BUIL-D-EX, A KNOWLEDGE-BASED EXPERT SYSTEM FOR THE DIAGNOSIS OF BUILDINGS CRACKS

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ABSTRACT:
Expert systems are computer systems developed to preserve the human expertise about specific domains in a well-structured form suitable for retrieval and manipulation by computers. They have been used in many fields of applications and proved to be beneficial. This paper addresses the role of Knowledge-based expert systems in building construction; particularly in the diagnostics and assessment of buildings' cracks. The paper presents BUIL-D-EX; a prototype for a Buildings' Diagnostics Expert system intended to assist architects, structural engineers, contractors and even building owners in identifying and suggesting remedies to concrete and masonry surfaces' defects. The system identifies the kind of crack, states its most probable causes and its degree of danger, suggests a technical remedy and finally suggests several commercial names for materials to be used for curing the defect, and how to apply them. BUIL-D-EX offers complete explanations for all its questions to the users, as well as justifications for all its decisions and answers whenever needed.

ملخص البحث :

نظم الخبرة هى أنظمة حوسبية تم تطويرها لحفظ الخبرة فى مجالات محددة بشكل يسمح باستخدامها بسهولة ويسر عند الحاجة إليها، حيث أثبتت فاعليتها فى كثير من المجالات التطبيقية. تقدم هذه الورقة البحثية نموذجاً أولياً لنظام خبير قائم على قواعد المعرفة فى مجال تشييد المبانى، وبالتحديد فى تشخيص ومعالجة الشروخ بالأبنية المختلفة سواءً كانت ذات إنشاء هيكلى أو من الحوائط الحاملة. هذا النظام المقترح من شأنه مساعدة المعمارى والإنشائى والمقاول وحتى شاغرى هذه الأبنية فى تحديد وتشخيص الشروخ المختلفة. فيحدد النظام المقترح نوع الشرخ، ويحدد مسبباته ومدى خطورته، ثم يقدم مقترحات فنية للعلاج من خلال اقتراح أسماء لمنتجات تجارية يمكن استخدامها للمعالجة مع بيان كيفية استخدامها. كما يقدم النظام المقترح تسبيباً وشرحاً كاملاً لكل أسئلته ومقترحاته فى حالة طلب المستخدم لها.

INTRODUCTION:

So often, architects, contractors and even building owners are faced with building defects that they need to diagnose and remedy as soon as possible. However, this needs a lot of expertise that would have been gained through years of experience and may not be available at the time when this experience is mostly needed.

According to Liebowitz (1997), one area of computer software development that lends itself extremely well to the process of solving confined problems is expert systems development.

Expert systems are Artificial Intelligence (AI) computer programs specially designed to represent human expertise to solve problems in a particular domain when no human expert is available (Krishnamoorthy et al, 1996) and (Badiru, 1998). In addition to the declarative knowledge about a specific domain, expert systems also contain procedural knowledge, which allow them to emulate the reasoning of the human expert in that specific domain whenever needed. Expert systems' output will always be consistent and fair, applying the same criteria to every case, so that the same conclusion would be reached no matter who used the system to reach the decision (Tasso et al 1998).

PAPER'S OBJECTIVES:

This paper suggests that utilizing Knowledge Based Expert System technology is a powerful tool for a successful diagnosis and treatment of buildings' cracks under normal loading conditions. The objectives of the paper are bifold:

1. To develop a prototype of an expert system for the diagnosis and treatment of buildings' cracks (the case of low rise buildings – less than 15 meters high - under normal loading conditions).
2. To present an example application to illustrate the proposed methodology.

THE EXPERT'S REASONING PROCESS:

