user interaction with the KBCES can be carried out via the questioning. Three kinds of responses can be activated by human interaction.
Illustrations are presented in terms of images, sound and written text. Secondly, explanation of why the question is being asked and of what kinds of factors and ratios, related to the building design, are being influenced by the selection. In return, construction cost is affected. Finally, the questioning process can be backward for a reselection or stop. In the human interaction, the system handles three types of files: 'help', 'images' and 'sound'. The 'help' files are text files that are used for verbal explanation of options. The 'image' files consist of images, which are related to the site situation, building appearance. The 'sound' files are the wave (voice) formats to store explanations. In each question, relevant 'image', 'help' and 'sound' files are attached.

Rule Sets

There are five sets of rules in the system: questioning, superstructure, site, substructure and foundation. They are shown in Fig.3. The questioning rule set governs the sequence of questions and determines the information required for the building design and site condition. For the superstructure rule set, it evaluates the upper levels of the building, i.e. number of storey, gross internal floor area, building envelope and building services installation, etc. The site rule determines the site situation related to ground water and rock problems, leveling and size of the site. The target of substructure rule is to find out any basement construction elements, required earthwork and basement enclosure. Based on the information evaluated from the other rule sets (superstructure, site and substructure) the foundation rule can calculate the types and quantity of foundation work for that particular construction project.

As seen in Fig.3, all rule sets excluding questioning are used to find out the types of elements and quantities of elements for that construction. Cost is not part of the rule sets. Costs of all elements is calculated by using a 'Deterministic' cost model (summation of the element unit quantity times element unit cost). Total cost for a construction project is the cost of elements with the calculation of project duration, interest rate, inflation rate, preliminaries and contingencies.

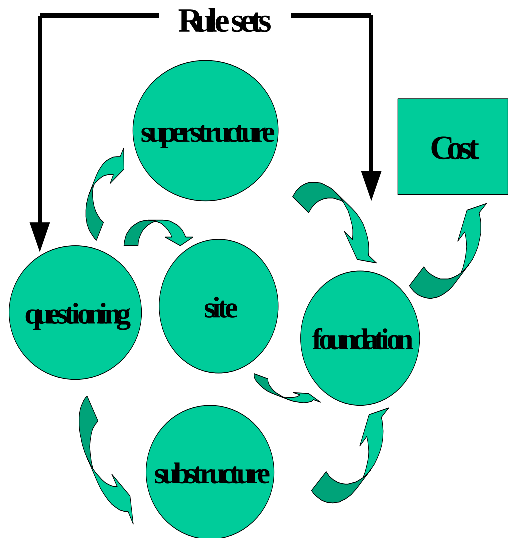


Fig.3. The relationship of the rule sets

Types of Questions

Questioning is an essential and crucial section in the KBCES. Questions are critical to mimic human expert reasoning about site condition, building outline, structural appearance, quality of the building. These questions help the system to determine the choice and quantity of material, methods of construction and then costs.

Non-technical questions raised in KBCES are related to areas of site situation, functionality and appearance of the building. The numbers of questions in the areas are different, depending on the cost effective terms. For examples, the number of storey and the height of building affect the type of foundation used and these will affect the cost dramatically. Because of those reasons, the number of questions related to the site and building are more important. The functionality type of questions will only affect the internal partitions, quality of facilities. Costs for these elements are not as significant as other core elements in a construction project.

Structure of Questions

As mentioned in the above section(Rule Structure), the sequences of the questions are governed by a rule set called ‘questioning’. Three groups of questions (site, functionality and appearance) have interrelationship. Each rule contains one question. Information was obtained after questioning are:

- site location,
- ground water problem on site,
- rock problem on site,
- site area,
- site classification,
- site leveling,
- building height restriction,
- basement level,
- car parking in upper and/or basement levels,
- quality of the building,
- purpose of the building,
- size of the building,
- height of the building,
- percentage of executive staff,
- shape of the building,
- types of external walls,
- percentage of air-conditioned areas in the building,
- intelligent building or not.

In order to obtain the essential information mentioned as above, structured questions are clearly set up. The number of questions is determined by the knowledge in the system. The more expert knowledge in the system, the less number of questions and the less technical the questions will be. There are three types of answers: figures, text selection or unknown. Some questions must have answers, such as the area of the site. It is because this can be used to calculate the gross internal floor area (GIFA) and number of storey with the presence of plot ratio and site coverage percentages. The followings are detailed explanations of the questions and some of the interfaces are shown in the Appendix.

