Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 58 (1989)

Artikel: Expert system applications in construction materials technology

Autor: Serén, Karl-Johan

DOI: https://doi.org/10.5169/seals-44914

Expert System Applications in Construction Materials Technology

Systèmes experts en technologie des matériaux de construction

Expertensysteme in der Baustoff-Technologie

Karl-Johan SERÉN
Research Scientist
Technical Research Centre
Espoo, Finland

Karl-Johan Serén, born 1958, received his MScTech degree in mechanical engineering at Helsinki University of Technology. For five years he has been involved in research projects concerning automation in the concrete industry, with special interest in application of advanced electronic data processing techniques, such as knowledge-based systems.

SUMMARY
This paper deals with the application of expert system technology in construction materials technology. Two expert system applications are described. The problem domain of the first system is diagnosis of brickwall damage. The application area of the second system is repair of concrete balconies. Both systems run on microcomputers. Moreover, other expert system applications dealing with construction materials developed or under development in Finland are presented in brief.

RESUME
Le présent rapport explique l'application de la technologie des systèmes experts à la technologie des matèriaux de construction. Deux applications sont décrites, l'une destinée à la diagnose des défauts des murs en briques, l'autre à la réparation des balcons en béton. Les deux systèmes marchent sur micro-ordinateurs. En conclusion, d'autres applications du système expert développées ou en voie de développement en Finlande dans la technologie des matériaux de construction sont discutées.

ZUSAMMENFASSUNG
Dieser Vortrag befasst sich mit der Anwendung der Expertensystemtechnologie auf die Baustofftechnologie. Zwei Anwendungen werden beschrieben. Bei der ersten Anwendung handelt es sich um die Diagnose der Schäden an Ziegelwänden. Die zweite Anwendung behandelt die Reparatur von Betonbalkonen. Beide Systeme laufen auf Mikrocomputern. Abschliessend gibt es eine kurze Zusammenfassung anderer Expertensystemanwendungen, die in Finnland für die Baustofftechnologie entwickelt wurden oder in Entwicklung sind.

1. INTRODUCTION

1.1 General

Expert systems have a great application potential in the field of construction materials technology. Material related decision-making spans over the whole construction process, from design to actual usage of the structure, and a considerable amount of economical assets are bound to these decisions. The decision processes related to construction materials, for instance selection of materials, diagnosis of material-based structural damages and selection of correct working and repair procedures, involve a lot of heuristics and judgment knowledge of conceptual nature. These processes are generally impossible to model using traditional algorithmic computer programs. Therefore it is quite natural that the expert systems technology has been gaining a lot of interest lately in this context. It may be noticed that one of the first generally known applications of expert or knowledge-based systems in civil engineering, SPERIL-I [3], was from this domain of application (assessment of structural damages).

One aspect worth considering is that the conceptual decision-making process, which can be modelled by rule-based inferencing in expert systems, is often linked to other types of data processing. For instance data bases can be used for convenient storing and updating of basic material data. Furthermore, some kind of numerical processing as well as graphical presentation of data is often needed. This makes the integration capabilities of expert system development software a key issue. In this respect the future of expert systems looks promising, because the newest microcomputer-based expert system shells have quite good interfacing capabilities (see for instance [6]).

1.2 Civil engineering expert system applications in Finland

Research work concerning expert systems in civil engineering and construction has been carried out in the Technical Research Centre of Finland (VTT) from mid-1984 onwards. Apart from some surveys and feasibility studies, for instance concerning expert systems in the concrete industry [7], the research activities have concentrated on actively developing small and mid-sized expert system prototypes. General information about these systems and experiences gained from developing them can be found in [4, 8]. Some of the prototypes are related to construction materials technology: an expert system for the selection of ready mix concrete [9], an expert system for repainting of wooden facades [4], an expert system for diagnosing brickwall damages [5] and an expert system for repair of concrete balconies [7]. The two last ones of these systems will be presented in this paper.

2. CASE 1: BRICKWALL DAMAGE EXPERT SYSTEM

2.1 General background

The *Brickwall Damage Expert* is a typical diagnostic expert system intended for analyzing damage to brickwalls. The system was developed by one of VTT's research scientists, Kalle Kähkönen, during a two month visit to the Loughborough University of Technology in England. The development work was carried out under the supervision of Dr. Allwood at the Department of Civil Engineering which provided both know-how, hard- and software. The source of the knowledge incorporated into the system is a book written by Elbridge [2], which deals with common defects in British buildings and is especially intended for practical application and people concerned with building maintenance. The Brickwall Damage Expert is quite restricted and it can be considered as a demonstration prototype. The system is described in detail in [5].