Defining the causes, selecting the most probable cause among the different possible causes, defining the degree of danger and suggesting treatment measures for a specific crack involves several steps on behalf of a domain expert. An expert would first investigate whether the crack is superficial or does it cut deep into the structure. Then he/she would define the type of construction system, whether it is skeleton or bearing walls. Then he/she would define the construction material where the crack is found; is it in the masonry, or in the concrete or in both masonry and concrete. After that, the expert would define the shape of the crack itself, whether it is horizontal, vertical, inclined or a combination of two or more of the three shape cases. The next step for an expert would then be to give answers for questions of the type: *WHAT* and *WHY*; i.e., *what* is the degree of danger regarding a specific crack, and *why* did it happen, or *what* are the possible causes of this crack, and *what* is the most probable cause among all the different possible causes of the crack under study. The expert would then select from his/her vast knowledge in the field, a suitable remedy for the curing and treatment of the crack, whether be it through the use of special chemicals, or by recommending a certain process to be executed on site. The expert would then answer questions of the type: *HOW TO*. He/she might be asked to provide an opinion as to *how* this crack could have been avoided in the first place, and, in case of using chemicals, the expert would recommend *how* this chemical is supposed to be used for the curing or the treatment of the crack, its technical workability, its quantity and its way of preparation. The above-mentioned process has been implemented in BUIL-D-EX, as shown in figure (1).

SELECTING THE EXPERT SYSTEM DEVELOPING TOOL:

Expert system tools provide specific techniques for handling knowledge representation, inference and control that help knowledge engineers to model the different characteristics of a particular class of problems. Criteria for selecting an expert system developing tool can be found in a variety of references, e.g. El-Dessouki (1992), Adelman et al (1997) and Mohan (2000). However, the most important criteria is the type of the application, which depends mainly on the nature of the problem, and how the involved data can be handled by the knowledge representation structure of the tool. Developing BUIL-D-EX as an expert system for the diagnosis of buildings cracks required a flexible expert system shell with the initial design of the system taking the form of a *knowledge tree*, to represent the decision tree of the expert, incorporating several rules related to his domain of expertise. Therefore, it has been concluded that the proposed system should primarily be composed of a knowledge base consisting of a set of rules to be encoded in an expert system shell that is primarily designed for the development of rule based expert systems. Another functionality component of the required shell would be to demonstrate ability to *communicate with external programs*, to call existing programs and demonstrate data exchange, especially to *access database programs*. This has to be an important and necessary feature of the expert system if it is to use knowledge of special chemicals for curing and treatment of cracks. Therefore, the expert system shell must allow for the external communication with other programs, especially database programs. Another desirable feature of the required shell would be its applicability to *display information graphically*, or in a pictorial form, as it is advantageous to display the form of the chemical products packaging, and whether be it sheets, granules or liquids, or any available pictorial information related to the suggested product.