1) Where is the site location? (peak, reclaimed land or general area)
In Hong Kong, location factor is not taken into account because it is a small city. However, most of the areas are hilly. The site location would help to decide whether the proposed site has any water or rock problem.

2) Does the site have water problem? (1-10 degree, unknown)
If the site is in peak or general area, it is likely to have rock problem while ground water problem may often occur in reclaimed or general area.

3) Does the site have rock problem? (1-10 degree, unknown)
For water and rock problems, there are 1 to 10 degrees of the problems. '1' means no problem while '10' represents serious one. An 'unknown' can be chosen to let the system to determine the degree of problems.

4) How big is the site?
This question should be asked because much information can be deduced from it. However, the shape of the site is not important.

5) What is the site classification? (class A, B or C)
The plot ratio and site coverage are governed by a site class (A, B or C). Class A means a site that abuts on one street not less than 4.5 meter. Class B site means a corner site that abuts on 2 streets with at least 20 per cent of the boundary of the site abuts on the streets neither of which is less than 4.5 meters wide. Class C site means a corner site that abuts on 3 streets with at least 60 per cent of the boundary of the site abuts on the streets none of which is less than 4.5 meter wide.

6) What is the slope of the site? (smooth, a small leveling, a large quantity, others or unknown)
This question is used to decide the amount of earth to be removed in order to get a leveled site. A 'smooth' option means ±15 degree of site slope that is acceptable for a leveling site. 'A small leveling' means the slope is ±45 to ±70 degrees while 'a large quantity' is greater than ±70 degrees. 'others' option lets a user to input an exact degree of slope. The 'unknown' option causes the system to evaluate the site slope itself.

7) Does the site have a height restriction on the building? (yes or no)
If the site has a building height restriction due to surrounding buildings or airplane route, 'yes' must be chosen otherwise it is 'no'.

8) What is the height restriction limit?
A building height limit is required to calculate the floor area and number of storey of the building. The greater the height limit, the lesser the floor area will be provided.

9) How many basement level will be required in the building? (0-6)
The provision of basement is either for commercial activity or for car parking. The greater the number of basement level, the higher the construction cost.

10) How many car parking levels are required? (upper level or basement)
The car parking levels can be chosen in the upper or basement levels because it is not common to have external car parking in Hong Kong due to the scarity of land.

11) What is quality of the building? (class A, class B or class C)

In Hong Kong, quality of a commercial building is divided into three classes. Class A is the best quality while Class C is general.
12) What is the purpose of the building? (self-used, rent or selling)
If a building is built for renting or selling, the size of it is maximised, otherwise, next question is proceeded.

13) How the size of the building be determined? (staff need, usable space or total floor area required)
If selection in the previous question is self-used, one of the above options must be known in order to calculate the size of the building.

14) What is the percentage of executive staff? (1-100 or unknown)
The executive staff ratio is used to quantify the amount of internal partitions and quality of decoration

15) What is the shape of the building? (square, rectangular, triangular, circular or more than four sides)
The longer the perimeter of the building, the higher the wall-floor ratio, and the greater the area of external walls.

16) What kind(s) of external walls are required? (percentage in tiles, metal cladding, marble cladding, curtain wall, windows)
The external walls can be made up of cladding (metal, marble), curtain walling, concrete walls with finishing, etc.

17) How many percent of the building is air-conditioned? (1-100 or unknown)
The percentage of air-conditioned space is used to evaluate the types of AHU required.

18) Does the building have an intelligent services control system? (yes or no)
Intelligent building means a central computerised control of the building services installations, lifts, escalators, fire alarm system, etc.

Conclusion

Cost estimation of construction projects is extremely difficult especially at the conceptual stage of a design where detailed information about the site situation and building are not available. Therefore, estimation requires experienced professional personnel. With the help of this knowledge-based system, human expert reasoning on construction costs can be undertaken by non-technical users. One of the main objectives for the development of this KBCES is to tutor construction-related undergraduate students on cost estimation. With the use of multimedia design, undergraduates can understand and familise with the cost estimating process. With the collaboration of several reputable quantity surveying firms in Hong Kong, the types and structures of questions are carefully set up, on cost effective term, and are most appropriate and practical in Hong Kong construction industry.

Future Development

It is anticipated that this KBCES can be treated as one of the computer assisted learning package. Undergraduates can understand and familise with the cost estimating process by using this multimedia knowledge-based system.

