EXPERT SYSTEMS FOR THE MANUFACTURING PROCESS IN PRECAST CONCRETE BUILDING COMPONENT FACTORIES AND CONCRETE CONSTRUCTION

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1 INTRODUCTION

Expert systems offer a new way of solving various problems related to concrete. A wide variety of potential knowledge engineering applications can be found in the precast concrete industry as well as on site in concrete construction. In Finland the research activities in the field of artificial intelligence in building construction have mainly focused on the practical aspects, i.e. what expert system techniques offer in the way of problem solving and decision support; what knowledge engineering applications from other branches of industry can be used; the state of art of software tools, such as commercially available expert system shells; building small expert system prototypes for demonstrational purposes to prove the feasibility of the technique etc.

The spectrum of problems related to concrete is broad: problems related to concrete as a material and to the manufacturing of fresh concrete; problems related to the manufacturing of building components and in situ casting of concrete structures; problems related to the design of concrete structures; problems related to repair and maintenance of concrete structures, to name a few.

2 POTENTIAL APPLICATIONS OF EXPERT SYSTEMS IN THE CONCRETE INDUSTRY

The conclusion of a brief study (Serén 1986) was, that several potential applications for knowledge based systems can be found in the concrete industry. The manufacturing process in a precast concrete factory, being more closely related to normal industrial engineering than the rest of the construction industry, is interesting in that knowledge based systems used in other branches of industry may be transferred to the concrete industry with minor modifications.

One aspect to consider are the differences between the concrete industry branches, especially in view of automation level and type of production. The concrete industry branches can be divided into three categories (Alasalmi & Ratvio 1984):

- Ready mix concrete plants. These are usually highly automated by conventional methods. The production is mainly a continuous process.
- Concrete product factories and some of the precast element factories with large production lot sizes, such as the hollow core slab factories. These are to some extent automated, especially the concrete product factories manufacturing such mass-produced articles as concrete blocks and flagstones.
- Precast element factories with small production lot sizes consisting of individually shaped concrete elements, such as sandwich wall panels. The production is manual and thus labour intensive.

According to Doumeingts (Rembold & Dillmann 1984) the computer aided manufacturing process can be divided into several subcategories:

- Computer aided design (CAD), from which all product speci-

fications needed for the production should be obtained.
- Computer aided manufacturing (CAM), which controls the manufacturing operations.
- Computer aided production planning and control, which coordinates all the manufacturing functions.

And, as the automation level rises, also
- Computer aided quality assurance.
- Computer aided maintenance.

The potential applications of knowledge based systems in the concrete industry will be discussed using this categorization.

Design and its impact on the manufacturing process

Several expert systems assisting the design process have been reported. As an example one could mention the work done in Sheffield Polytechnic in conjunction with Ove Arup and Partners to develop an expert system written in Prolog which relates to reinforced concrete beams design (Wager 1984).

The expert systems relating to architectural and structural design do not usually deal with the constraints of the manufacturing process and the need for such systems is obvious. An expert system of this kind should be able to consider the constraints set by the mould and casting equipment, make the selection of materials and check the dimensions of the elements (depending on the precast concrete factory manufacturing the elements) as well as check the design in relation to the national building codes and structural aspects.

The manufacturing operations

The use of expert systems for the control of manufacturing equipment and machinery obviously requires a high level of automation. The implication of this is that, in the short term, application areas for manufacturing operations expert systems can be found mainly in ready mix concrete plants and in concrete product factories manufacturing mass-produced articles.

In ready mix concrete plants expert systems can be used to automatically choose the appropriate mix proportion according to the structure to be cast. Another application would be monitoring the mixing process and interpreting the signals from various probes and sensors.

In the future knowledge based systems can be used in various robotic applications, for instance in the control systems of autonomous mobile robots (Weisbin et al 1986).

Production planning and control

Production planning and control seems to offer the highest application potential in the short-term for expert systems in the manufacturing process of precast concrete factories. The optimization of production is difficult due to the great amount of information. It is often difficult to form production lots from different orders even though these may contain similar elements. The detailed scheduling is also difficult because of the great amount of possible control parameters.

An additional difficulty is that the element factory does not have the final manufacturing drawings, the order in which the elements will be erected or the erection schedule at its disposal when the production planning is done. For a human being, such a dynamic environment is hard to master, and conventional computerized production planning systems are too inflexible.

