Integration of knowledge management and Information Technology into the repair of concrete structures: an innovative approach

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ABSTRACT | The use of Information Technology (IT) in design and construction can exploit strategic opportunities for new ways of integrating, sharing and facilitating information and knowledge in any field of engineering. The technologies available are sophisticated computer programs which store expert knowledge on specific subject and are applied to a broad range of engineering problems. The integration of separate areas of IT can be used to bring a group of experts and specialists in any field of engineering closer together by allowing them to communicate and exchange information and expertise.

The research described in this paper is based upon a total management system for repair of concrete structures with sufficient flexibility to allow an inexperienced user to develop his interest in concrete repair technology whilst at the same time allowing an expert to contribute knowledge towards improving and evolving problem solving capability in the field of concrete repair. This computerised management system, which is called DEMAREC, comprises a knowledge expert system (DEMAREC-EXPERT) and a database management system (REPCON) alongside visualisation technologies and an evaluation system (ECON). It is developed to produce an innovative platform which will facilitate and encourage the development of knowledge in education, evolution, evaluation and diagnostic modes of concrete repair. The methodology is developed to provide technology transfer of information and expertise from the research community in the repair of concrete structures to other practitioners and vice versa, and to allow the promotion and relegation of knowledge according to the opinion of users of different levels of ability from expert to novice.

KEYWORDS | Information Technology (IT), concrete repair, knowledge management system

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1 Introduction

Information Technology (IT) is the application of systems of information and knowledge to gather data and create information that is valuable to users who make decisions. Researchers, software developers and practitioners are now applying Information Technology to automate different parts of the design and construction processes. The nature of construction activity, its structure and its operating environment are fluid and dynamic. This dynamism is growing at an increasing pace, offering proportionately greater strategic opportunities while posing significant threats. A principal feature of how design and construction processes could cope with these changes would be to strategically exploit Information Technology (IT). The use of IT in design and construction is becoming increasingly sophisticated with object-oriented techniques, virtual reality, expert systems (ES), database management systems (DBMS), case-based reasoning and neural networks among the latest technological advances. These technologies can be used to enhance the integration and sharing of information between the various processes of design and construction [1].

Of the generic technologies, the research community has made most reference to the technologies of visualisation, intelligence and integration. Multimedia and other visualisation technologies, knowledge-based expert system and database management system are used as specific technologies of research priorities in this work.

Knowledge-Based Expert Systems (KBES) or Expert Systems (ES) are sophisticated computer systems which store expert knowledge on specific subjects and can provide answers to questions on these subject areas. They provide new ways of tackling many existing problems and allow more complex tasks to be undertaken by using Information Technology (IT). These systems can make a particular expert's knowledge more generally available and can thereby save valuable resources by assisting decision making and multiplying available skills [1,2].

There is a wide range of IT applications using knowledge-based expert systems that have been developed for concrete design, condition assessment and repair and rehabilitation of concrete structures. Adeli [3] presented several expert systems in civil engineering including structural and construction engineering for a satisfactory solution to the problems of diagnosis, fault detection, prediction, monitoring, planning and design. A survey of many of the existing prototypes and operational expert systems developed for the construction industry has been presented by Kaetzel and Clifton [4]. The other specific prototypes of IT applications for concrete durability, repair and rehabilitation, and condition assessment are known as CRACKS [5], DURCON [6], REMR [7], HWYCON [8] and COBDA [9]. Most of the existing prototype applications in the field of concrete repair have been restricted to limited amounts of data and have no facility for sophisticated information/knowledge management.

Powerful database applications have facilitated the essential capability of sorting data to overcome an increasing information malaise as design and construction processes are faced with too much unstructured information. Knowledge-based systems can be linked to an integrated database. It is the coupling and integration of these technologies which will provide the ultimate benefits to the design and construction processes. Integrating these technologies can be used to bring a group of experts and specialists in any field of engineering closer together by allowing them to communicate and exchange information and data. Indeed, the exchange of information could accelerate the creation of knowledge which might impact upon all areas of endeavour. The success of the research program presented in this study is derived from the close co-operation of groups of users whose origins and experiences are diverse and who are willing to see IT as a means of helping to integrate their efforts as much as in providing a platform for the exchange of information.

Design and construction processes are highly dependent upon the transfer and exchange of information between project participants. Information Technology (IT) is considered to be a relevant approach for addressing this challenge as it would allow the design and construction process to be reviewed and exchange to be adjusted.

The most important way in which future design and construction processes will differ from the present will be through a greater measure of integration. Many future projects will have greatly improved flows of information between their participants. This will encourage the use of diverse technologies to work towards the integrated project database concept. This improved information flow will lead to re-engineered and improved processes of design and construction. It will also enable greater integration of the process of design, construction and facilities management. The construction and future operation of buildings will be assessable at design stage through integrated IT, based on established information and design standards.

All generic technologies of visualisation, intelligence, communication and integration need to be supported on a continuous basis for the long term in the strategic interests of the construction industry. Visualisation and integration are considered to be the key generic technologies of strategic significance for design and construction. Key tools that are likely to emerge in future academic research and its subsequent development in industry are concerned with building performance, design and integration. Key research themes also include access to information and the review of the design and construction processes.

The research described in this paper is based upon a total management system for repair of concrete structures with sufficient flexibility to allow an inexperienced user to develop his interest in concrete repair technology whilst at the same time allowing an expert to contribute knowledge towards improving and evolving problem solving capability in the field of concrete repair. The new methodology of data/user evaluation and the modelling of the evolution within a field of expertise which is presented in this research study is to suggest that innovating with Information Technology (IT) can be applied to any areas of design and construction. The central feature of this research is the integration of two hitherto separate areas of Information Technology (IT) comprising a knowledge expert system (DEMAREC-EXPERT) and a database management system (REPCON) alongside visualisation technologies and an evaluation system (ECON).