2.2 Development software

The Brickwall Damage Expert was developed using the *Savoir* expert system shell. Savoir is basically a bayesian inference network type of expert system shell. The three main components of the knowledge representation language are: a) questions, referred to as "Questions", b) rules, referred to as "Variables" and c) demons, referred to as "Actions". In addition the shell has the capability to interface to external functions by a module called the "trap handler". Savoir is equipped to deal with both classical logic and uncertain reasoning. The main probability operator provided is the bayesian inference rule to which is added some fuzzy logic operators. There is no default control strategy. Instead the knowledge engineer can build a control procedure to meet the specific requirements of a domain by defining the "Actions". The shell supports both backward- and forward-chaining. The end-user interface can be quite freely constructed by the knowledge engineer. The Savoir shell is available for a variety of computers including IBM PC, DEC PDP-11 and IBM mainframes. Further information about Savoir can be found in [1].

2.3 Problem domain issues

During preliminary discussions it became clear that the brickwall damage diagnosis process should be focused on the causes of cracks. The secondary goals should aim to provide guidelines on remedial work. However, the finding of the main goals (causes of cracks) is quite a demanding task, including probabilities and thus the causes became the most important factor in developing this expert system. The repair guidelines are linked to the particular causes and the feature of presenting corresponding repair instructions can easily be added to the system later.

The knowledge was analyzed into a tree structure by the use of a computer aided drawing tool starting from possible causes of cracking and linking every possible symptom leading to each specific cause. Twelve different causes of brickwall damage were found from the source book and the seven which seemed to be the most important were selected to be used as goals of the system (fig. 1).

2.4 System structure

The knowledge base consists of nine separate knowledge files from which the system is built up during compilation (fig. 1). One of these files is called the main knowledge file into which other knowledge files are included during compilation. Other tasks of this file are: a) starting of the consultation, b) leading of the inference process in an appropriate direction and c) displaying of the conclusions. One file called "the initial question file" contains the initial questions to be asked at the beginning of the consultation. Other files include the knowledge related to the calculations of the probability of a certain cause. As a whole the knowledge base consists of 45 questions, 33 variables and 19 actions taking up 36 KBytes of memory in source code form and only 2.5 KBytes of memory in compiled form. The system runs on an ordinary IBM PC -type of microcomputer.

The user interface of the Brickwall Damage Expert is based on the standard user interface provided by the Savoir shell. It consists of overlapping windows each of which has a pre-defined function, size, colour and place on the screen when the window is displayed. The system includes 36 pre-defined questions for defining the symptoms of brickwall damage. During the asking of questions the system calculates the probabilities of all relevant causes. Once the relevant questions are asked a display is shown with the most probable cause of the damage and the probabilities of the other causes (fig. 2).

3. CASE 2: EXPERT SYSTEM FOR REPAIR OF CONCRETE BALCONIES

3.1 General background

The expert system for repair of concrete balconies (*Concrete Balcony Repair ES* for short) is another quite typical diagnostic expert system based on classification of knowledge. The system was developed during a preliminary feasibility study in the Concrete and Silicate Laboratory of VTT and at present it is a quite rough demonstration prototype. The system is intended to be used as an aid in preparing the repair planning documents, but it may also be used by the contractor to aid in preparing the working plans. The knowledge for the system was provided by a research scientist specialized in repair and rehabilitation of concrete structures.

3.2 Development software

The Concrete Balcony Repair ES was developed using the *Xi Plus* expert system shell. Xi Plus is a rule-based shell with some interesting features [10]. In addition to ordinary backward-chaining rules (If-Then rules) forward-chaining can be used. Furthermore, a wide variety of inference control statements and rules can be used, for instance so called "Demons" (When-then rules) which can be applied as a kind of meta-level control. The knowledge representation includes the possibility to assign class membership to an identifier by the use of the "is a" relation and to use variables in the rule statements as well as attributes in the form of "<attribute> of <identifier>". Moreover, interfacing capabilities to external programs, spreadsheet data files and graphics (GEM) are provided. Knowledge bases can be linked together in a divided structure to provide for a more economical memory usage and to make the updating of the knowledge easier. The Xi Plus shell runs on IBM PC and compatible microcomputers.

