

## EXPERT SYSTEMS FOR CONSTRUCTION PROCESSES

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## EXPERT SYSTEMS FOR CONSTRUCTION PROCESSES

**O. Kapliński, E. Zavadskas**

### 1. Introduction

Knowledge based expert systems, or *expert systems* for short, have been evolving for over 15 years. These systems employ computers in ways that differ from conventional data processing applications.

An expert system (ES) is a knowledge-intensive program that solves problems which normally require human expertise. Moreover, it performs many secondary functions, as an expert does, such as asking relevant questions, explaining its reasons and the like. Expert systems allow for:

- manipulating and reasoning about symbolic descriptions,
- functioning with data containing errors, using uncertain judgmental rules,
- contemplating multiple, competing hypotheses simultaneously,
- justifying their conclusions.

A rule based expert system consists of three key parts: *inference engine*, collection of known facts called a *knowledge base*; collection of IF-THEN rules called a *rule base* and a *data base*. These are the basic expert system components that have been designed and implemented in a variety of ways. Sometimes specific design components are developed. Different integration of these components has led to various systems of architecture. A generalized model of ES to be used in construction is presented in [18, 41].

Proceedings of CIB symposiums are a good foundation for review of the first applications of ES in the construction process. The paper presented by A. WARSZAWSKI [37] is significant. Interesting results of a survey of 64 expert systems being used in industry or under development have been presented by A. GAARSLEV [5] (cf also [6]). Results of the symposium AICE in Oxford [34] are the next milestone in the presentation of developments and applications of ES in construction. Knowledge in this field has developed quite dynamically. Relations be-

tween expert systems and robotics are well described in [36].

Such notions as: construction of an expert system, an architecture of knowledge-based systems, a logical formalization of design processes, naive physical theory of design objects, coupled systems for expert computation, the incremental construction of large systems, inferencing strategies, weaknesses of expert systems are well described in the bibliography, also in the works of the authors' team - cf J. BRZEZIŃSKI [1, 2]. A review of ES applications in construction, state of the art and trends, is presented in our book - see: E.ZAVADSKAS et al [42].

Section 2 discusses the authors' and their team's experience in the modelling of construction processes through the application of expert systems. Special attention is paid to differences and difficulties encountered when attempting to apply expert systems to design process and to the technology, organization and management of construction. Similar difficulties are not encountered in expert systems applications in the design and selection of machine parts or in diagnostics. The basis of rules is of great importance and considerably determines the success of ES application in construction management. Thus, Section 2 focuses on two kinds of knowledge: micro- and macroknowledge. A discussion of these forms of knowledge follows a description of the research project and the building of an expert system. Section 3 criticises the "pure" expert systems approach. Instead, so-called hybrid expert systems are suggested.

### 2. A prototype expert system

#### 2.1. Expert systems application to the construction design of monolithic buildings

An expert system is a tool which can aid the design of technology and organization of construction and significantly increase engineering knowledge. An expert system was used to design the con-

struction of grain silos (cf the article by KAPLIŃSKI and HAJDASZ [13]). A number of silo batteries will be built in Poland and in Lithuania. For example, sets of several 9 and 16-chambered silo batteries were planned. Investigations of a few batteries presently under construction shows that the efficiency obtained is much lower than that envisaged due to faulty work organization. Moreover, a number of technological errors were made.

The silos are being constructed by the slip method. The apparatus consists of inside and outside slip forms. The forms are raised by hydraulic jacks fixed at each yoke which grip the jack rods. The machine moves at a fixed rate with all the equipment placed on the working platform and all working units under operation. The realization of monolithic works during different seasons of the year requires that an adequate technology and forms of organization be applied.

Component elements of the production system under discussion (henceforth referred to as objects) and relationships between them are shown in Fig 1. By objects are meant production resources (machines and equipment, work crews, and so on)

which are subject to the design as well as the object being manufactured (a set of silo units - batteries) whose parameters may be given or may be subject to design. Fig 1 also shows technical-construction and exploitation (basic and supplementary) parameters which characterize the objects. Figs 1-4 have been borrowed from the quoted article [13] and paper [12].

The purpose is to design an optimal set of objects (from among the many possible variants) taking into account one or a few of the criteria mentioned (for example, maximum efficiency, minimum realization time, minimum costs, minimum losses, maximum balancing etc) to make a project of the technology and organization of works for the adopted set. All parameters shown in Fig 1 are subject to the design.

Generally the problem lies in providing such resources that make possible the erection of walls at an optimal rate, as influenced by concrete casting time, all of which requires a complex mechanization of the work. Accordingly, the efficiency of machines and work crews should be adjusted to the slip movements.