2 Research Objectives

The present work is motivated by a need to transfer knowledge and expertise from the research community in the repair of concrete structures and to make that knowledge and expertise available to practicing structural and construction engineers. Although the repair of concrete research programmes have produced a large body of expertise, applying that expertise remains difficult for the inexperienced users. There is a need to provide technology transfer of information with practical guidance from experts and specialists to other practitioners and vice versa. The objective of the research was to develop a total management system for the repair of concrete structures with sufficient flexibility to allow an inexperienced user to develop the interest in concrete repair technology while at the same time allowing an expert to contribute experience and knowledge towards improving and evolving problem-solving in the field of concrete repair.

3 Methodology and System Architecture

The central feature of this research is the integration of two hitherto separate areas of Information Technology (IT). Firstly, integrated engineering computing systems have evolved and these are based upon sets of algorithmic programs that interact with a central database management system (DBMS). Secondly, knowledge-based programming techniques or expert systems (ES) are applied to a wide range of engineering problems. As expert systems are integrated into complex engineering computing environments, the database management capabilities of the integrated systems must be adapted to serve these new components.

The need exists for an interface between the knowledge-based expert systems and DBMS. The maintenance and repair of concrete structures represent a classical problem for the application of expert systems in collaboration with database management system (DBMS). The Diagnosis, Evaluation, MAintenance and REpair of Concrete structures - DEMAREC application [10], which is presented in this paper, is developed as a new software which focuses on integration of concrete distresses (including cracking, surface and miscellaneous distresses), investigation and diagnosis problems, repair materials and methods and giving recommendations relating with them.

DEMAREC is a Visual Basic interface (Figure 1) in which a multiple production rules expert system (DEMAREC-EXPERT) is coupled to an independent database management system (REPCON) and an evaluation management program (ECON). A coupled independent subsystem connection between the DBMS and the expert system (ES) is considered for use in this research because of the need for flexibility and functionality in the interaction between the expert system, database and the user. The main implementation part of DEMAREC is characterised by an input and reporting system in the form of a visual edit screen, creating a database using Microsoft Access and the evaluation of uncertainty problems in concrete structures which embody Visual Basic programming. The M.4 [11] expert system development tool used to develop the DEMAREC-EXPERT is an example of commercial software available. The main features of this research software include:

- Evolving knowledge and database.
- The integration of pictures and descriptive information in a way that makes problem solving easier.
- The creating of Graphical User Interface (GUI) gives inexperienced users the ability to access the full range of DEMAREC program capabilities in order to control the communication between the components of the program.
- An environment in which both experts and their added data can be evaluated and tested to ensure that the evolving system retains its integrity.

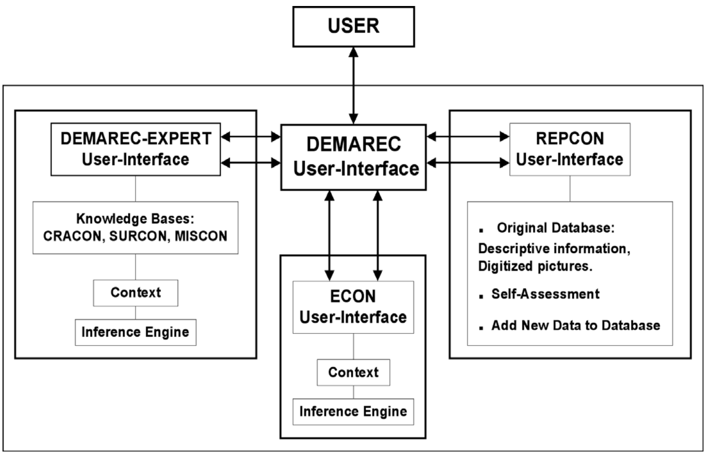

Figure 1. DEMAREC architecture

The new methodology of data/user evaluation and the modelling of the evolution within a field of expertise which is presented in this research study suggests that innovation with Information Technology (IT) can be applied to any areas of design and construction. The experience gained in implementing DEMAREC reveals several insights about the utility and integrity of the system. It was decided to select organisations from the Concrete Repair Association (CRA), the International Concrete Repair Institute (ICRI) and other civil engineering contractors, consultants and material suppliers in the UK. The respondents to this study who were experts at Newcastle upon Tyne University and selected organisations in the UK have suggested a number of tools that may emerge from future research. The important design and integration tools are on-line collaboration, simulation models, tools to capture client's requirements, communication and the Internet. One dominant research issue is improving the access of construction industry participants to information. The other dominant research theme is concerned with improving or visualising the design process.

4 DEMAREC Inference Procedure

The DEMAREC inference procedure is divided into two parts. The main implementation part includes input and reporting system, expert system development environment, database management system and the evaluation management system. The second part is the user-interface. DEMAREC is a flexible application which can be used in four modes: evolution, diagnostic, evaluation and education modes.

4.1 DEMAREC Implementation

Input and Report System

The input comprises a full description of the user requirements such as structure and component types, structural design and construction types and visual inspection data such as distress and symptom categories. In this part, the help option in each section provides assistance for users in the form of pictures, text and/or combination thereof.

The reporting system summarises the consultation result in the form of a visual edit screen. These results comprise the conclusion from the expert system including causes and effects of distress, repair materials required, methods and recommendation from the database and conclusions from the evaluation process.