Expert systems could be used for the production management in cases such as the one described above, for instance, to generate acquisition proposals, production schedules and work descriptions. In other branches of industry expert systems have been developed for this purpose. One example is Isis (Bourne & Fox 1984), which is a reasoning system addressing the problem of how to construct accurate, timely, realizable schedules and manage their use in job-shop environments. Isis constructs schedules by performing a hierarchical, constraint-directed search in space of alternative schedules. The search is divided into four levels: order selection, capacity analysis, resource analysis and resource assignment.

Quality control

Automated quality control is a potential application area for knowledge based systems. Advanced sensors, such as machine vision systems, laser gauges (Miller 1985) and ultrasonic pulse systems (Hillger & Neisecke 1985), are being developed to perform repetitive inspection tasks (for instance dimensional measurements and defect detection) more economically and more accurately. Knowledge based systems can be used to interpret the signals and to make a statistical analysis of the production output to minimize product error and downtime with automatic correction control of the manufacturing machinery.

Maintenance

The maintenance of a complex item of machinery involves a diagnostic procedure incorporating many rules as well as judgment decisions by the maintenance mechanic. Expert systems can be utilized to assist maintenance personnel by presenting menu-driven instruction guides for the diagnostic task. Many examples of such systems have been reported (Miller 1985).

3 EXPERT SYSTEMS FOR CONCRETE CONSTRUCTION

Two expert systems relating to concrete and concrete structures will be briefly described. Both are intended for use on building site.

3.1 An expert system for choosing the type of ready mix concrete

General information about the system

This expert system is intended to be utilized as a decision support system for the building site personnel in choosing the type of fresh concrete to be ordered from the ready mix concrete plant. At present the system is a demonstration prototype and it can't be used in production as such due to its somewhat limited knowledge base (the knowledge base does not contain any information about special cases). It can be used for educational purposes though.

The system runs on IBM PC/XT/AT and compatible microcomputers under PC-DOS 2.0 or MS-DOS 2.11 or later operating system versions. The recommended configuration is at least 512 kbytes RAM and a hard-disk drive.

The software tool used for developing the system is a commercially available expert system shell called Insight 2+. The knowledge is presented in the form of productions (IF-THEN-ELSE -rules), which are formed of statements or facts bound together by logical operators (AND, OR and NOT). There are four fact types: simple facts, object-attribute facts, numeric facts and string facts.

The inference system is mainly goal-driven (backward-chaining), although some simple inference control statements can be used to achieve a forward-chaining like function. The

Insight 2+ system includes a sub-set of Pascal, a full screen editor, a dBase II and III compatible database editor and functions to call procedures written in other languages.

The knowledge bases are developed by writing the source code in the knowledge representation language and by thereafter compiling the knowledge bases into an inner representation form, which the inference system can use during a consultation. The inference system automatically generates menu-type queries when it finds a statement with an unknown value during the search through the rules. Textual information can be attached to the facts to give a more finished appearance to the user interface.

The knowledge base

In Finland the building site personnel has to inform the ready mix plant about the following properties when ordering fresh concrete:

1. The compressive strength class (defined by the designer), taking into consideration appropriate concreting techniques.
2. The consistency value of the fresh concrete (usually defined as VeBe-time or sVB).
3. The maximum size of aggregate.

The domain is therefore divided into three sub-problems or contexts, each of which is a typical classification problem, i.e. the system has to choose from a number of pre-defined solutions. Weiss & Kulikowski (1984) have stated that a production system is a natural way of solving problems like this. The production systems have one major drawback (Applegate et al 1986): the search space easily grows very large and the system becomes inefficient.

The general outline of the inference and the knowledge base is presented as a flowchart in fig. 1.

The first context contains knowledge about the compressive strength class and about appropriate concreting techniques. First the system checks the required minimum value for the strength class and compares it to the strength class defined by the designer. If the strength class given by the designer is too low the system gives a warning about this. The system queries following fact values from the user for this purpose:

- environment class,
- water impermeability requirements,
- frost proof requirements,
- corrosion proof requirements and type of corrosive environment and
- the compressive strength class given by the designer.

Secondly the system gives recommendations about appropriate concreting techniques, such as curing, heating and heat treatment; increasing the strength class for the ordered fresh concrete in some cases; some general information about the use of admixtures. The fact values queried from the user for this purpose are

- the outdoor temperature at the building site and
- the desired production cycle time (form stripping time).