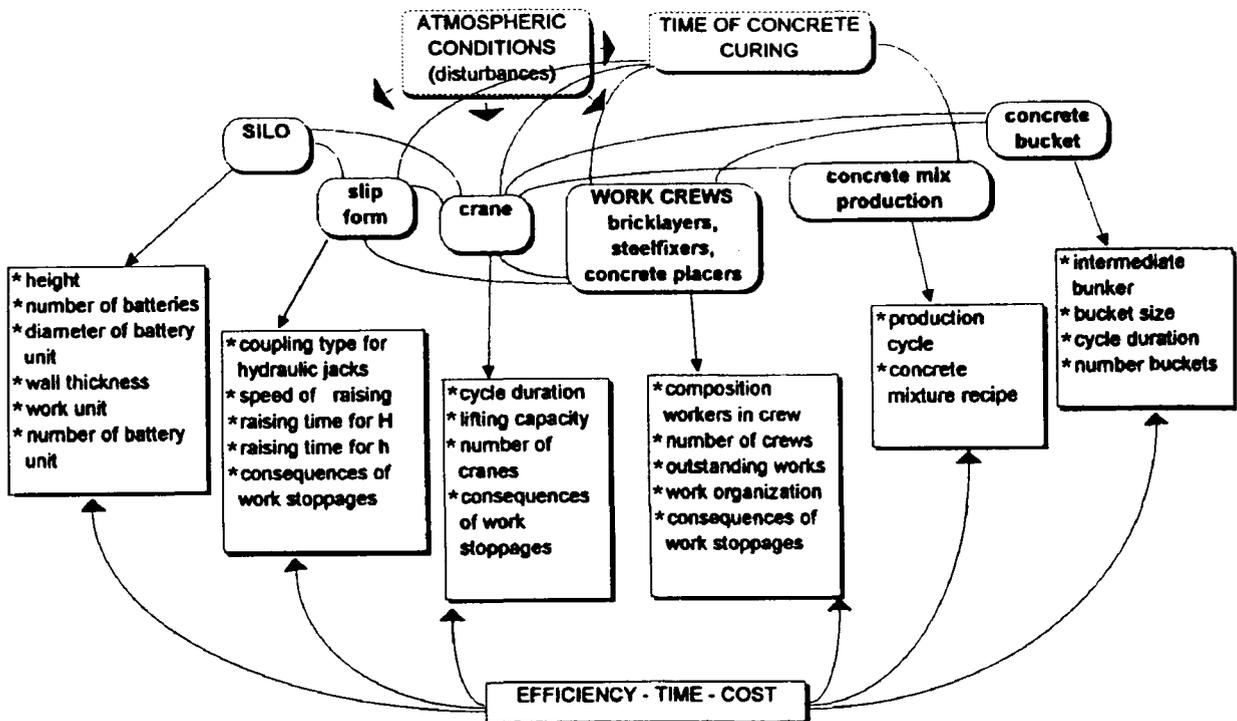


Fig 1. Production resources subject to design and parameters characterizing production resources, inclusive of efficiency-affecting relations

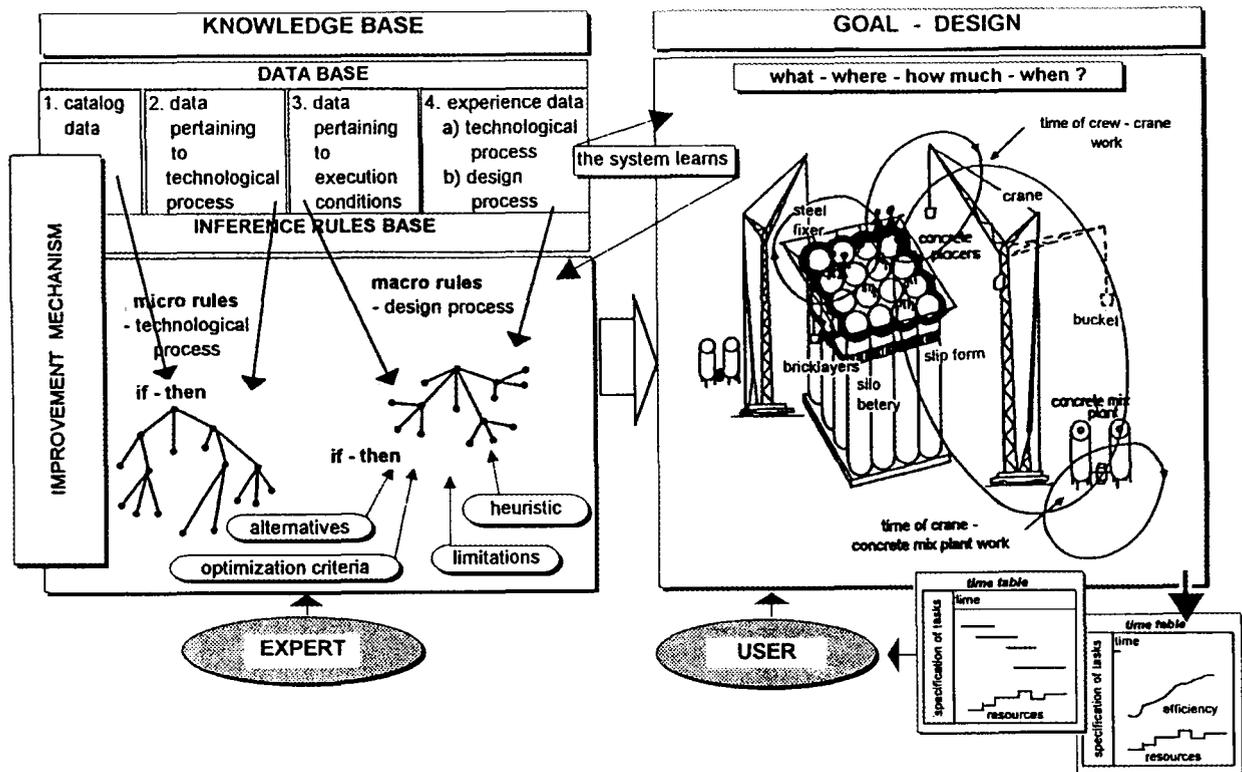


Fig 2. The basic structure of a prototype expert system

## 2.2. Building of the expert system

The prototypical expert system includes: a data base and an inference rule base which make up the system's knowledge base. The next stage of the research is to augment the system with mechanisms to verify existing inference rules and to generate new rules. A scheme for the ES is shown in Fig 2.

When constructing a knowledge base, a number of problems have to be solved and several questions answered. In the case in question, the data base contains knowledge of four kinds (cf left side and top of Fig 2). The knowledge contained in the fourth group, obtained directly from experts and practically not recorded anywhere, is particularly valuable. It comprises data obtained from experience:

a) on the technological process, including difficulties and experience gained during its realization from disruptions, time-keeping studies, deviations from standards (frequency, extent and effect), breakdowns, damages, and errors in operation;

b) on the design process, including alternative methods of design, the art of design by "designers of genius," comparison with similar projects, innovative design, errors of design, studies of completed buildings, and the designer's intuition.