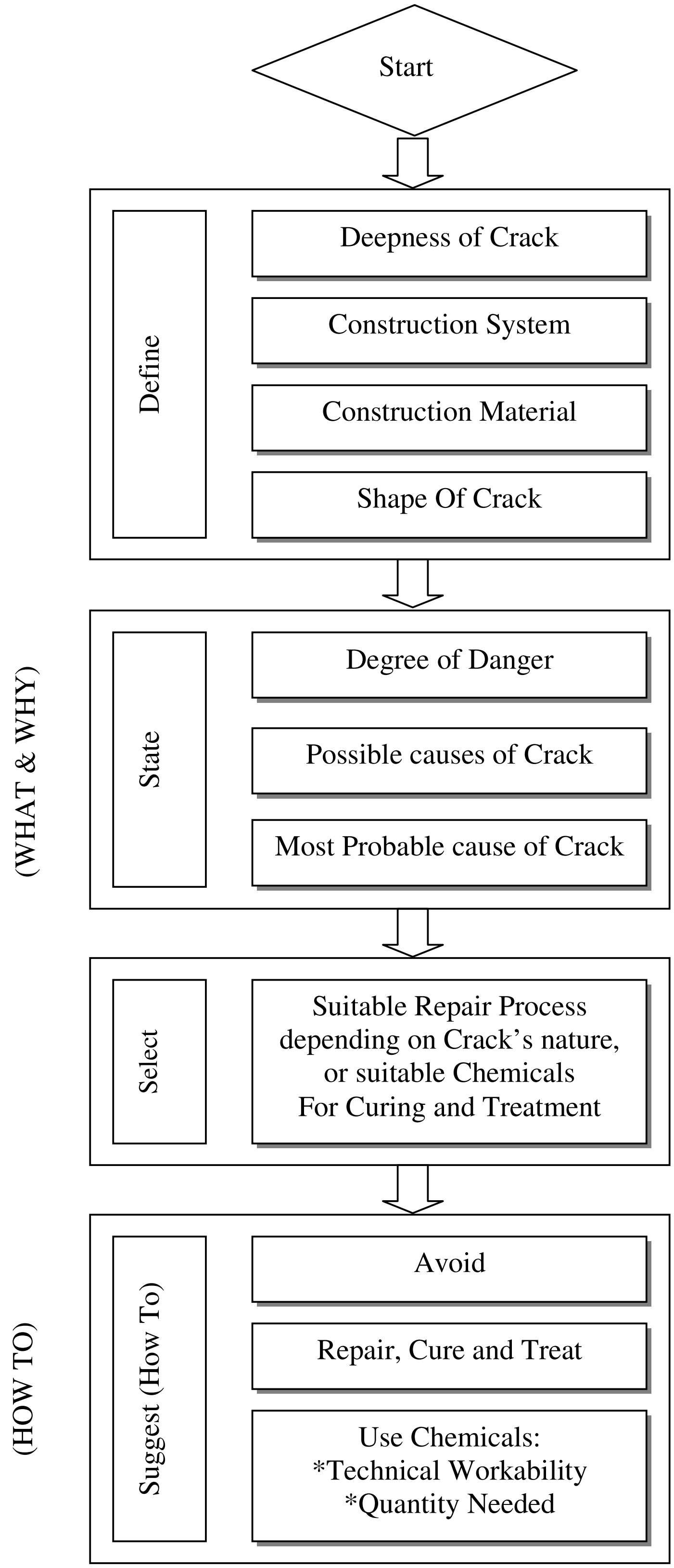

Fig. 1: BUIL-D-EX Reasoning Process

Since most users of expert systems are not necessarily experts at using computers, it is also desirable that the required shell would *provide help options such as hypertext* for help on specific keywords.
In order to appropriately represent the knowledge of BUIL-D-EX with all the required tool capabilities previously mentioned, “LEVEL5 OBJECT™” Object Oriented Expert System Tool (1990) has been chosen.

THE DECISION PROCESS:
In order to develop an expert system to diagnose cracks in masonry and concrete buildings and suggest remedies and/or chemical products for their treatment or curing, knowledge from experts had to be used, (Hawass, 1990) and (Aboul Magd, 1993), along with databases that contained information about these chemical products, in the form of technical sheets from different companies working in the field of chemical additives for buildings.
The information obtained consisted of different kinds of cracks in different building types; skeleton and bearing walls, the crack’s shape, its degree of danger, what are their potential causes, how to avoid having these cracks in the future, how they may be remedied, treated and cured, what additives or chemical products or any other processes should be preformed in order to treat or cure these cracks. The databases contained information such as the product’s commercial name as for (Company’s name), its description, field of application, advantages, properties, dosage, packing and instructions for use. All these information were used to form rules that the expert system could use to identify the crack, state its cause(s), suggest a remedy and select a suitable chemical product for its repair and treatment or curing.
These expert systems usually represent knowledge as sets of production rules. The rules consist of a set of conditions, and a set of actions, in the form of:

IF *condition*,
THEN *action*

If all of the *conditions* in a rule are true, then the *actions* are executed. The premise or conditions are contained in the "IF" part, and the consequent actions in the "THEN" part. The core of BUIL-D-EX is made up of the decision tree shown in figure (2), which can be translated to rules of the form shown in figure (3).