3.3 Problem domain issues

When analyzing the domain knowledge two general classes of damages in concrete balconies could be identified: a) surface damages and b) cracking. Each of these two classes has a set of possible causes for damages with corresponding symptoms or properties in a similar manner to the Brickwall Damage Expert. The repair methods can in general be determined by the causes of damage with additional information concerning the level of damage.

Accordingly, the problem domain could be divided into two general classes of damages, with two contexts each: a) diagnosis of the damage and b) determination of damage level and corresponding repair method. Each of the general classes has five possible damage causes. 18 different types of repair methods could be identified. It may be noticed that no probabilities were used and that the damage causes are stated explicitly. The use of probabilities is often questionable, because they usually represent a subjective view of one expert and some experts find it hard to define any numerical probability range for different cases.

3.4 System structure

In accordance with the analysis of the problem domain the knowledge base was divided into three smaller units: a) a small general knowledge base containing only two rules for loading appropriate sub-knowledge base according to user selection, b) a sub-knowledge base for surface damages containing 18 rules (fig. 3) and c) a sub-knowledge base for cracking containing 10 rules (fig. 4). The two rules in the general knowledge base are so called "Demons" mentioned in sub-chapter 3.2. Each sub-knowledge base has two contexts the execution of which is controlled by control statements in one rule each: a) diagnosis of the damage and b) determination of the repair method.

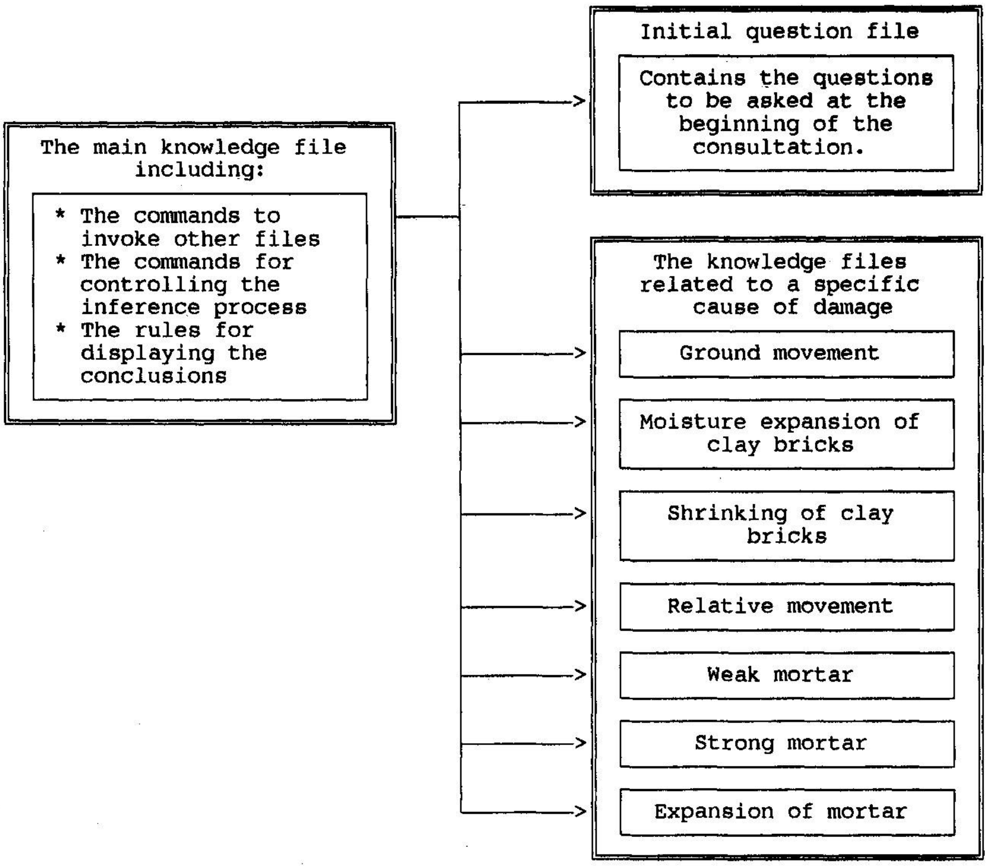

Fig. 1. The structure of the knowledge base of the Brickwall Damage Expert [5].