The *inference rule base* includes all knowledge pertaining to technological and organizational conditions shown as a dendrite. Using it, relations holding between all objects (their parameters) of a complex production process have been established.

The expert system in question pertains to two aspects:

- #### the art of design, and
- #### the technology and organization of monolithic works.

Hence, it appeared necessary to distinguish a two rule base: a microrule base which describes the technological-organizational process and a macro-rule base which governs the design process.

### *Microrule base*

Microrules are the result of a detailed analysis of the technological process which takes into account organizational conditions (eg principles defining possibilities and consequences of cooperation between individual machines etc). Individual parameters subject to design can assume specific values from intervals from which it is possible to eliminate some of the values when relations holding between successive elements are taken into account. For example, a single concrete layer can be from 5

to 50 cm thick, yet, because of the vibrator's work (parameters), it must be restricted to 40 cm. A dendrite made of microrules eliminates some of the data from the database. Examples of microrules are the following:

**Example No 1:** if the thickness of a single concrete layer ( $h$ ) increases *and* the 24-hour efficiency ( $H_{24}$ ) remains constant, *then* the time during which the concrete mix is in the shuttering ( $T$ ) increases.

In short notation:

if  $h \uparrow$  and  $H_{24} = \text{const.}$ , then  $T \uparrow$ ,

**Example No 2:** if the height of the silo ( $H_{\text{sil}})$  rises *and* production resources (crews  $G$ ) are constant, *then* the crew's efficiency ( $E_g$ ) decreases.

In short notation:

if  $H_{\text{sil}} \uparrow$  and  $G = \text{const.}$ , then  $E_g \downarrow$ .

**Example No 3:** if the height of the silo ( $H_{\text{sil}})$  rises *and* the production resources (crane  $C$ ) are constant, *then* the realization cycle time ( $T_c$ ) increases and the 24-hour efficiency ( $H_{24}$ ) decreases.

In short notation:

if  $H_{\text{sil}} \uparrow$  and  $C = \text{const.}$ , then  $T_c \uparrow$  and  $H_{24} \downarrow$ .

In the course of building a microrules base, it became clear that there were many connections, dependencies, interfaces and even feedback links between parameters and objects which are shown in Fig 1. In this connection, the concept of so-called sheets was introduced. The relations, formulas, functions and even diagrams are on these sheets. Several dozen sheets were obtained. Exemplary sheets are shown in Figs 3 and 4. Interfaces and microrules, which are presented on the exemplary sheet (Fig 3), are the results of technological constraints (first block in Figure) (eg  $T$ ,  $g_h$ ,  $Q_H$ ,  $H$ ,  $h$ ) and structural conditions (eg  $S$ ,  $x$ ,  $H_{\text{sil}})$  where:

- $T$  - time at which concrete is in the shuttering,
- $g_h$  - content of concrete (function of a cycle duration of concrete placing) [ $\text{m}^3$ ],
- $Q_H$  - 24-hour efficiency (content of concrete mixture built-in during 24 hours) [ $\text{m}^3$ ],
- $H$  - height of silo ( thickness of concrete layer according to  $Q_H$ ),

- $h$  - thickness of a single concrete layer [cm.],
- $H_{\text{sil}}$  - height of silo/battery [m],
- $S$  - surface of building (one chamber of battery) [ $\text{m}^2$ ],
- $x$  - number of chambers.

The considerations presented on this sheet are also important to designers of building equipment. The diagrams presented in Figs 3 and 4 are, in fact, ideographs. The bottom of the diagrams (cf Fig 3) shows the next interface: from  $Q_H$  results  $H$  (in relation to  $S$ ).

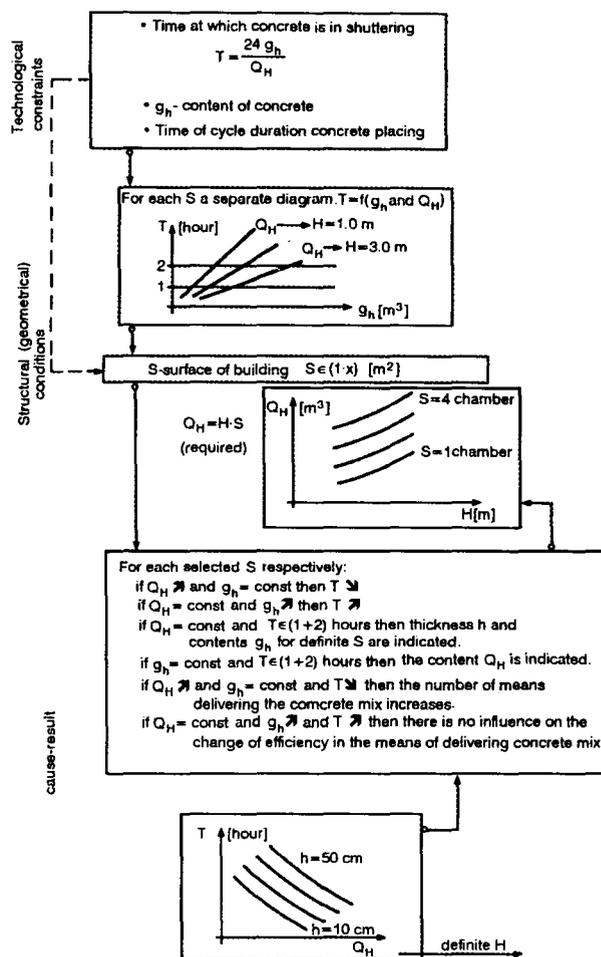


Fig 3. Exemplary sheet of interfaces and microrules

Fig 4 illustrates two ways of knowledge representation, ie as a function or in a tabular form.