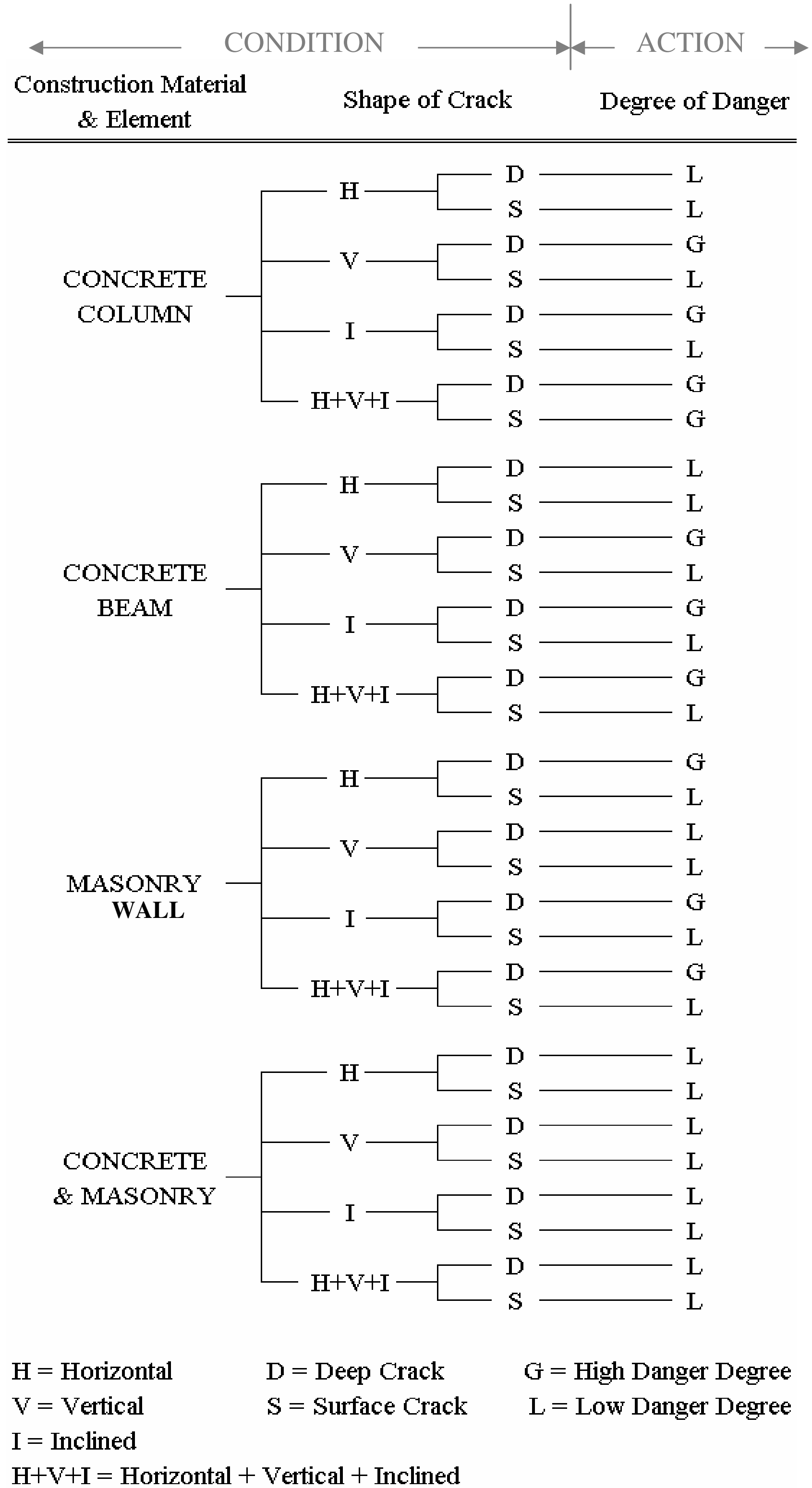

Fig. 2: BUIL-D-EX Decision Tree showing different Degree of Danger as an output for different cases

The following rule is one example of the rules used to identify the degree of danger of a crack.