Expert System Development Environment

All consultation modules are configured by M.4 [11] which is a commercially available Expert System Development Shell integrated into the Visual Basic Graphic User environment through the Visual Basic

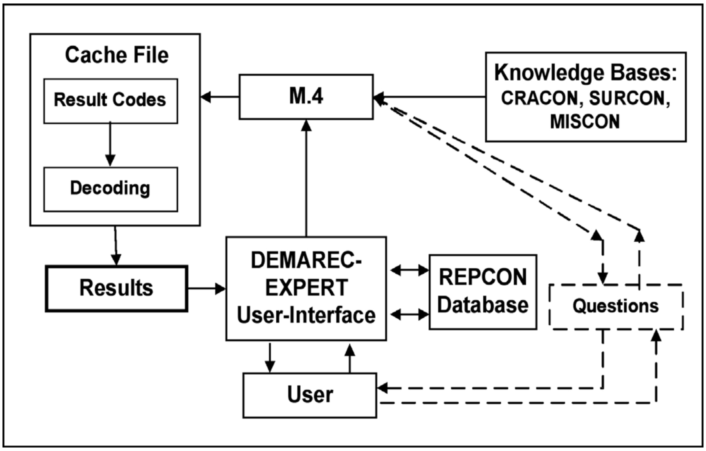

Figure 2. The DEMAREC-EXPERT consultation flowchart

Controls. In this control there exist procedures which are called by the M.4 Kernel when the Kernel requires data from the Visual Basic application or needs to send data to the application. These procedures control the initialising and termination of an M.4 expert system consultation. The DEMAREC-EXPERT consultation module, shown in Figure 2, includes three knowledge bases: CRACON cracking in concrete, SURCON surface distresses and MISCON miscellaneous distresses.

The user can read the parameters and answer the questions through the Visual Basic user interface. In some of the questions, the user can seek visual assistance in selecting an option by clicking on the Assist button. This button activates the REPCON database enabling the user to view descriptive information and pictures. The M.4 expert system accesses the knowledge bases and based on the input variables makes a decision. The results are stored as codes in a separate text file and then decoded and fed into the user interface where the user can review the result. Then, the system is independently coupled to the REPCON database for making recommendations in durability, repair materials and methods.

In the development of an expert system, knowledge acquisition is a crucial aspect of developing a knowledge base and it is important that the source of knowledge for any system is carefully selected. The knowledge bases for DEMAREC-EXPERT are developed using the best sources available during the development stage. Sources are investigated and used based on the analysis and interpretation of high-level experts. Because of the vast amount of knowledge and the need to assess its validity, acquiring and validating the knowledge is the most crucial and difficult part in the development of an expert system.

For this purpose, the use of multiple sources is considered in developing the DEMAREC-EXPERT knowledge bases. They have been obtained from literature searches, codes of practice, manuals, textbooks, technical reports, journals and conference proceedings, civil work reports and experienced concrete specialists. Most of the knowledge is directly taken from the following major organisations:

- Strategic Highway Research Program [8]
- American Concrete Institute [12]
- British Standard Institution [13]
- American Standard Testing for Materials [14]
- International Concrete Repair Institute [15,16]
- RILEM Draft Recommendation [17]
- The Concrete Society [18]
- U.S. Army Corps of Engineers [19]
- Federation Internationale de la Precontrainte [20]

The initial step of the development strategy for the knowledge base is to organise the tacit knowledge and then integrate it with codified knowledge using the author's experience and experts at Newcastle upon Tyne University. Secondly, a narrative description of the knowledge is developed in a question-and-answer format and conclusions and recommendations are also included. Then the diagnostic (hierarchical) trees are generated to provide a logical sequence to the knowledge and to represent how the knowledge is linked together.

Database Management System

The REPair of CONcrete (REPCON) [21] database is developed using Microsoft Access which is a relational database management system running within Microsoft Windows. The structure of REPCON database comprises thirteen tables which deal with the following themes [10]:

- Structural Types
- Structural Components
- Construction Types
- Structural Design Types
- Concrete Distresses
- Symptom Categories
- Investigation and Diagnosis
- Compatibility of Repair Materials
- Concrete Removal for Repair
- Repair Methods

- Repair Materials
- Repair Material Suppliers
- Durability and Maintenance Recommendation

Most of the REPCON data comes from documented material. However it was often difficult to use information which was unclear and contradictory. The use of multiple sources was considered in developing REPCON in order to ensure the validity of the data stored. Therefore, the data has been obtained from codes of practice, manuals, textbooks, technical reports, journals and conference proceedings, the internet, civil work reports and experienced concrete specialists.

This user-friendly software, which was evaluated through a workshop, is developed to run on a personal computer and a user-interface is provided in the form of visual edit screens which embody the Visual Basic programming language. Microsoft Access database was linked to Visual Basic through the data control in cases where the data did not require any subsequent manipulation. Some databases were linked to the application through the Structured Query Language (SQL) code in cases where there was need to manipulate the data. The database can be accessed by the user independently of the expert system.

Evaluation Management System

Condition assessment of concrete structures is apparently far more difficult than the analysis or design [9]. The Evaluation of CONcrete (ECON) [10] is implemented in the form of visual edit screens which embody the Visual Basic programming language. The criteria for the evaluation of a concrete structure consist of cracking, disintegration and scaling, and spalling and delamination [22]. The assessment procedures of concrete structures that enable the user to consider the current condition of the structure and its components are the main objective of an evaluation management system (EMS). These procedures are expressed numerically using a confidence level (CL) to take the best recommended action in the repair and maintenance management.

4.2 The User-Interface

The user-interface is an important component of the computer software responsible for the interaction with the user and is fundamental to the effectiveness of the program in fulfilling its primary objectives [23]. In view of this, the user-interface is designed to make the program flexible, easy to learn and use and it contributes to the success of the program when carefully designed.

Traditionally, the development of computer software for civil and structural engineering applications addressed by software developers has focused far more on the functional aspects of these systems than on user-interface design issues [24]. With increasing complexity of engineering problems, the design of the user-interface has become a major problem in software engineering. For example, knowledge-based expert systems share with other applications the problems associated with an inadequate user-interface. The user-interface should be easy to use and natural in its dialogue with the user and should be matched with the experience and needs of the user. It also supports the explanation facility which provides for concise and helpful responses to users' queries and allows the user to interact with the system to seek explanations.