### Macrorules base

Macrorules indicate the proper order and hierarchy of the realization of successive design steps, determine the order of extracting knowledge from the microrule base and provide guidance on how all

the information contained in the knowledge base may be used.

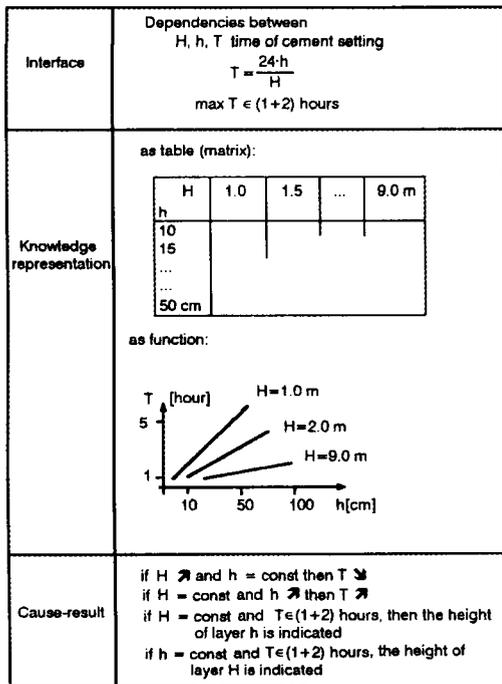


Fig 4. Exemplary interface and knowledge representation

The operation of macrorules is based on successive limitations which eliminate redundant information (factors). Four stages of reasoning have been distinguished. These are shown in Fig 5 and are now considered.

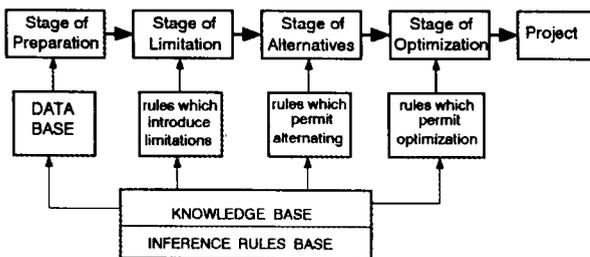


Fig 5. Four stages of operation of macrorules

#### a/ The Preparation Stage

The most significant exploitation parameters are shown in the same coordinate system (eg the efficiency of all elements of the system under design), and the types of machines, equipment etc, which can be applied, were specified.

#### b/ The Stage of Limitations

The rules which introduce the limitations are taken into account (generally described by the relation:

"if variants of production resources are prepared, then introduce the limitations"), eg

- the enterprise has only some types of machines and equipment at its disposal,
- the expert's experience indicates that applying specific types of machines is not practical; and
- conditions in a given area exclude ... etc.

#### c/ The Stage of Alternatives

The rules generally described by the relation:

"if variants of production resources are prepared and limitations taken into account, then consider rules which permit alternating sets of objects" are applied. The following problems are to be considered at this stage:

- is it possible to change the basic production resources during construction?
- is it possible to change auxiliary production resources?
- is it possible to change the composition and number of crews?
- can the slip form be rising during the performance of work by crews?
- is it possible to control the time of concrete curing?
- is a constant twenty-four hour efficiency required?

As a result, variants of solutions emerge, eg:

- A<sub>1</sub> - unalterable basic production resources and auxiliary production resources during the entire period of realization ### consequence: varying 24-hour efficiency, large losses of efficiency.
- A<sub>2</sub> - unalterable basic production resources, alterable auxiliary production resources ### consequence: varying 24-hour efficiency of the slip, decreased losses of efficiency.
- A<sub>3</sub> - alterable basic and auxiliary production resources ### consequence: stable or only insignificantly varying 24-hour efficiency, losses decreased to a minimum.
- A<sub>4</sub> - well-defined, indicated basic and auxiliary production resources ### consequence: varying efficiency, large losses.

#### d/ The Stage of Optimization

For particular variants of solutions the function of efficiency losses is defined, costs and time are included, the degree of the system's harmony is de-

terminated and an optimal solution chosen. Rules of this type are described by the general relation:

"if variants of object sets are known, then consider a rule which will permit making a choice".

In multicriteria tasks the ELECTRE III method is used - cf E.ZAVADSKAS [44].

This concept of four stages, which consists in successive limitations, is almost synonymous with G.NADLER'S *Ideal-Concept* [27].

The macrorule base is to be enriched in the near future by the verification (adjustment) mechanism. By means of this mechanism, inference rules will be verified and supplemented and facts whose occurrence in practice are unlikely will be eliminated.

As a result, an optimal technological and organizational design of work will be obtained (an optimal set of objects, situation plan, and a schedule illustrating the contribution of all outlays and production resources over time).

### 2.3. Remarks

1) The design problem of work technology and organization can be modelled and solved by means of ES. Due to the character of the ES application in design compared with earlier applications (such as in diagnostics) two kinds of rules should be included; microrules as relations which govern technological processes and macrorules which control the microrules. The so-called verification mechanism of inference rules also appears to be useful. A module pertaining to the varying realization conditions is often used.

2) Accordingly, ES can be used in other aspects, eg:

### ES permit not only the design of silos whose sizes are specified subject to a set of constructions on available resources, but also deal with the reverse problem, ie it is possible to investigate the maximum and minimum sizes of the silos in respect of performance capabilities by considering that the resources at one's disposal influence the technology of design,

### ES permit situations which can take place at the building site to be simulated and propose appropriate remedial measures.

3) It is possible to take into account the influence of stochastic elements on ES through the de-

termination of production parameters by means of simulators. Also, more attention should be paid to so-called combined methods including heuristic procedures. Combined methods link operational research with business games, case methods and training. All cases of modelling mentioned above (together with ES) can be used in participation simulation.

4) The object of the investigations, including the degree of the complexity of construction processes, their mechanization and recurrence are indispensable if the methods mentioned above are to be advantageous.