However, the system is still in its early stage of development, inference nets and rule sets for evaluate cost for superstructure, substructure and foundation need to be further developed. These costs include structural, building services installation and decoration.

References

[1] Brandon et al, "Computer Programs for Building Cost Appraisal",

[2] Oefverholm, "Building Cost Model", LABSE-Surveys, No. S-43/89, pp33-40, 1989.

[3] Brandon, "Building Cost Modeling and Computers", Transactions of the Building Cost Research Conference at the University of Salford, pp630, 1987.

[4] Li et al, "Using a Neutral Networks to Improve the Predicting Accuracy in Estimating Construction Cost", Proceedings of the Fifth east Asia-Pacific Conference on Structural Engineering and Construction, Vol.1 pp847-852, 1995.

[5] Ng et al, "Knowledge Base Systems, Their Impact on the Construction Industry", International Conference on Expert Systems of Building Economic and Construction Management (Australia), pp549-560, 1990

[6] Warszawski et al, "An Expert System for Construction Scheduling", International Conference on Expert Systems of Building Economic and Construction Management (Australia), pp643-649, 1990

[7] Mathur et al, "Expert Systems in Building Design, a Multiple Domains Approach", International Conference on Expert Systems of Building Economic and Construction Management (Australia), pp514-524, 1990

[8] Stathopoulos, "Knowledge-based Wind Loading for Envelope Design: Beyond Building Codes", vol.53, No.1/2B, pp177-188, 1994.

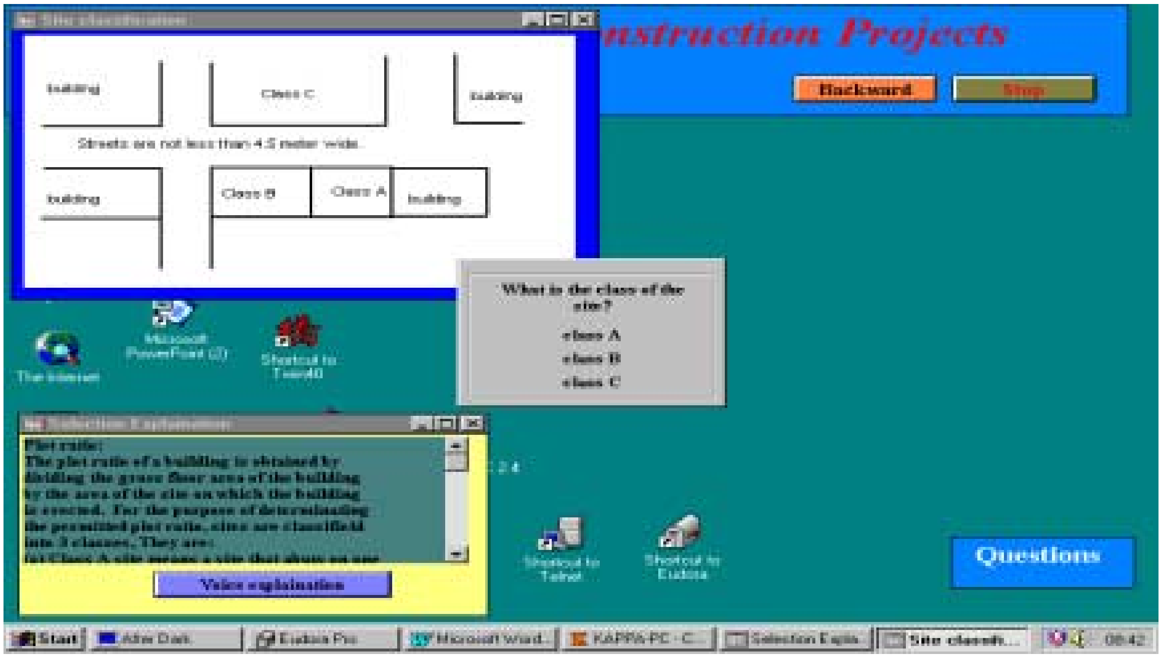
[9] Gowri, "Building Codes and performance Standards as Knowledge-based for Design", Joint CIB Workshops on Computers and Information in Construction, pp235-241, 1994

[10] Demirkan et al, "A Knowledge-based Space Planning System", Architectural Science Review (University of Sydney), vol.35, No.1, pp3-7, 1992.

[11] Brandon, "Application of Expert System to Quantity Surveying", Quantity Surveyors Division of the Royal Institution of Chartered Surveyors in Collaboration with the University of Salford, 1988.

Appendix

Main Interface



Site Classification