DEMAREC User-Interface

The DEMAREC user-interface shown in Figure 3 is developed in Microsoft Visual Basic. The user-interface is not designed as a separate component of the program but it is essentially a menu driven system. Rather, the user-interface is a domain visual edit screen and consists of the various interface operations defined with the domain objects. One of the attractive features of Visual Basic is its access to the Microsoft Access Database Engine through Structured Query Language (SQL) and data control and its access to the M.4 Visual Basic User through data control and its communication features. The main interface comprises three interfaces such as REPCON, DEMAREC-EXPERT, and ECON interfaces.

Figure 3. Main screen of the DEMAREC application

The REPCON user-interface is provided with all objects in repair of concrete database. It is used to help the user with viewing the original database, to introduce the self-assessment process, to add to the database and to search the database. The DEMAREC-EXPERT user-interface is an interface which allows the user to apply an expert system to a specific problem. It is used to help the user in selecting one of the three knowledge bases namely CRACON (cracking in concrete), SURCON (surface distresses) and MISCON (miscellaneous distresses). The Evaluation of the CONcrete (ECON) user-interface shown in Figure 4 is structured with three different objects such as cracking, scaling and disintegration and spalling and delamination. It is used to allow the user to create assessment procedures for the current condition of the structure and its components.

5 DEMAREC Innovative Features

DEMAREC [10] is a platform for everyone who deals with concrete repair problems and who needs to conduct accurate diagnosis, select appropriate repair materials and techniques, and recommend durable repairs. The features which distinguish DEMAREC from other applications are its innovative interactive features built into its Educational, Evolution, Evaluation and Diagnostic modes as well as assessing knowledge and users, and durability recommendation.

5.1 Educational Mode

In the *Educational* mode, the main database in the first year of use contains information about concrete distresses, investigation and diagnosis problems, repair materials and methods and recommendations for durability. It is envisioned that in the second year the database will be used by a number of users with different levels of ability from *Expert* to *Novice*. The integration of pictures and descriptive information simplifies problem solving and allows a better understanding of the repair of concrete problems, particularly for *Novices* and *Trainees*. It is anticipated that the number of users in years three through eight will increase and that the database should encourage the more rapid development of knowledge and

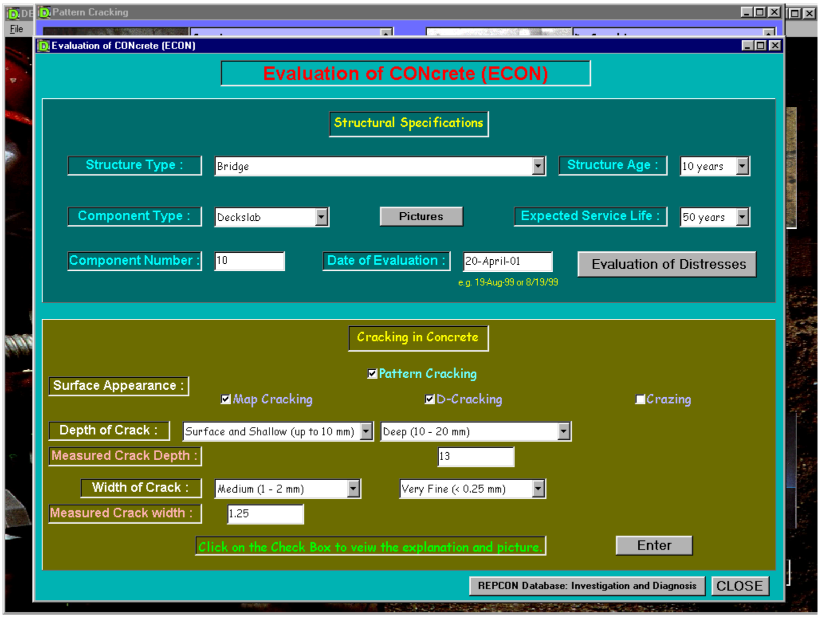

Figure 4. The ECON user-interface in DEMAREC application

experience for users with lower levels of experience in concrete repair.

5.2 Evolution Mode

The primary objective of the *Evolution* mode of the DEMAREC built into the REPair of CONcrete (REPCON) database [25] is to allow users to contribute experience and knowledge to the database thereby evolving the system. The original system will be enhanced during the second year of use as users contribute new knowledge. As shown in Figure 5, any category of user can use the main database passively by reviewing existing documents or by retrieving data from the database and choosing suitable repair methods and materials. This same user could re-enter the system and contribute new knowledge after accessing the self-assessment process [26] which comprises five questions to be randomly chosen from a question bank, relating to distresses in concrete. He might then be re-assessed as *Experienced Generalist* who might be an expert in related subject matter and is now seeking to develop expertise in concrete repair. This user can contribute his new knowledge to the *Symptom Category* Table of the backup database but not into the main database. Another user who has been assessed as *Expert* with authority in the subject can add new data to the *Concrete Distress* Table of the main database and/or to the backup.

This *Expert* in year three might transfer the data which was contributed by the *Experienced Generalist*, from the backup database to the main one. Because of advances in concrete repair, another *Expert* user 10 years later might relegate this data to the backup database when, for example it had fallen out of common usage. This is one of the main innovative features which are built into the DEMAREC application.