## 3. Hybrid expert systems in construction

### 3.1. Classical methods and hybrid expert systems

So-called hybrid expert systems are considered in this section. The importance of hybrid ES is derived from two basic premises [17, 18]:

Firstly, "pure" ES appear as academic solutions with a limited scope, particularly in practical applications of such construction. "Pure" ES are those systems built on a simple knowledge base and which do not include any additional external elements, eg, data bases, and do not interact with other applications.

Secondly, such practical methods as simulation, analytical methods (including operations research) have abundant theoretical literature and applications. For this reason, they cannot be neglected when ES are constructed as they are very useful in such problems as:

- optimization of production (including applications of multicriteria optimization),
- provision of numerical characteristics about modelled phenomena, which conditions production control and significantly enriches the "engineering knowledge", so important in ES.

The two premises, combined into one model, are shown in Fig 6. They form three basic levels of problem solution. Classical methods (simulation or operations research) constitute level 1. More sophisticated methods, the combined methods, constitute level 2. These are methods resulting from the combination of a few level 1 methods (models). In this case these are, for example, simulation-analytical methods and simulation-heuristic methods. They are described in [20]. They are particularly useful in the optimization control of production

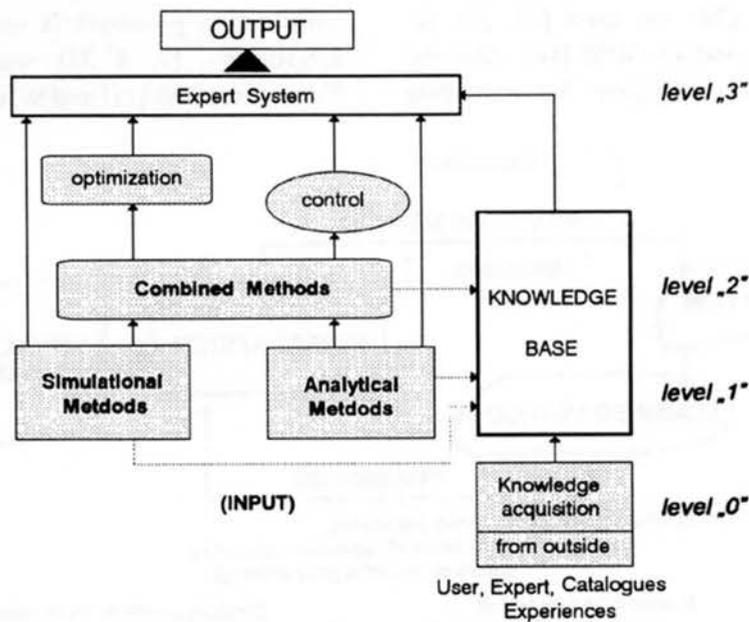


Fig 6. Interface between classical methods, combined methods and the expert system

processes. Level 2 methods are a hybrid combination. In this chapter, however, the concept of "hybrid" is reserved for inclusion of level 1 and 2 methods in the ES. The basic objective of level 1 and 2 methods is to provide information on production parameters of technological processes under analysis.

Generally the combined methods are those which result from the fusion of two or more classical methods (ie, simulations-analytical or simulations-heuristic methods). A hybrid expert system (Hybrid ES) is a system which takes into account at least one of the combined methods.

Lately, there have been many examples of integration of classical methods with expert systems. They are reviewed according to the applied method:

- network planning methods:
  - ### for construction planning and scheduling (O.MOSELHI and J.NICHOLAS [26]),
  - ### for construction project monitoring (A.MCGARTLAND and C.T.HENDRICKSON [25]),
  - ### for planning a construction operation (T.P.WILLIAMS and R.KANGARI [38]),
  - ### for project network generation (D.NAVINCHANDRA et al [28]),
  - ### for project management (W.N.HOSLEY [9]), (R.E.LEVITT et al [24]),
- fuzzy theory and fuzzy logic reasoning - for network resource allocation under uncertainty conditions (T.C.CHANG et al [4]),

- simulation (R.R.LEVARY and Y.C.LIN [23]), (K.CHAHARBAGHI et al [3]), (A.TOURAN [35]),
- CAD techniques for aiding the design process by monitoring and refining design decisions (D.JAIN and M.L.MAHER [11]),
- operational research methods (R.M.O'KEEFE et al [29]).

This direction of ES development in the field of construction engineering and management was forecasted by C.W.IBBS [10].

The approach presented in Fig 7 depicts how it is possible to use a special procedure for modelling production processes in the construction industry. The organizing method, based on the inductive method, is the basic research method which takes us to modelling (including the control of complex construction processes). Expert systems particularly require the use of the inductive method (eg in constructing a knowledge base which incorporates a data base).

As follows from Fig 7, the inductive method combines three groups of methods: simulation, combined methods and ES. Heuristic rules link combined methods with ES.

### 3.2. Combined methods in the expert system

The combined methods mentioned above proved, in many cases, to be more adequate than classical methods such as operations research and digital simulation. However, in both types of cases of combined methods mentioned below, two simula-

tors programmed in CSL are used [31, 32], ie "CIBU" and "FAZA", and in GPSS [14]. Also the MicroCyclone simulator designed for modelling

construction processes is used, cf D.HALPIN and L.S.RIGGS [7, 8 33] and our applications - T.KOMOROWSKI [21] and W.KORPIK [22].