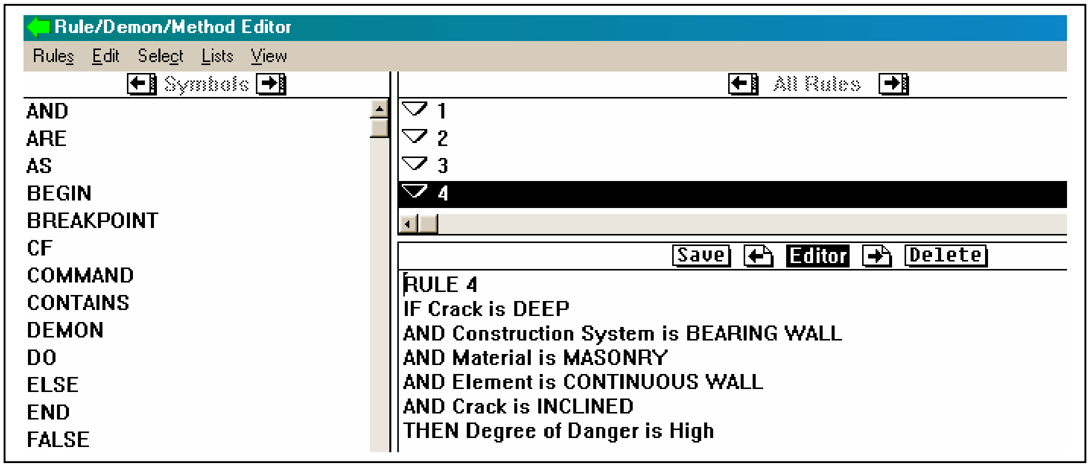

Fig. 3: One of the rules used to identify the degree of danger of a crack

BUIL-D-EX uses backward chaining for its inference. This type of inference is known as goal-driven inference, since the process starts with the desired objective or goal (an existing case of a crack) and proceeds backwards along a chain of reasoning to find evidence to support the hypothesis or the goal (its degree of danger and what caused it).

Backward chaining is useful for applications such as diagnostics and classification problems, where the solutions are known but the required data is not known. In the "IF" part of this rule BUIL-D-EX may not know any or all of the information, therefore, it will prompt the user for the data it does not know. If it can derive the data from another rule, then it will do so without prompting the user for an input. When selecting a commercially available chemical product, BUIL-D-EX accesses the products database. A part of this database is shown in Table 1.

Currently the database contains information about the product's commercial name, description, its field of application and its packing form.

The following rule shows an example of rules that require a database access.

RULE 17
IF: Required Product Index is Joint Filler
OR Crack Filler
OR Hole Filler
AND Crack is VERTICAL
AND Structural Material is CONCRETE
THEN: Product is given the value [Commercial Name]
AND Description is given the value [Description]

AND Field of Application is given the value [Field of Application]
AND Packing Form is given the value [Packing Form]

Table 1: Part of the Products' Database

Commercial Name	Index	Description	Field of Application	Packing Form
EUXIT TG 10	Joint Filler, Crack Filler	A Solvent free, highly elastic joint filler Resin, of Tar-POLYURETHANE base with Isocyanate hardener	Filling structural HORIZONTAL and VERTICAL cracks and joints of all kinds	Containers of 4 kg, 12 kg Resin and Hardener are supplied in correct mix ratios
EUCO-REPAIR-MORTAR	Crack Filler, Hole Filler	Exposed Concrete Mortar based on Cement	Repairing Exposed Concrete faulty edges and surfaces, and filling cracks and holes	Bags containing 25 kg of Powder
EUCOLITE	Waterproof Mortar	Waterproofing admixture for mortar available in two forms, EUCOLITE L in liquid form and EUCOLITE P in powder form	Achieving a waterproof mortar with high compressive strengths and reduced tendency to crack and shrink, for rendering brickwork mortar	EUCOLITE L in bags containg 25 kg, EUCOLITE P in drums containg 100 kg

Before the "THEN" part of the rule is accessed, the "IF" condition must first be satisfied. The selected product should be joint filler or crack or hole filler, and the crack is vertical in a concrete structure. When the "THEN" part of the rule is fired, BUIL-D-EX automatically accesses the database file containing the Products' Database, and selects the available product that meets the required criteria. BUIL-D-EX makes this selection by associating frames with variables in the rule base. A frame consists of several components; the database to access, a condition, and the column headings of the values to be returned, that is the column with the heading "*Commercial Name*"; "*Description*"; "*Field of Application*" and "*Packing Form*". For the frame to work, the database must be of a form similar to the one shown in Table 1, containing columns with headings. The frame uses the condition in the "IF" statement to search for the record that matches this condition. Once this is done, the frame returns the value of this record with its associated data.

DISCUSSION:

BUIL-D-EX, the expert system presented in this paper, is designed on an IBM Pentium III, using LEVEL5 Object Oriented shell. The identification of the degree of danger of the buildings' cracks and the selection of a suitable repairing process or adding a chemical material for the treatment and curing of these cracks, and the decision of which material or chemical to use was based on the identification of the deepness of the crack, the construction system, the construction element whether it is a column, a beam or a wall, the construction material and the shape of the crack itself. BUIL-D-EX also gives information as to what may have caused this crack and how it may have been prevented in the first place. It also gives recommendations as to how the suggested chemical material is to be used, its packing form and what is the needed quantity.