5.3 Evaluation Mode

One objective of an evaluation management system is to create assessment procedures that will allow the current condition of the structure and its components to be expressed numerically so as to assist in choosing

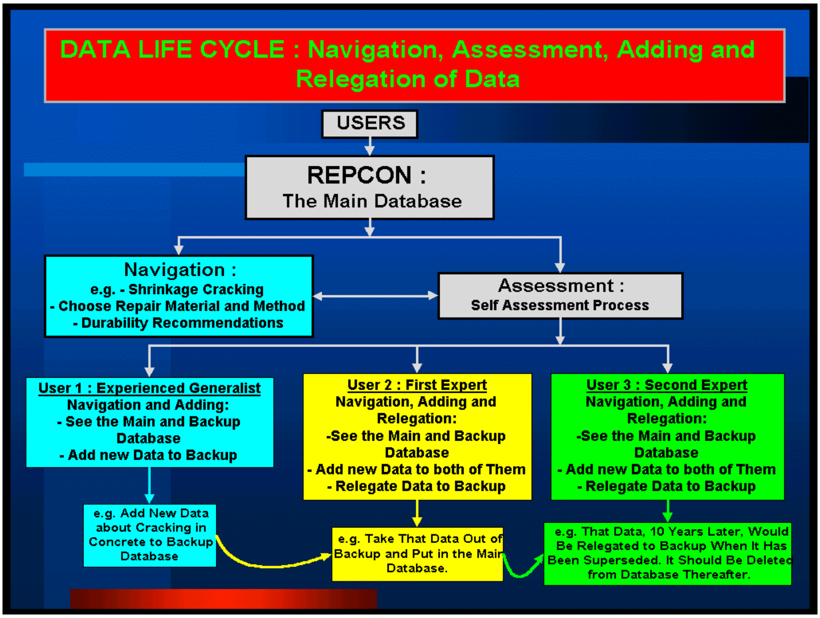

Figure 5. REPCON database and user interaction by navigation and adding data

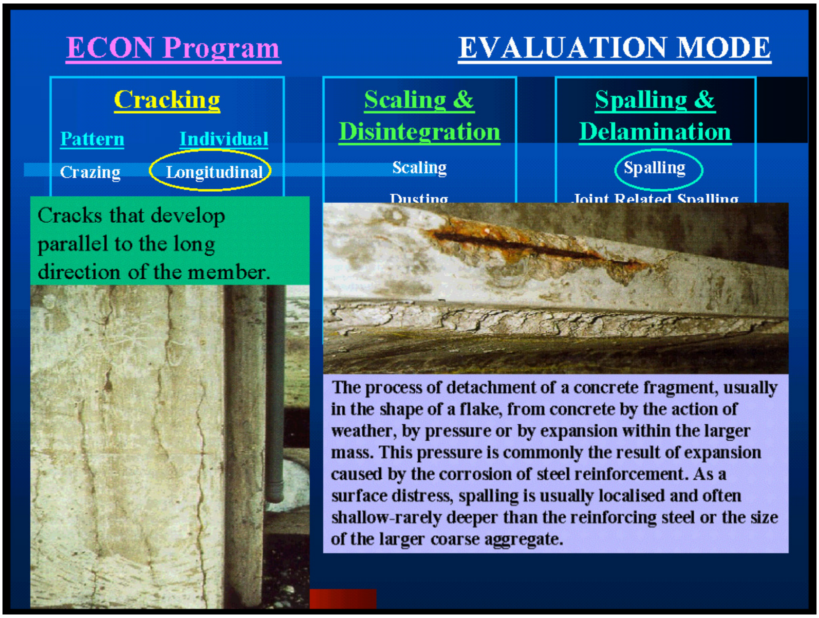

Figure 6. Combining of pictures and descriptive information for better understanding of concrete problems

the best course of action in the repair and maintenance management. Engineering judgement and experience were needed to develop a set of criteria [22] in order to implement a quantitative rating of the overall state of concrete using the results of the observation of signs of distress and weighting scales based on severity and extent. It is important that the conditions observed be described in unambiguous terms that can be used by the user to be able to take engineering and management actions for the repair and maintenance of the structure. In the Evaluation mode of application, the user can obtain assistance from the REPCON database of pictures alongside the descriptive information attached to each type of distress. Visual information (photographs and drawings) such as the one shown in Figure 6 enhance the interpretation of results and can often describe failure modes for materials and structures. Once the distress has been identified, several repair materials and alternative methods can be reviewed. Information relating to several different repair materials and methods for concrete structures has been gathered and stored in the REPCON database [10].

5.4 Diagnostic Mode

The application of expert systems that are an effective decision-making tool to diagnostics and repair activities is of benefit to concrete structure inspectors, engineers and decision-makers. It can assist the user in identifying the distresses, diagnosing the cause of impairment, recommending various repair strategies and providing information for budgeting, planning and life-cycle-costs. The large body of knowledge usually required in engineering information systems can be made available to an expert system through an existing commercial database management system. Integrating these two separate areas of Information Technology (IT) can provide technology transfer of information from *Experts* and *Specialists* to other practitioners and vice versa and it provides much needed guidance for practitioners whilst serving as a decision support system for other *Experts* and *Specialists* in the fields.

Information regarding causes and effects of concrete distress related to cracking (CRACON), to surface distresses (SURCON) and to other miscellaneous forms of distress (MISCON) has been gathered in three prototype knowledge-based expert programs [10]. REPCON helps the knowledge engineer to improve the problem-solving capability of the expert system by abstracting knowledge from the database. The knowledge included in the REPCON database offers information relating to selection of materials and methods for repair and rehabilitation and gives the recommendation to enhance durability (Figure 7). Misperception of the structure's conditions and requirements, misstatement of the inspectors or the absence of information may cause the conclusion and recommendation to be invalid. This is why users are encouraged to conduct tests and procedures recommended by the REPCON database.

5.5 Assessing Users and Knowledge

A central feature of DEMAREC is the Confidence Level (CL), which is a numerical assessment of the skill of the user. The criteria for a Contributor's Self Assessment (CSA) [25] extends from 0 to 100, with 0 indicating someone who has no experience (a Novice) and 100 indicating a user who has authority in the subject as an Expert. The self-assessment process [26] assesses the competence of the users who wish to contribute new data to the system. The skill level depends on how many questions the user can answer correctly and is graded from 0 to 5. For instance, if four questions out of five are answered correctly, the user's level of knowledge is assessed as a Specialist (fallen in Zone 1) with a confidence level of between 76 and 90. Such people can see the main database and the backup and can contribute their knowledge and experience directly to them.