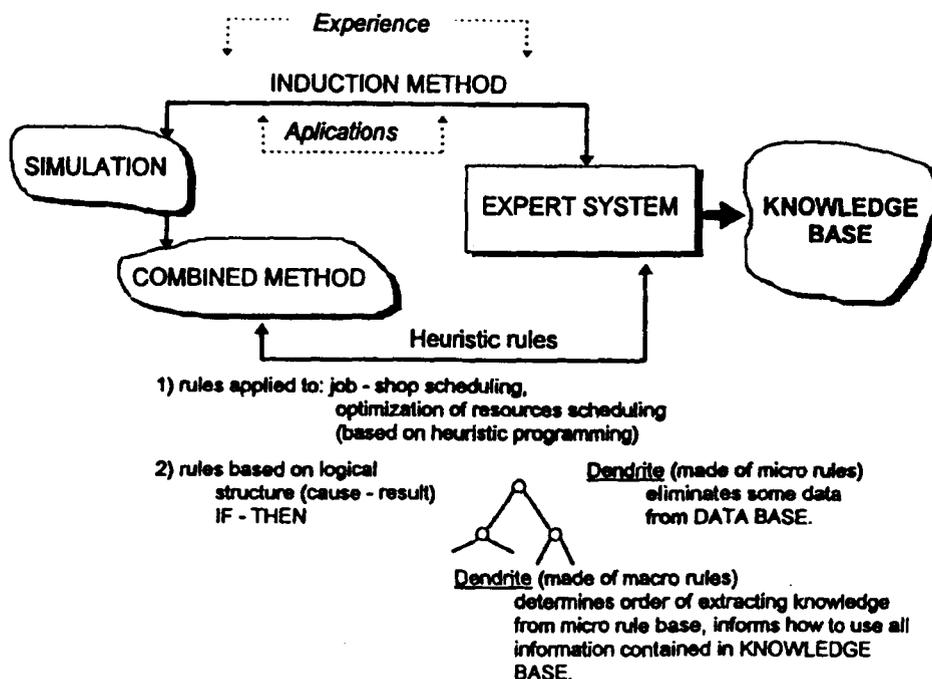


Fig 7. The significance of induction in ES for construction

In the simulation-analytical approach, the "CIBU" simulator is used to define production parameters of processes represented by means of any network of service channels. It is used to investigate the efficiency of asynchronous production lines under stochastic conditions. An elementary module of the program is shown in Fig 8. Using these modules, it is possible to build a service network [31, 32].

The simulator is used to define the most probable efficiency of the production system at different periods. Parameters of the structure of production

processes and the variables and parameters of production are fed to the simulator as input data. The relation between them is expressed by an equation representing the conditions of the production system at time  $t$ . Next, with the help of the "branch and bound" algorithm, the control task may be solved. Using discretization and integer programming, the method can be applied to a current control of the production line. The minimization of costs (added to production scheduling) is most often the criterion of control.

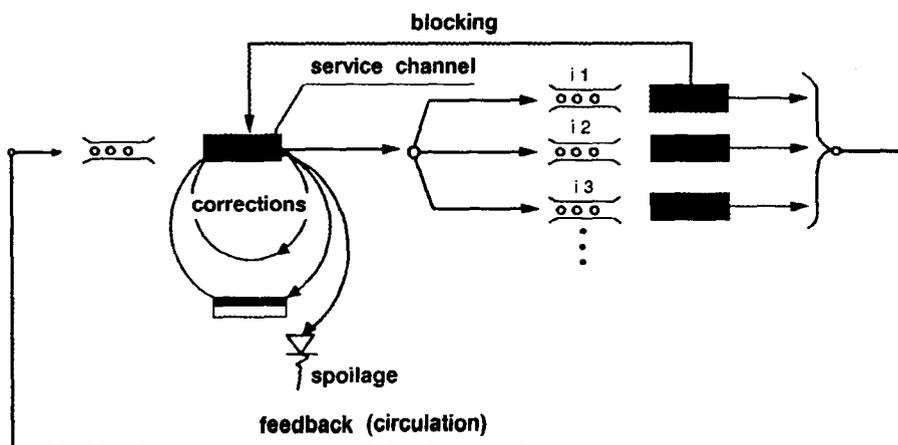


Fig 8. An elementary module of the production system

An integration of a simulator of that type with ES provides the following abilities:

### knowledge acquisition, in this - provision of numerical characteristics about the modelled object or phenomenon,

### control and optimization of production.

The simulation-heuristic method was invented for evaluating and controlling the reliability of any production system. The investigation methodology is based on the decomposition and synthesis of the reliability structure of the entire system as well as on an atypical measure used to evaluate reliability (a distribution of time at which the system works properly). For this purpose two simulators ("FAZA" and "GPSS") were constructed. Examples of reliability analysis are presented in [16, 19]. These simulators use the model with the series structure, but each phase possesses alternative sub-structures.

The simulators are used to control reliability (maintain it at a specified level), most often by means of so-called reserves. When optimization and control are combined, it suffices to find such a number of reserve elements (in a specified phase of the system) which will guarantee the desired level of reliability at minimal costs accrued due to the formation of reserve elements. A linear and integer model is, thus, obtained. Since it is very labour-consuming and expensive to determine the reliability of a system and the total cost of reserve formation for the entire set of solutions possible by means of simulation experiments, in order to find a solution, a heuristic rule is applied [32]:

$$h_k(X) = \mu \xi h(X_i) = \frac{R_i(X_i + 1) - R_i(X_i)}{C_i R_i(X_i)}, \quad 1 \leq i \leq n$$

where:

$R_i(X_i)$  - phase reliability before the inclusion of the reserve system,

$R_i(X_i + 1)$  - phase reliability after the inclusion of the reserve element,

$k$  - phase number for which function  $h_i(X_i)$  assumes a maximal value.

$C_i$  - cost of one reserve element in the  $i$ -th phase.

In accordance with this rule, a reserve element is included in the  $k$ -th phase.

The method mentioned above, concerning the application of the reserve (or adequate redundancy) is one of the methods of reliability control. Of course, it is possible to apply the so-called inertia method. The interpretation of inertia as a phenomenon is described in [14, 39].