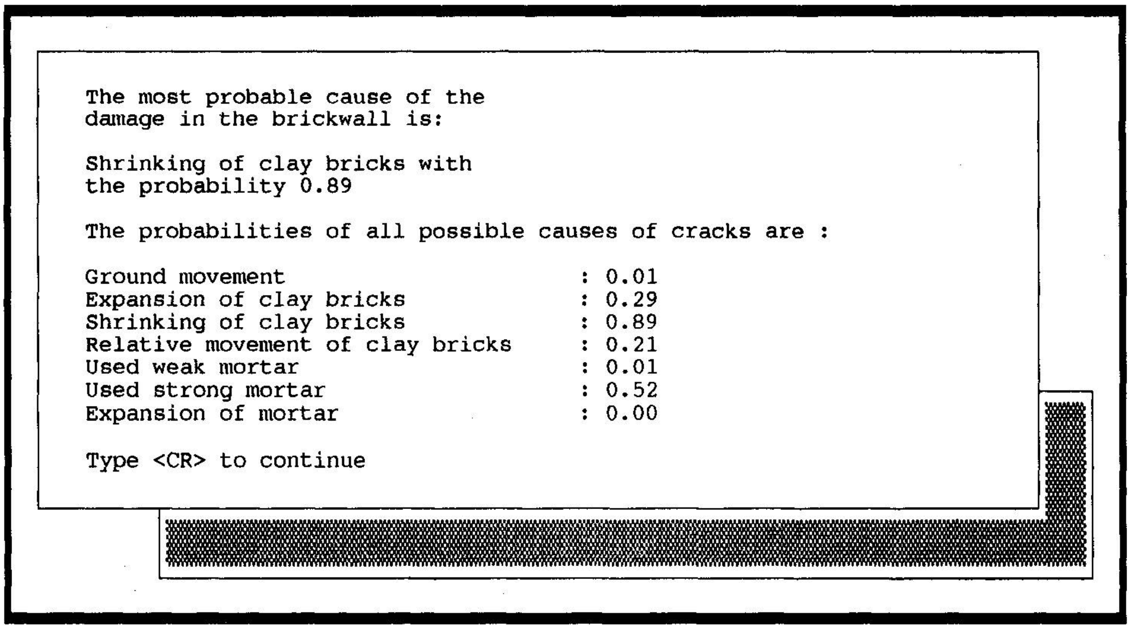

Fig. 2. The concluding display of the Brickwall Damage Expert. Example from [5].

The user interface of the Concrete Balcony Repair ES is based on the standard user interface of Xi Plus which is divided into windows. The questions presented by the system are automatically generated by the Xi Plus inference engine in the form of menu type queries based upon question definition statements in the beginning of each knowledge base. The results are displayed to the screen in the form of normal text output.