The other unique feature of DEMAREC is the quality assessment of User Contributed Data (UCD) [25], which is a numerical indicator and descriptive function of the new added data. A Confidence Level (CL) must

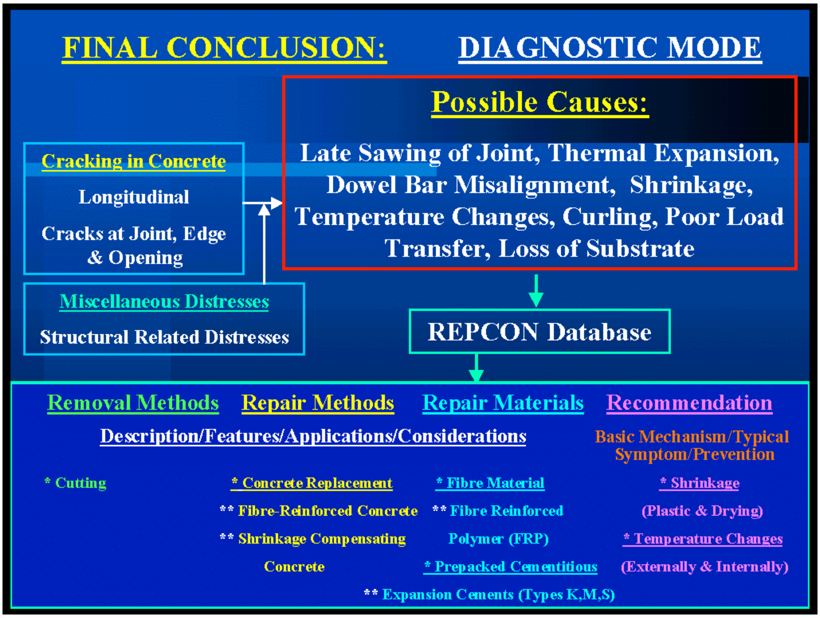

Figure 7. Retrieving information from database regarding repair methods and material and durability recommendation

be chosen and entered in a prepared field when the user wants to contribute his knowledge and experience to the database. The quality level extends from 0 to 100 with 0 representing hypotheses and 100 representing accepted state-of-the-art information. For example, the confidence levels of Possible Case and Innovative Idea in Zone 3 (0 – 30) have been introduced for persons contributing unsure information or ideas. It is important to recognise that such information can be as important as more definitive information, but only if a user knows that it is in zone 3.

5.6 Durability Recommendation

It is important to gain an understanding of the basic causes and mechanisms of the various forms of distress which may attack concrete. Gathering available information and data in the maintenance and repair of concrete structures allows realistic and proper diagnosis of the cause(s) of the distress, provides expert advice on material selection and enables adequate repair techniques. Information regarding maintenance and durability of concrete structures has been stored in the REPCON database. Most of the information is taken directly from codes of practice such as the American Concrete Institute [12] and British Standards Institution publications [13] and from technical reports published by concrete associations [17,19,20]. This data is strictly for information to inform the user who may be conducting research on developing his preliminary strategies and is optional by selecting an appropriate code of practice. This information has been classified in four main categories and gives recommendations on the design of concrete for a wide range of durability areas such as construction and design errors, settlement and movement, frost attack, sulphate attack, shrinkage, chloride attack, alkali-aggregate reactivity, concrete material recommendations.

6 Validation and Case Study

The principal value of DEMAREC is as a platform for the long-term development of an integrated engineering computing environment. The conceptual architecture for the environment consists of multiple knowledge base tools, user interfaces, evaluation program and databases supported on networked processors to form a simple integrated system.

The central feature of this research is the integration of two hitherto separate areas of Information Technology (IT), i.e. a database management system (DBMS) and a knowledge-based expert system (KBES). Certainly the research has succeeded in addressing many of the issues in the coupling of knowledge-based expert systems with database management systems for concrete repair applications. The original focus of research on developing a flexible interface system has been substantially achieved. In the prototype implementation, knowledge-based expert systems may pose arbitrary queries in the context of their own data structures which are then answered using data from the database that is hidden from KBES.

As a database interface for a knowledge-based expert system, a major strength of DEMAREC has proved to be its provisions for handling dynamically added data. In addition, DEMAREC deals with engineering data and the needs of engineering applications with respect to that data in the field of concrete repair. Considerations were given to the design process for DEMAREC. The global schema uses a data model to provide maximum semantic representation capabilities. This is illustrated by comparing pictures and technical data in a way that makes decision and problem solving easier.

Finally, the DEMAREC results is validated by three case studies taken from actual cases of concrete diagnosis and repair and from the literature, i.e. (1) cracking to the external concrete paving at Unit A, Hams Hall [27], (2) the settlement and cracking in a warehouse floor at Chatham Dockyard [28,29], and (3) HYWCON expert system [8]. In these case studies, it is shown that the results of this research could have been used to enhance the process of determining the cause of failure and in selecting the repair material and method.

Figure 8. In some bays, the cracks quartering the bay are connected by a short 45 degree crack [27]

Case Study 1- External Concrete Paving

Cracking to the external concrete paving (Figure 8), at Unit A, Hams Hall [27] currently being used by Tradeteam as a consumer-products distribution centre is considered. The cracks are full depth and move with moisture and temperature variation. Spalling and general deterioration in the slab and near openings and joints is occurring. From the pattern cracking, and from the other test reports, it is clear that there is insufficient release of restraint at the joints for the slabs to operate by the joints moving and thereby accommodating temperature/moisture induced volume changes. A secondary contribution to the development of the cracking has resulted from dowel bar misalignment. It was recommended that the slabs should be replaced with unreinforced concrete and that either air entrainment or polypropylene fibres should be included in the concrete.