### 3.3. An example of an integration of the simulator "FAZA" with ES

The procedure of the investigation and evaluation of production parameters is expanded, namely, it is used as an element of expert systems. The idea of such an approach is shown in Fig 9. The "FAZA" simulator here is the example of our consideration. Irrespective of expert system applications, it is very important to build a data bank and a set of experiences pertaining to functional structures and their mapping onto the reliability structures and to collect information on the kinds of work time and downtime distribution for each phase which represent not only failures, but also the quality of a crew's work, machines, shortage of materials, personnel, organizational deficiencies, etc.

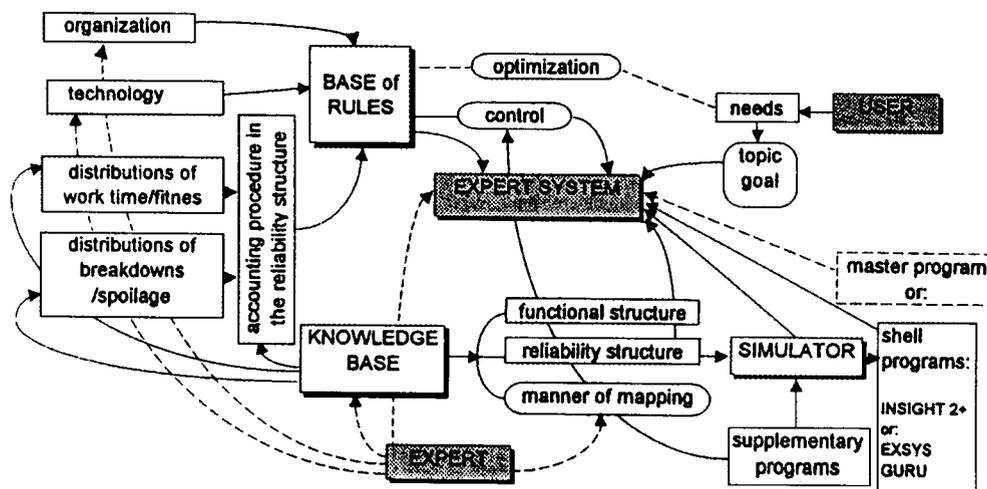


Fig 9. Example of simulation in ES

Combined methods are integrated with ES not only through simulators, but through interaction with the "shell" program, as well. One example is the GURU shell program, which permits the incorporation of a fuzzy sets theory and fuzzy logic reasoning in the expert system (cf R.N.PALMER and B.W.MAR [30]). Simulation modelling can be integrated with expert systems at different levels for many purposes, eg for decision-making during simulation, for analyzing the results, for debugging models.

Four kinds of "shell" programs have been used in this research. Micro-Expert was used for a choice of building machines on the building site (eg assembly cranes). Earth moving problems (chiefly in education) and construction of sewage system in rural areas are solved by means of Micro-Expert and INSIGHT 2+. After one failure in the application of INSIGHT 2+ and EXSYS, we have preferred the GURU program.

### 3.4. Micro- and macrorules in hybrid ES and optimization problem

The realization of a battery of grain silos in monolithic technology (the slip method, see section 2) is one of the examples of the application of ES to construction. It was necessary to design such resources that it would be possible to build walls at optimal speed, constrained by the time of concrete setting. This required complex mechanization of the work (the efficiency of machines and work crews adjusting to the slip's advance).

Several hundred microrules were identified.

Knowledge representation was possible in two ways:

- ### through the definition of the dependence function (technology, efficiency of machines and people, etc),
- ### in the discrete (tabular) form, when it was impossible to define the functions in the manner described above.

Examples of microrules (of constructing a grain silo - the slip method) are presented in two papers by O. KAPLIŃSKI and M. HAJDASZ [12, 13]. Apart from that, the rules for the choice of technology (monolithic or prefabricated) for silo construction are presented by J.BRZEZIŃSKI [1, 2].

The identification of macro (meta) rules in hybrid ES was very useful. Microrules control the construction process, whereas macrorules control the design (planning) process:

- ### indicate the proper order and hierarchy of the realization of successive design (planning) steps,
- ### determine the order of extracting knowledge from the microrules base,
- ### inform how to use all the information contained in the knowledge base.

The operation of macrorules is based on successive limitations which eliminate redundant information (factors). Four stages of reasoning have been distinguished and described in section 2. These stages and the names of sets of rules which start macrorules are shown essentially in [13].

The operation of macrorules can be additionally explained with the help of Fig 10. The Figure shows the concepts of the analysis of "losses" in the output of a concrete mix plant (*CMP*), (losses 1.) and the working crew (*G*), (losses 2.) depending on the height of the silo ( $H_{silo}$ ) and the lack of balance between parameters of particular control objects. This is an example of a successive consideration of limitations which eliminates redundant information and the influences of various factors. In this case, it is one fragment of a range of results obtained at the stage of alternatives. The following steps of the diagram in Fig 10 correspond to successive stages of the influence of macro rules.

At stage 1 we get two axes,  $H_{silo}$  and  $Q_H$  and a number of variants for lines *CMP*, *G* and *C*. After the introduction of limitations (stage 2) for the line (ie output) of each object (*CMP*, *G* or *C*) one or two lines are selected (eg top and bottom limits) for a given variant of objects. We get a number of variants, and next, having introduced rules which permit optimization, we select the best variant from among different variants of operation, many relations between objects etc. Although these variants are different as regards their contents and dependencies between objects, yet, a common system of coordinate axes remains, in this case that of  $H_{silo}$  and  $Q_H$ .

Obviously, the stages shown in Fig 10 require formulation in accordance with IF -THEN rules.