The second context contains knowledge about the consistency value of the fresh concrete. The system deduces the suitable consistency value using following fact values queried from the user:

- structure
  * the type of structure
  * the thickness of the structure

* the spacing between the reinforcement bars

- production equipment
  * the compaction method
  * the transport method for fresh concrete used on the building site.

A flowchart of the course of inference in this context is presented in fig. 2.

The third context contains knowledge about the maximum size of aggregate. The facts influencing the choice of maximum aggregate size are

- structure
  * the type of structure
  * the thickness of the structure
  * the spacing between the reinforcement bars
  * the desired quality of the concrete surface

- environmental requirements
  * water impermeability requirements

- production equipment
  * the compaction method
  * the type of form, number of joints in the formwork and the sealing of the joints.

It may be noticed that some of the facts mentioned above have been queried in the previous contexts.

The results from each context are shown on the display as the inference proceeds. The results from the strength class checking and concreting recommendations are shown as textual displays and the results of the determination of the consistency value and maximum size of aggregate are shown as bar-charts, where the suitability of each alternative is given by the length of the bar (fig. 3).

The Insight 2+ system does not adequately support the generating of summary reports in knowledge bases, which are divided into several contexts. Therefore a procedure has been written in Turbo Pascal to perform this task. The result displays are stored in a cumulative ASCII-file during a consultation. When the session is over, the Pascal procedure is loaded from the knowledge base and it reads the ASCII-file to form a summary report, which is shown on the display, printed out as a hardcopy or both according to what the user wishes.

3.2 An expert system for the repair of concrete structures

General information about the system

The expert system for the repair of concrete structures is intended to be used as aid in preparing the repair planning documents, but it may also be used by the contractor to aid in preparing the working plans. At present only a small subset of the final knowledge base is implemented. The implemented part of the knowledge base contains knowledge about repairing concrete balconies.

The software tool used to develop this system is an expert system shell called Xi Plus. The system runs on IBM PC/XT/AT and compatible microcomputers. Like Insight 2+, Xi Plus is a rule-based shell. The main difference between these two shells is, that Xi Plus has a more versatile knowledge representation language, with powerful inference control elements and better interfaces to other programming languages. Xi Plus is, however, a bit slower than Insight 2+.

The knowledge base

As stated earlier, the knowledge base contains information about the repair of concrete balconies. The domain consists of two main damage types: surface damages and cracking. The knowledge base is divided into three separate knowledge bases: a small main knowledge base, from which one of the two sub-knowledge bases for the different damage types are loaded. This divided knowledge base structure is chosen to maintain the efficiency of the system and to make it easier to add new parts to the knowledge base.

Each sub-knowledge base has two contexts. First the system makes a diagnosis of the damage. It queries from the user a number of properties related to the damaged concrete and concludes from these the possible causes of the damage.

Secondly the system determines the level of damage based on some facts queried from the user, after which it gives recommendations about repair methods.

The knowledge base structure is presented as a simplified chart in fig. 4.

3.3 Conclusions

The experiences show that it is quite possible to build feasible microcomputer based expert systems with the software tools available at present. There are some restrictions: the problem domain should be very small and clearly defined. If possible, the knowledge bases should be divided into separate smaller knowledge bases to maintain a reasonable performance of the systems.

The first of the described expert systems is presently being modified for educational purposes. It will, however, take some time before systems like these will be taken into production use on building sites. The rapidly developing hardware and software technology, though, will inevitably lead to an extensive utilization of knowledge based systems on building sites as well as in the rest of the construction industry in the future.