In order to assess the validity of the DEMAREC system results in assessing the reasons for the pattern of cracking in the Tradeteam external pavement, the following conclusion can be reached. Firstly, causes and effects of cracking (Figure 7) obtained from the DEMAREC-EXPERT conclusion could help the user in correctly diagnosing the distresses. Secondly, alternative repair materials and methods alongside the durability recommendation extracted from the REPCON database allow the user to select

Table 1. Comparison of results between DEMAREC application and external paving investigation

	Possible Causes Considered	Alternative Materials	Alternative Methods
DEMAREC System	- Dowel Bar Misalignment - Late Sawing of Joint - Thermal Expansion - Shrinkage - Temperature Changes - Curling - Poor Load Transfer - Loss of Substrate	- Fibre Reinforced Polymer (FRP) - Expansion Cements (Types K, M, S)	**Concrete Replacement** - Fibre-Reinforced Concrete - Shrinkage Compensating Concrete
External Paving Investigation	- Temperature & Moisture Changes Led to Shrinkage and Curling - Dowel Bar Misalignment - Poor Load Transfer - Differential Settlement	- Air Entrainment - Polypropylene Fibre	**Concrete Replacement**

the best course of repair and maintenance. Engineering judgement and experience alongside the site investigation and in-situ and laboratory examinations were able to confirm the final conclusion. The comparison of results is also shown in Table 1.

Case Study 2- Warehouse Concrete Floor

The settlement and cracking (Figure 9) which is considered in a warehouse floor at Chatham Dockyard [28,29] is proving to be a significant hindrance and these is a need to undertake a full investigation. From visual inspection, it is concluded that the cracking occurs because concrete is stiff and cannot bend to accommodate the settlement. It is clear that the majority of pattern cracking is due to large differential settlement and those that started as shrinkage cracks have developed further owing to the settlements in the slab. With the differential settlements experienced, it is quite possible that either the joints have opened up or a drain has cracked, allowing any water to escape into the ground below, which will increase the rate or compaction of these layers and increase the differential settlement of the slab. A full range of options was reviewed [30] such as adding a lightweight reinforced screed, construct ground beams and suspended floor slab, expanded head piles and suspended RC floor slab and vibro-replacement stone columns with ground bearing slab. However, for the warehouse to be put back into full service for the full life span of the building it could be recommended that the total slab is replaced with a reinforced suspended concrete slab on a grid of piles or steel fibre reinforced concrete floor.

Figure 9. Pattern of cracking around a local hard spot [29]

To assess the validity of the DEMAREC system results, the emphasis is put on comparing the experimental and actual investigation of causes of distress at the Chatham Dockyard concrete floor and those given by the system. The causes and effects of cracking obtained from DEMAREC-EXPERT conclusion (Figure 10) and alternative repair materials and methods alongside the recommendation regarding durability retrieved from the REPCON database helps the user to take the engineering judgement and experience for repair and maintenance. This comparison is shown in Table 2.

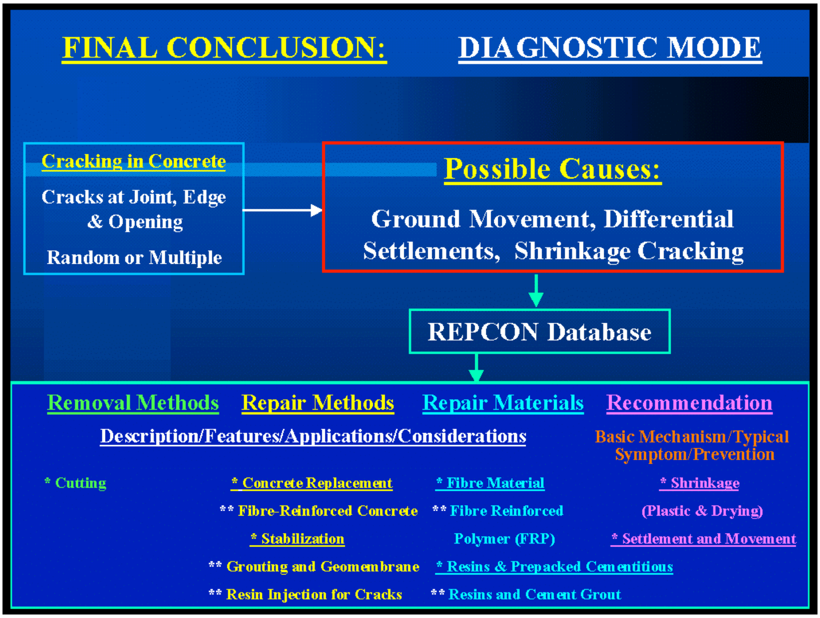

Figure 10. Alternative repair materials and methods and recommendation in durability for the Chatham dockyard floor retrieved from the database

Table 2. Comparison of results between DEMAREC application and the Chatham dockyard concrete floor investigation

	Possible Causes Considered	Alternative Materials	Alternative Methods
DEMAREC System	- Ground movement - Differential settlements - Shrinkage cracking	- Fibre Reinforced Polymer (FRP) - Cement Grout - Resins	**Concrete Replacement** - Fibre-Reinforced Concrete **Stabilization** - Grouting - Geomembrane - Crack Resin Injection
Chatham Dockyard concrete floor Investigation	- Differential Settlements - Shrinkage Cracks	- Fibre Reinforced Polymer (FRP) - Resins	**Concrete Replacement** - Fibre-Reinforced Concrete - Reinforced Suspended Concrete slab on piles **Stabilization** - Decoupling - Flattening - Monitoring - Crack Repair