LEVEL5 Object Oriented expert system shell has been chosen because of its flexibility and functionality in performing backward chaining, ability to communicate with external programs, and support hypertext functions to provide the user with help items whenever needed.

When BUIL-D-EX runs, it starts by asking the user some questions. As the user provides the answers, BUIL-D-EX begins to draw conclusions by executing rules. The following is an example of the kind of questions that BUIL-D-EX asks in a typical consultation session:

Is it true that crack is Deep?	True	or	False
Is it true that construction system is Bearing Wall?	True	or	False
Is it true that construction material is Masonry?	True	or	False
Is it true that element is Continuous Wall?	True	or	False
Is it true that crack is Inclined?	True	or	False

BUIL-D-EX starts by the first question to identify the deepness of the crack, if the user's answer to the first question is "True", then BUIL-D-EX prompts the user with the second question to identify the construction system type. If the user's answer is also "True", then BUIL-D-EX asks the third question, and so on. If the user's answers for all the above questions were "True", then BUIL-D-EX's recommendation would be as follows:

Based on your inputs, our recommendation is:

Degree of Danger is LOW	FALSE
Degree of Danger is HIGH	TRUE

Figure (4) shows BUIL-D-EX's screen showing the different help buttons. For example, when the user presses the "WHY" button before answering the question:
[Is it true that the construction element is Continuous Wall?], BUIL-D-EX would prompt the user that it is important for the system to differentiate between continuous walls running from floor to ceiling, and sill walls just underneath the window sill, as the causes and the degree of danger for such cracks may differ.

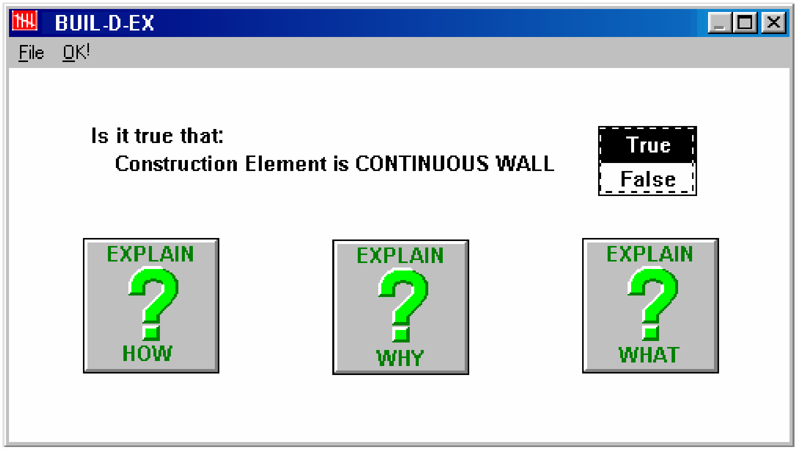

Fig. (4): BUIL-D-EX screen showing the different HELP buttons

When pressing the "WHAT" button after BUIL-D-EX recommendation that the degree of danger is High; BUIL-D-EX would prompt the user with a text box stating what would be the possible causes of this kind of crack, as shown in fig. (5).