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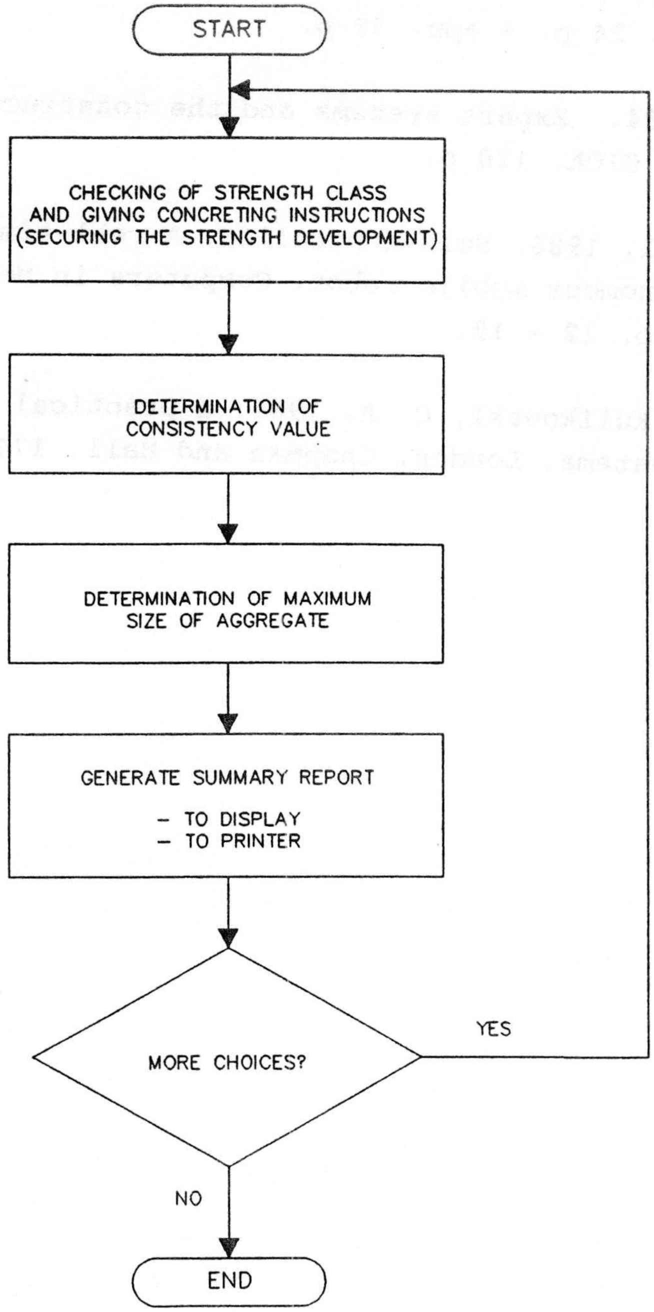

Fig. 1. General outline of the expert system for choosing the type of ready mix concrete.