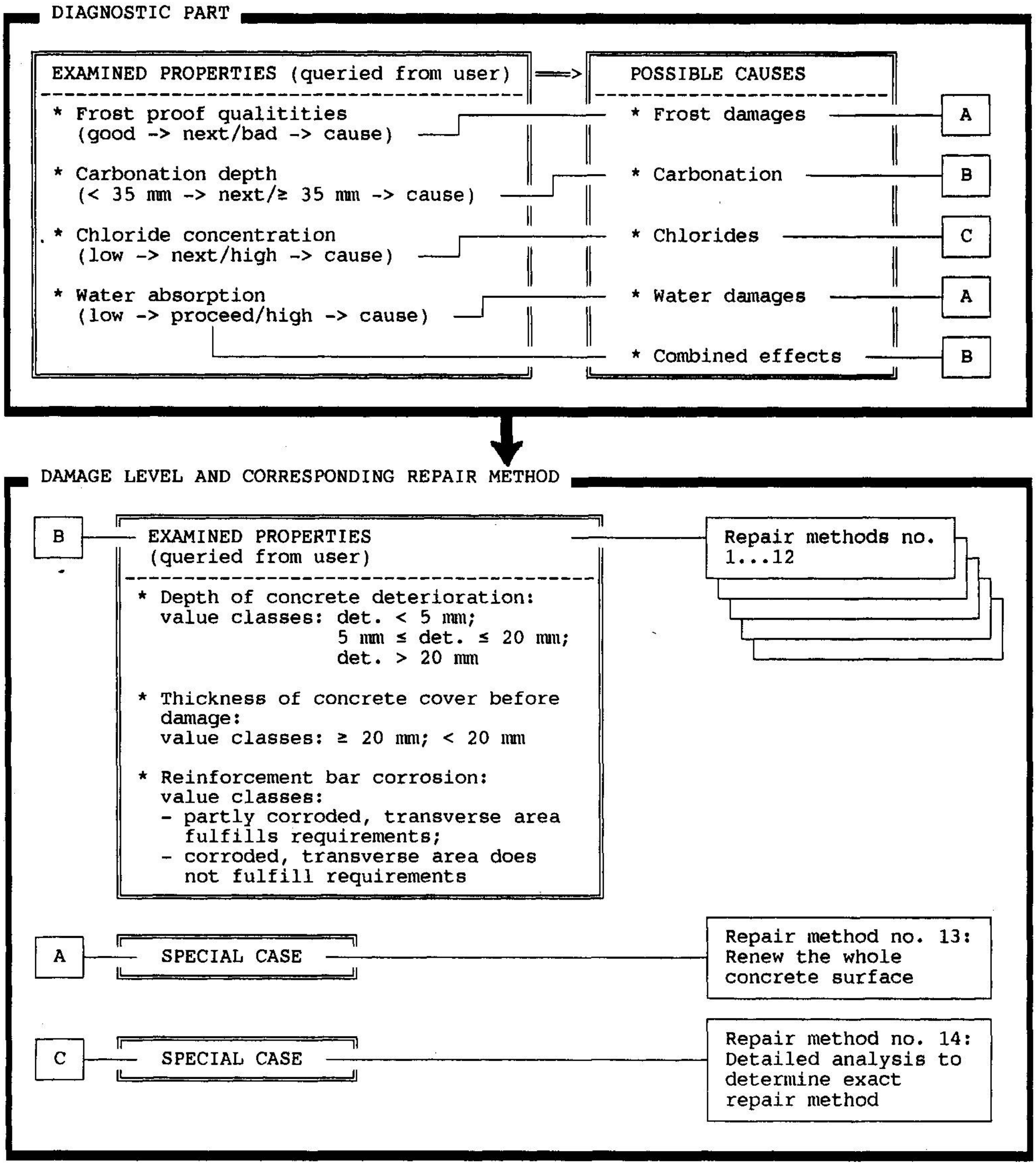

Fig. 3. Structure and function of sub-knowledge base for surface damages (Concrete Balcony Repair ES).