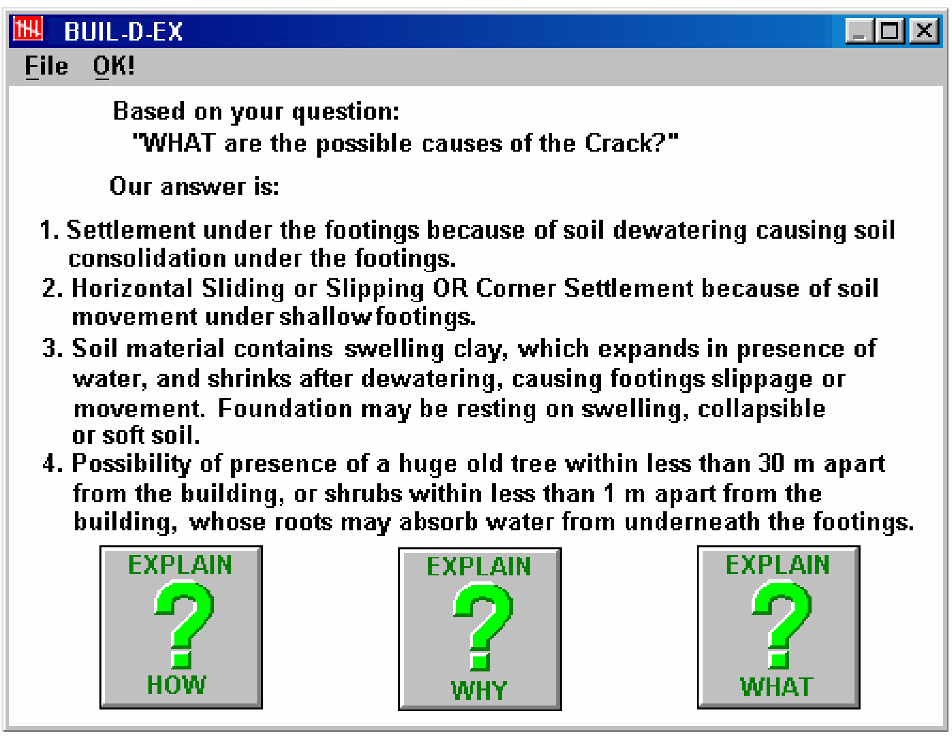

Fig. (5): One of BUIL-D-EX screens showing its explanation capabilities

One important advantage of expert systems is their ability to update and expand according to the future available knowledge, or the growing knowledge of the system's users. A special advantage of LEVEL5 Expert system shell is its ability to easily access its knowledge base and edit its rules, or add more rules. Another advantage of the tool is its ability to use its knowledge base to run on different hardware platforms, this is done by exporting its knowledge base to an external file with the extension ".PRL" i.e. Production Rule Language. This file contains all the rules of the system and can be edited by any available word-processing software, in order to run on different platforms or hardware environments. Once the knowledge base is in text form, it can be imported to ".KNB" file (a knowledge base file) on a different hardware platform.

To achieve a satisfactory level of system reliability and accuracy, BUIL-D-EX in its current implemented version has been tested, and verified based on a continuous series of experts' interviews. Table 2 summarizes the recommendations given by BUIL-D-EX considering those obtained from the experts. However, it could be noted that different experts (or even the same expert) can have different opinions or solutions for the same case. This problem has been remedied in BUIL-D-EX by considering all the experts' opinions that they have associated with every case.

Table 2: BUIL-D-EX recommendations:

Case No.	**Deepness of Crack**	**Construction Material & Element**	**Crack's Shape**	**Degree of Danger**	**Code of Possible Causes**
1	D	Concrete Column	H	L	1, 2, 3, 4, 5, 7, 16
2	S	Concrete Column	H	L	9, 11, 12, 13, 14, 15, 16, 17
3	D	Concrete Column	V	G	5, 6, 7, 11
4	S	Concrete Column	V	L	9, 16, 18, 19
5	D	Concrete Column	I	G	1, 2, 3, 4
6	S	Concrete Column	I	L	13, 14, 15, 16, 17, 18
7	D	Concrete Column	H+V+I	G	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18
8	S	Concrete Column	H+V+I	G	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18
9	D	Concrete Beam	H	L	15
10	S	Concrete Beam	H	L	15
11	D	Concrete Beam	V	G	5, 6, 15, 18
12	S	Concrete Beam	V	L	12, 13, 14, 15, 16, 17, 18
13	D	Concrete Beam	I	G	7, 11
14	S	Concrete Beam	I	L	7, 13
15	D	Concrete Beam	H+V+I	G	5, 6, 7, 11, 12, 13, 14, 15, 16, 17, 18
16	S	Concrete Beam	H+V+I	L	5, 6, 7, 11, 12, 13, 14, 15, 16, 17, 18
17	D	Masonry Wall	H	G	1, 2, 3, 4, 15
18	S	Masonry Wall	H	L	1, 2, 3, 4, 15
19	D	Masonry Wall	V	L	15