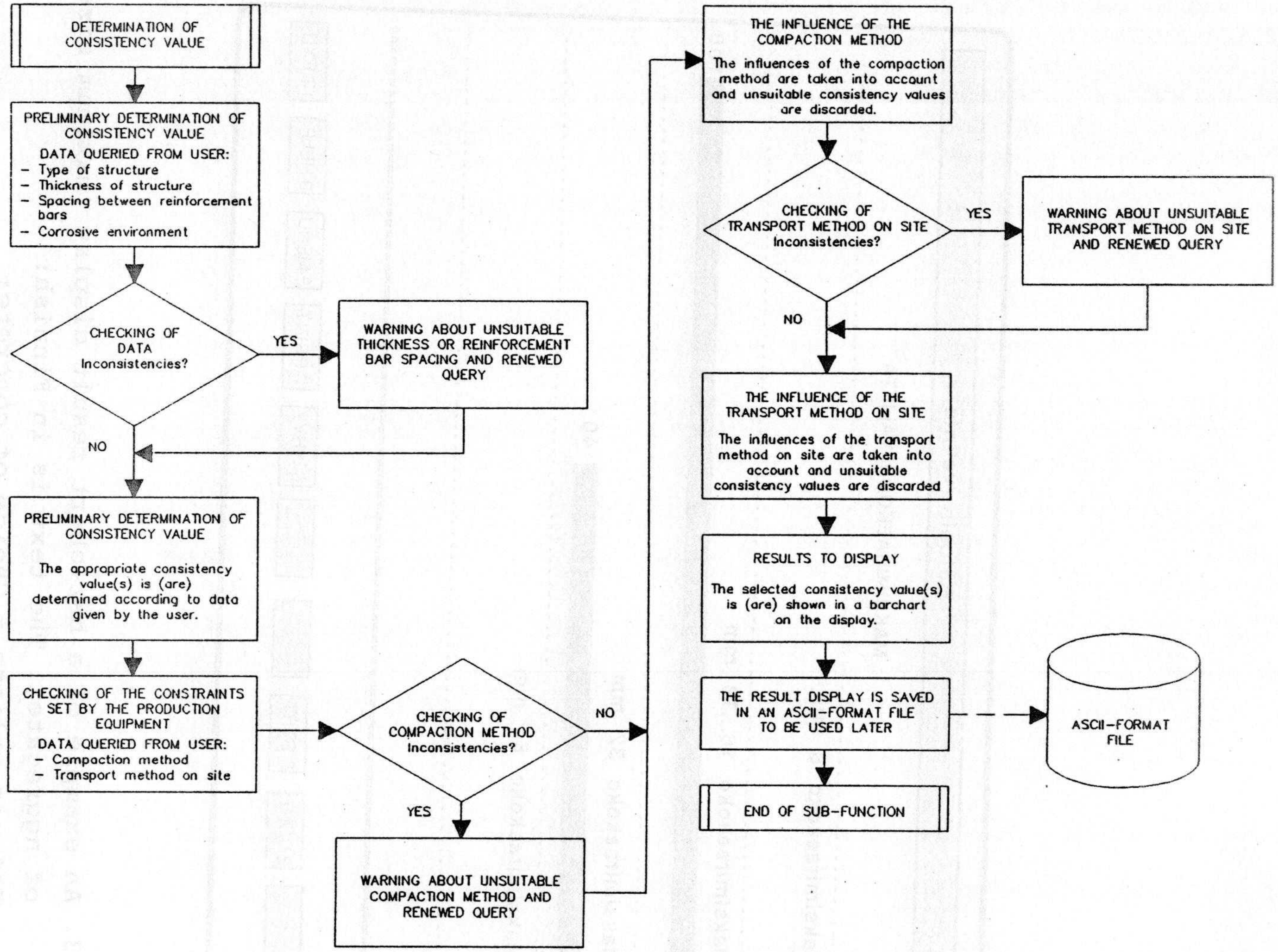

Fig. 2. The course of inference in determining the consistency value of ready mix concrete.

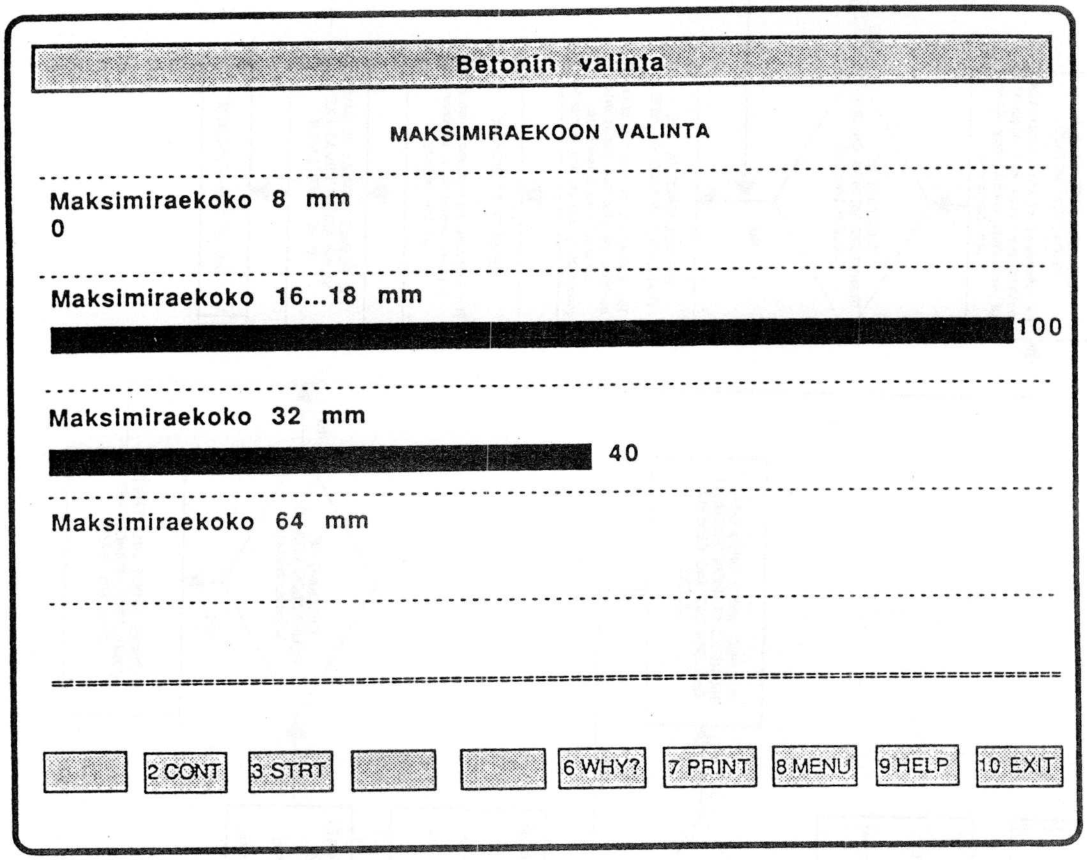

Fig. 3. An example of a bar-chart result display (maximum size of aggregate). The text is in Finnish:
Betonin valinta = Choice of concrete;
Maksimiraekoon valinta = Choice of maximum size of aggregate;
Maksimiraekoko = Maximum size of aggregate.