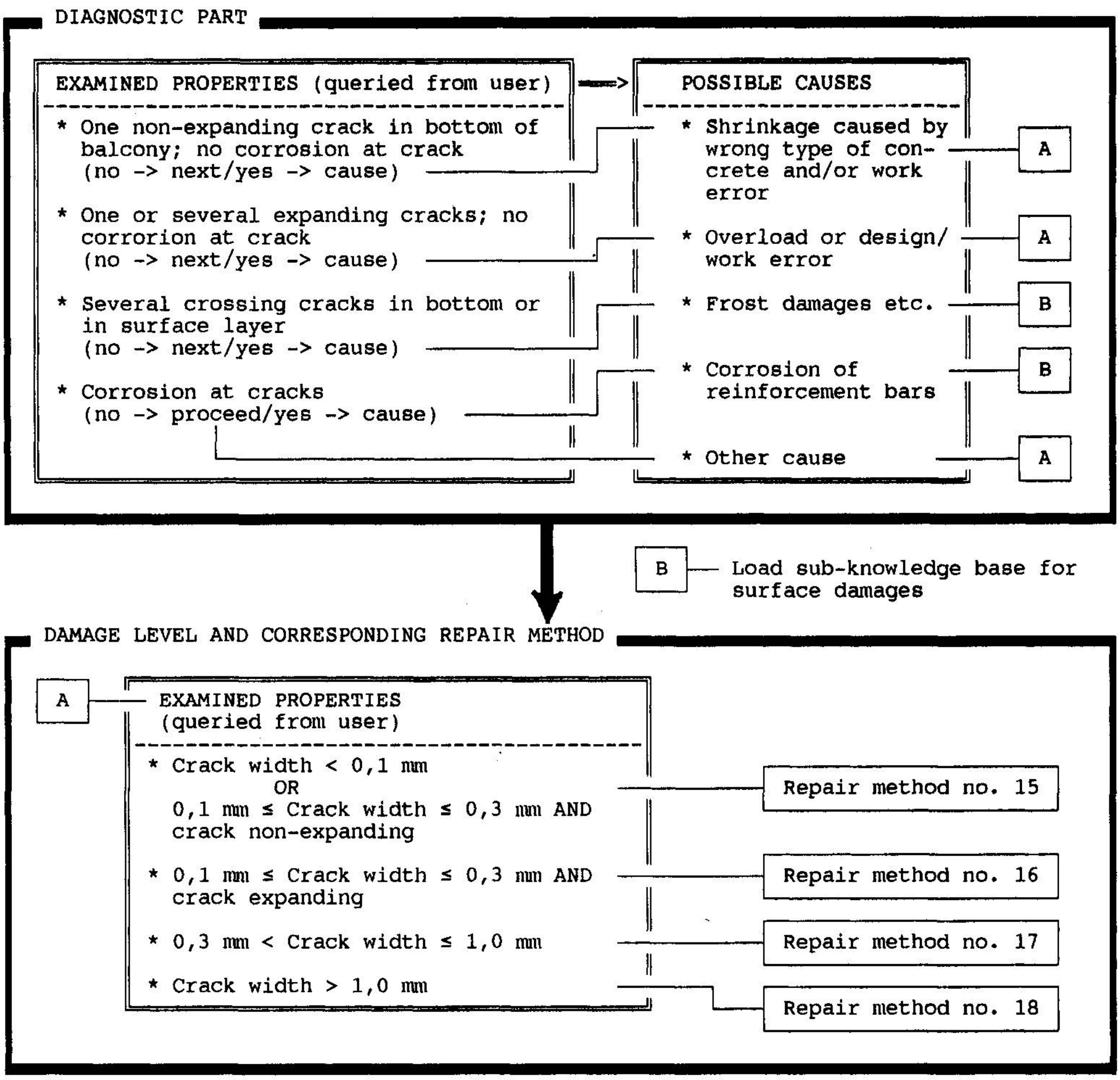

Fig. 4. Structure and function of sub-knowledge base for cracking (Concrete Balcony Repair ES).

4. ON-GOING RESEARCH WORK CONCERNING EXPERT SYSTEM APPLICATIONS IN CONSTRUCTION MATERIALS TECHNOLOGY IN FINLAND

Several research projects concerning civil engineering and construction industry expert system applications are going on or in preparation in VTT. Although the main focus at the moment is on application of knowledge-based systems in construction management, some project are related to construction materials.

In connection to a major three year research program called "Information and Automation Systems in Construction" the use of knowledge engineering approaches in construction materials technology will be studied. The feasibility of a framework interfaced to a product model database for selecting materials is under investigation. As a pilot-study the framework will be applied to renovation of facade cladding and surface coating (paint, plaster, clinker tiles etc.). This pilot-study will include condition assessment of facade structures. Some preliminary studies have shown that a generic framework is difficult to extract because of the very differing needs of different potential user groups (materials researchers, designers, contractors etc.).

Lately, however, some promising results have been attained by applying an object-oriented approach to the knowledge analyzing, by which it seems possible to develop a conceptual framework for the domain. The implementation environment will be the Hypercard hypermedia running on Apple Macintosh II with a software link to the Nexpert Object expert system shell.

A project concerning the development of a methodology for damage assessment of concrete structures is in preparation in the Concrete and Silicate Laboratory of VTT. In connection to this project an expert system aiding the assessment procedure will be developed.

5. CONCLUSIONS

The experiences show that microcomputer-based expert system applications are well suited for narrow problem domains which incorporate classification type of knowledge structures. However, a lot of work remains to be done before this type of expert systems can be taken into everyday use. The vast majority of the known expert systems of this kind have been developed in universities or research institutes and to the authors knowledge none of these have been taken into practical production use. The two example applications described in this paper are typical in this sense. The two systems have not gone through any critical evaluation and they could hardly be used in practice due to their roughness and restricted knowledge bases.

In the future more attention should be paid to the actual needs of different potential end-users. The expert system software technology itself can be considered mature enough for practical applications. The main difficulty is related to the difficulty to model the actual deeper knowledge of the decision processes involved in this kind of applications. This is a key factor in larger system applications with real practical viability. For the end-user it makes no difference what kind of computer techniques a system is based on, as long as the system is easy to use and behaves in a sensible manner. The implication of this is that a lot of effort should be directed to develop systems with complete and robust knowledge bases and good user interfaces, which could tailored for different user groups.

ACKNOWLEDGEMENTS

The main part of the work described in this paper was funded by the Technical Research Centre of Finland (VTT). Several persons have contributed to the results presented. The author would especially want to thank research scientist Kalle Kähkönen (Laboratory of Urban Planning and Building Design of VTT) who developed the Brickwall Damage Expert; senior research scientist Kalle Tanskanen (Concrete and Silicate Laboratory of VTT) who provided the knowledge for the Concrete Balcony Repair ES; and techn. stud. Jukka Kuisma who assisted in developing the Concrete Balcony Repair ES. All uses of soft- and hardware trademarks are also acknowledged.

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