20	S	Masonry Wall	V	L	15
21	D	Masonry Wall	I	G	1, 2, 3, 4
22	S	Masonry Wall	I	L	1, 2, 3, 4
23	D	Masonry Wall	H+V+I	G	1, 2, 3, 4, 15
24	S	Masonry Wall	H+V+I	L	1, 2, 3, 4, 15
25	D	Concrete + Masonry	H	L	15
26	S	Concrete + Masonry	H	L	15
27	D	Concrete + Masonry	V	L	15
28	S	Concrete + Masonry	V	L	15
29	D	Concrete + Masonry	I	L	1, 2, 3, 4
30	S	Concrete + Masonry	I	L	1, 2, 3, 4
31	D	Concrete + Masonry	H+V+I	L	1, 2, 3, 4, 15
32	S	Concrete + Masonry	H+V+I	L	1, 2, 3, 4, 15

D = Deep
S = Superficial

H = Horizontal
V = Vertical
I = Inclined

G = High (Great)
L = Low

Codes for causes of cracks:

1. Settlement under the footings because of soil dewatering causing soil consolidation under the footings.
2. Horizontal sliding or slipping or differential settlement because of soil movement under surface footings
3. Soil material may contain swelling clay (Tafla) or BAGA which swells in the presence of water, and shrinks after dewatering, causing footings' settlement or movement.
4. Possibility of presence of huge old tree within less than 30m apart from the building, or presence of lots of shrubs within less than 1m apart from the building whose roots may absorb water from underneath the footings.
5. Possibility of presence of high-tension force.
6. Possibility of presence of high-compression force.
7. Possibility of presence of high-shear stress.
8. Thermal stresses.
9. Shrinkage or creep of concrete.
10. Direct exposure to the weather or a corrosive environment.
11. Inadequate reinforcement arrangement.
12. Deteriorated reinforcement.
13. Poor quality concrete.
14. Deteriorated concrete.
15. Poor workability
16. Honey-combing.
17. Low cement content in the concrete mix.
18. Too much water in concrete mix.

SUMMARY:

Defining the degree of danger for buildings' cracks, and suggesting suitable remedial actions or adding special chemical materials for their curing and treatment is, perhaps one of the most experience demanding aspects of addressing buildings' cracks. There are too many facts for any one person to know or even understand. One way of solving this problem is to make both the problem and the solution more definite so it can be solved by a computer program. Expert systems are computer programs that use knowledge from experts and databases containing different information pertinent to specific domains. This paper presents BUIL-D-EX, a prototype for a Building Diagnostic Expert System developed using LEVEL5 Object Oriented Expert System Shell, working on an IBM PC.

BUIL-D-EX defines the degree of danger for the crack, and suggests its possible causes, suggests the crack's remedies and selects suitable chemical materials from an external database, on the basis of what has been presented in this paper. Because BUIL-D-EX selects chemical materials based on a set of rules, its selection is very consistent. Given the same set of inputs, BUIL-D-EX will always select the same product, while consulting with experts might result in the selection of different products each time. This is not to be taken that expert systems should replace experts in this field, nor purchasers of building chemical products should only use recommendations from expert systems to select their products, but simply to state that expert systems should be used more often as decision supports in the diagnosis of buildings' cracks and the selection of the most suitable remedial actions or chemical products used for their curing and treatment.

CONCLUSION:

The development of a knowledge-based expert system for a complex and multi-faceted process such as the diagnosis of buildings' cracks and suggesting their remedies passes through a series of investigation levels. BUIL-D-EX, the presented prototype covering the expertise knowledge about the diagnostic process and suggesting different remedies has been developed and presented in this paper. BUIL-D-EX's main features have been introduced and discussed. The key features are the capability of defining the most probable cause of a crack among a number of different possible causes, defining the degree of danger of the crack under study, and selecting a suitable repairing process or adding a chemical material for the treatment and curing of this crack. BUIL-D-EX also gives information as to what may have caused this crack and how it may have been prevented in the first place. It also gives recommendations as to how the suggested chemical material is to be used, its packing form and what is the needed quantity. Future versions of BUIL-D-EX will hopefully address a wider range of cases than those investigated in this prototype, among which would be the case of high rise buildings, considering different loading conditions.

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