Case Study 3- HYWCON expert system

HYWCON [8] was designed to assist state highway departments in three areas: (1) diagnosing distresses in highway pavements and structures; (2) selecting materials for construction and rehabilitation; and (3) obtaining recommendations on materials and procedures for repair and rehabilitation methods. In this case study, the DEMAREC-EXPERT results were validated against concrete repair problems undertaken by HYWCON expert system involving concrete bridge deck and substructure diagnostics. Emphasis was placed on comparing the knowledge

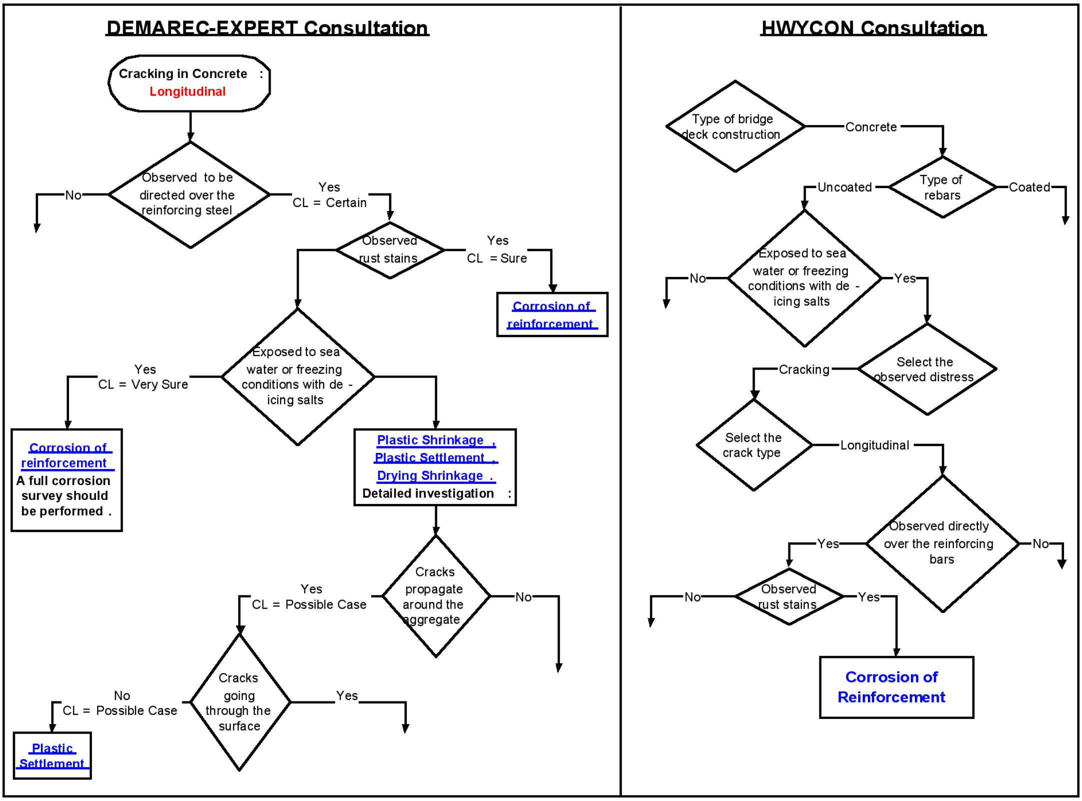

Figure 11. An instance of comparing between DEMAREC-EXPERT and HYWCON consultation

areas, the development and implementation tools and the experimental results obtained by HYWCON with those given by DEMAREC-EXPERT.

HYWCON used both backward and forward chaining inference. But, the major disadvantage of using Level 5 Object in the development HYWCON is the use of Yes/No mode of confidence level. It means that if the confidence of the user to answer the question is not definitely "Yes" or "No", there is no longer any reason to pursue the hypothesis. DEMAREC-EXPERT development and implementation were validated against development tool used by HWYCON. Emphasis was placed on comparing the development tool and programming productivity. M.4, as an expert system shell, is used as a development tool that provides a platform for further enhancement and the addition of knowledge as well as providing a high level of programming productivity. A comparative example between DEMAREC-EXPERT and HWYCON consultation results is shown in Figure 11.

The chief innovative characteristic of DEMAREC-EXPERT in comparison with HYWCON is the introduction of confidence levels (CL). CLs are words and descriptive functions with pre-determined confidence level value which are used to measure the strength of the knowledge and to conceal specific uncertainty within the meaning. If the confidence level of the premise is not "Certain", the conclusion is still noted because there may be a good reason to pursue the hypothesis, no matter how uncertain it might be now. Indeed, one of the strengths of the system is the way in which it allows the promotion and relegation of knowledge according to the opinion of users of different levels of ability from expert to novice. This chain of events in which seeking the value of one expression causes M.4 to invoke a relevant rule, and consequently to seek the value of another expression found in the premise of the rule is called backward chaining and is fundamental to the operation of the DEMAREC-EXPERT inference engine.

Conclusion

This research has wider implication than within the realm of concrete repair. It represents a radical approach to knowledge engineering: a database is no longer a static resource under the direction of one organisation. Rather, it evolves according to informed consensus. One of the strength of the system is the way in which expertise has traditionally evolved and it allows the promotion and relegation of knowledge according to the opinion of users of different levels of ability from expert to novice.

More effort has to be placed into supporting the exchange of information and knowledge between the various experts whilst allowing them to work on their respective parts of the knowledge and experience. Effectively, the benefit of using DEMAREC lies in the enhanced levels of confidence which can be attributed to the data and to contributors of that data so that the expertise moves on in a faster and more structured manner.

A central feature of the system is the opportunity for information to change status. This is important because the value of all knowledge changes with time and may eventually be of no worth. The success of DEMAREC could be gauged by a future scenario in which none of the original knowledge remained as the subject matter is superseded. Indeed, the very existence of DEMAREC could accelerate the turnover of knowledge. The value of DEMAREC can be gauged by considering how this acceleration in the turnover of knowledge might impact upon all areas of endeavour.

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