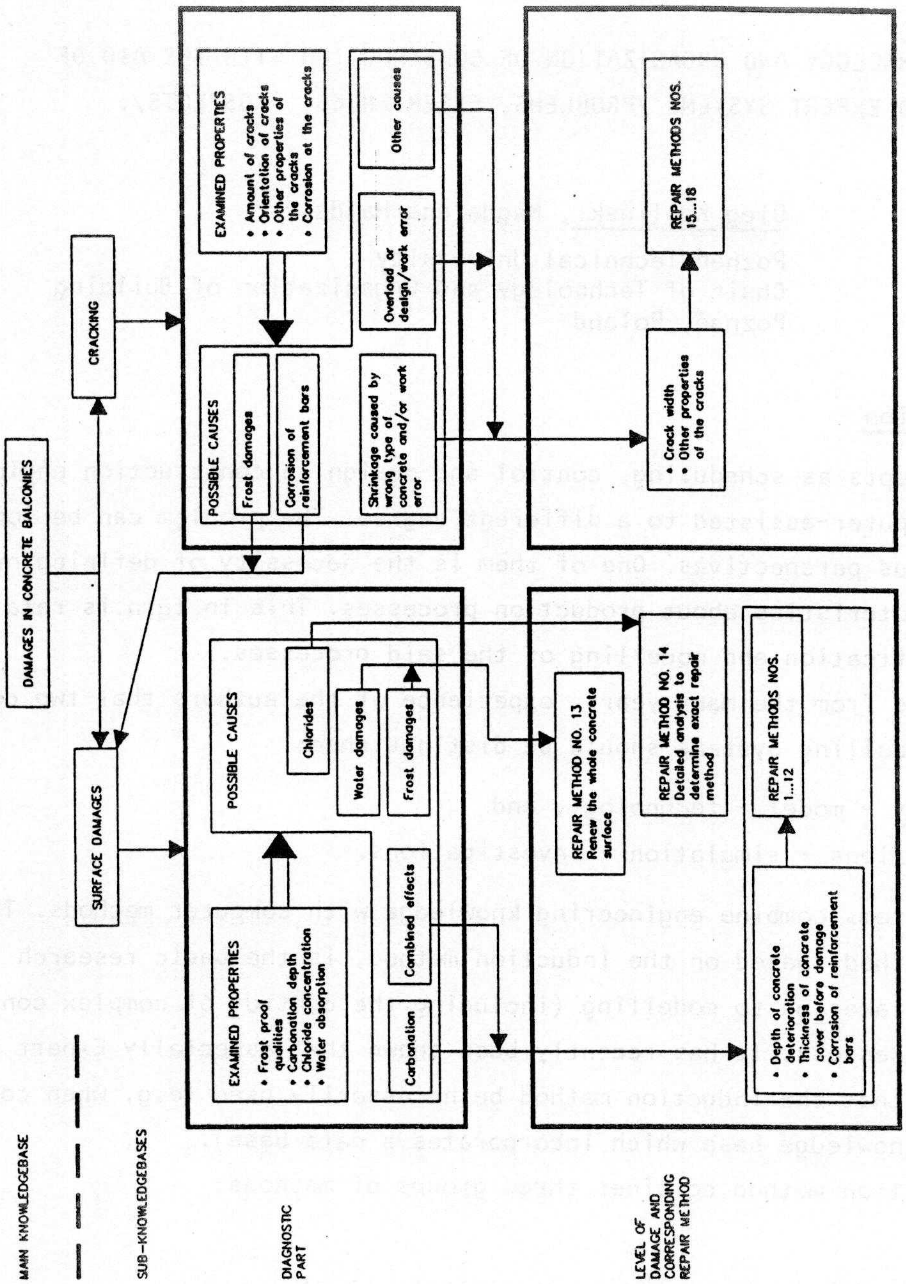

Fig. 4. General outline of the expert system for the repair of concrete balconies.