Optimization, for example, in respect of the selection of the best variant of a machinery set, working crews, etc can be made by "traditional" methods within the framework of operations research. We have successfully employed elements of multicriteria optimization. This is used to evaluate

dendrites of solutions, dendrites of limitations and, primarily, dendrites of variants and the influence of micro- and macrorules. Initially, we used the ENTROPY method. Today we prefer the ELECTRE III method which allows for a better evaluation of differences between variants and for a sensitivity analysis of results - cf E.ZAVADSKAS et al [40, 41, 43, 44]. A detailed description of sensitivity analysis is given in [15]. The methods require improvement which should follow two paths:

- ### increase (provision) of objectivity of introduced parameters, features and evaluations;
- ### universality of the method's application - greater accessibility in a computer program, automatic influence on the base of micro- and macrorules, potential for direct evaluation of the variant selected by a decision maker (in respect of construction engineering and management).

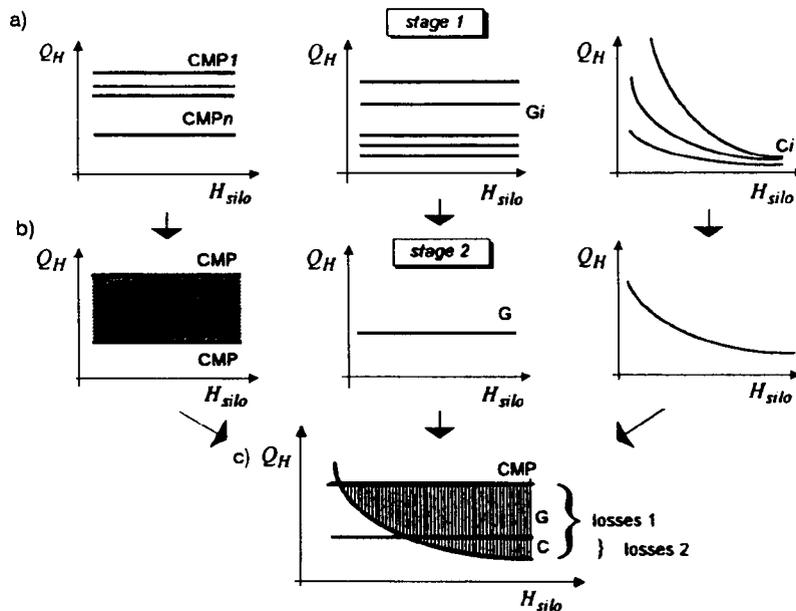


Fig 10. Exemplary operation of macrorules: a) preparations, b) limitations, c) stage of alternatives (fragment); C - efficiency of a crane CMP - efficiency of a concrete mix plant G - efficiency of work crew.

#### 4. Conclusions

ES technology is constantly developing; however, it is predicted that so-called "pure" ES will have a limited scope in its applications in construction management.

It is possible to account for the influence of stochastic elements on ES through the determination of production parameters by means of simulators. This means that Hybrid Expert Systems are very profitable and almost essential in expert systems relative to Risk Management.

There is urgent need to show the operation of hybrid methods in network methods (project planning) to increase the practicability of ES and to satisfy engineers from the construction management field. We are presently working on Hybrid ES, incorporating network planning and a cost estimating system (database) for construction planning. The aim is to use the network model, created directly on

the basis of cubing, within planning. This system will consist of three parts (cf Fig 11):

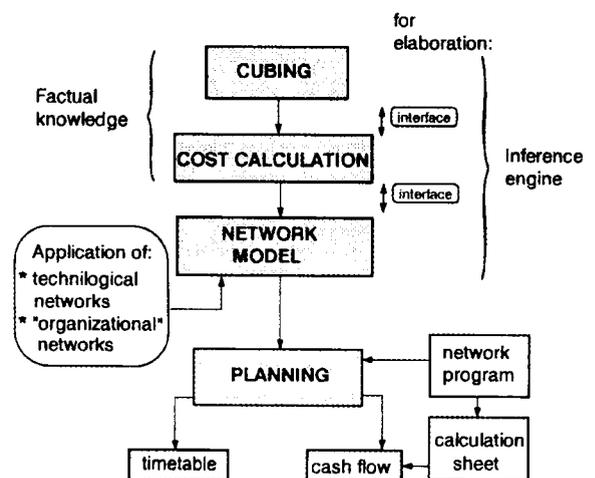


Fig 11. A scheduled decision-making expert system directly based on cubing

- cost estimating system,
- project planning system,
- expert system.

This should advance and simplify the planning process, which is of great practical significance to construction engineers.

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- suose, analizė atliekama ekspertinės sistemos, panaudotos monolitinės statybos technologijoje, pavyzdžiu.
- Antra straipsnio dalis remiasi teze, kad "grynų ekspertinių sistemų taikymų apimtis, ypatingai naudojamų statybos pramonėje, bus ribota. Todėl praktikoje naudoti siūloma vadinamąsias hibridines ekspertines sistemas. Straipsnyje šioms problemoms spręsti siūlomi trys problemų sprendimų lygiai: klasikinių metodų lygis, kombinuotų metodų lygis ir hibridinių ekspertinių sistemų lygis. Kombinuoti metodai yra dviejų arba daugiau klasikinių metodų lydinys. Hibridinė ekspertinė sistema turi mažiausiai vieno kombinuoto metodo elementus.

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## **EKSPERTINĖS SISTEMOS, NAUDOJAMOS STATYBOS PROCESUOSE**

**O. Kapliński, E. Zavadskas**

### **S a n t r a u k a**

Šiame straipsnyje analizuojamos ekspertinės sistemos. Pirmoje straipsnio dalyje nagrinėjamas ekspertinių sistemų naudojimas projektuojant statybos procesus. Dvi žinių rūšys yra būdingos ekspertinės sistemos struktūrai: mikrožinios ir makrožinios. Mikrožinios remiasi statybos technologijos principais, makrožinios - projektavimo menu. Straipsnyje ekspertinių sistemų, naudojamų statybos proce-