The purpose of the present work is to develop an expert scheduling system for producing ferrocement elements. The system is able to encapsulate some of the expertise used by planners in manufacturing environment. The knowledge acquisition process involves both the elicitation of knowledge directly from experts, and the analysis of reports from ferrocement factories. An application of the expert scheduling system is presented in order to verify its uses and to identify its principal difficulties and limitations. The model was implemented on an expert system shell called KAPPA Level 2.0, which runs in any standard IBM-PC micro-computer or compatible hardware. The evaluation of the system focused on the validity of the model, i.e. the degree at which the outcomes of the system resembled the outcomes of the human expertise being modelled in the knowledge base.

1. INTRODUCTION
The expert system developed in this study, in addition to the main objective, which is to minimize the production time of ferrocement elements used in civil construction, also aims at offering support to the technicians involved in the decision-making process and to the production administrators, who are the ultimate users of the system.

A further objective is to disseminate the technology used in Brazil in order to manufacture on an industrial scale the ferrocement components utilized for the construction of educational centers. This technology is not yet completely mastered or widely known, although it is very much utilized in building schools and public health centers. However, its application may also be advantageous for other kinds of construction.

2. ARTIFICIAL INTELLIGENCE IN PRODUCTION PROGRAMMING

Artificial intelligence is the part of computer sciences linked to the project of intelligent computer programs, i.e. systems that show characteristics that we usually associate with intelligence in human behavior (language comprehension, learning, reasoning, problem solving, etc.)

There are several different areas of artificial intelligence, such as: engineering of knowledge, pattern recognition, language processing and robotics.

Production planning and programming have been research areas in artificial intelligence over the last twenty years. The first systems focused on the plans to be carried out by robots. Subsequently more ambitious systems have incorporated the development of other areas in artificial intelligence. Conceptions through expert systems have especially influenced the development of many programs based on concepts of artificial intelligence. Some expert systems have been successful, when applied to manufactured products.

A expert system is a computer system that models human knowledge of a particular domain and is capable of making intelligent decisions within that domain. This is usually done by applying a set of facts so as to imitate the thought processes of a human expert in order to reach conclusions or make decisions.

The formalisms utilized for the representation of knowledge are frames and rules of production. Frames are utilized in the representation of objects and
concepts through a set of attributes and operators. Each object is associated with a name and a series of attributes or slots with their respective values.

The rules of production specify actions that are expected to occur in certain situations. These rules, as computational elements, must adequately represent the knowledge involved within the reasoning that is being simulated in the system. The rule is executed only when any one of the data of the problem coincides with the conditions for the application of the rule found in its predecessor, inasmuch as the rules form a chain. This chaining process may either move forward or backward.

3. PRODUCTION OF PRE-MOLDED FERROCEMENT COMPONENTS

The production of ferrocement involves a process that combines sand, cement and steel screening, resulting in thin and light elements, whose technology began to be developed towards the end of the nineteenth century. Ferrocement can be considered a special kind of reinforced concrete, composed specifically of cement mortar, joined together in small quantities and a diffused framework consisting of steel screening, with a small-opening mesh, distributed over the whole cross-section of the element. It was first manufactured by Joseph Lambot in 1848. It now has a place in building manuals, through the studies of Pier Luigi Nervi, the due to its clear superiority to the rest of the structural concrete family.

Pre-molded ferrocement elements are often utilized in metallic molds. Although there are other materials that may be utilized, metallic molds are more frequently utilized for this type of element. The molds are of a double type, involving a great deal of surface exposure of ferrocement elements.

In civil construction there is a concrete problem to be analyzed, namely the utilization of ferrocement on an industrial scale for the construction of educational centers and housing in a short time and at a low cost. Ferrocement technology, in turn, is not yet completely mastered, since there are still various technological problems in the programming of the manufacturing processes of pre-molded elements, so that it is necessary to make this technology available to several different companies in all regions of Brazil. Thus, this research has permitted the development of an expert system, that has the possibility of
acquiring the knowledge available for the industrial programming of this technology, so as to contribute to the modernization of Brazil.

The experts whose knowledge was modeled for this system, are production and civil engineers, since the former are responsible for production programming and the latter have the knowledge regarding the work project and the preparation of ferrocement.

The work project, in this case the building of educational centers, is what determines the number and the priority of premolded ferrocement elements to be manufactured. In this case, it is the number of educational centers to be constructed in a given period of time that is considered. The preparation of ferrocement, through its various processes, determines the restrictions in labor, raw material, equipment, duration of activities, transportation, etc., which are determining factors for optimized production programming. Besides these factors, other bottlenecks exist, such as, the optimization of the cutting of the screens, their double binding and number of spacers they have.

The process of producing these elements becomes more complex, inasmuch as the pre-molded elements have differences in dimensions, in the volume of ferrocement, in the framework, in the number of man/hours, in the molding and in the removal from the mold.

Figure 1 shows the general scheme of Ferrocement Production Process.
4. THE EXPERT SYSTEM

In the work we have carried out, the guidelines followed for the development of expert systems are those presented by Waterman 6, and are divided into five stages:

(1). **Identification of the problem:** In this stage, the scope of the problem is defined, so as to clearly determine the objectives of the system to be developed.
(2). **Definition of concepts**: The concepts and relations to be utilized in the system are defined in this stage. Here, there is also a definition of the functions utilized to acquire knowledge for the system.

(3). **Formalization of concepts and relations**: In this stage a formal description is made of the fundamental concepts and their relations, through frames and rules of production.

(4). **Implementation of the system**: All of the concepts and relations previously defined are now implemented and both the data structure to be utilized and the control structures are formalized. During this phase there is an integration of all knowledge into a single structure, since information gathering to constitute a basis for knowledge, occurs in a fragmentary form, until reaching its final objective.

(5). **Validation test for the system**: In this final stage, tests are made to verify the efficiency of the system, utilizing a real situation. For testing purposes, a project was chosen, that has all the characteristics defined in previous stages, so that the system might be applied. In this case the validity of the system is determined by the degree to which the plans produced by the system are similar to those carried out by an expert.

After the evaluation of the basic problem through a rapid prototype, the complete model was elaborated and extended. This process was simplified by the structure of the object.

The system is composed of four main phases of operation:

(1) **configuration** - This is a phase of building the production model, in which the objects, the frames, the functions and the methods are assembled and the rules of production are developed;

(2) **initialization** - In this phase the attributes of the objects and of the lists that store the programmings by period, are given their initial values, preparing them for the formation of system plans;
(3) production programming - Here the production plan is made for a given period of time, in this case up to 28 days; and

(4) production maintenance - In this phase real production is compared with the programming obtained by the system, shown by a comparative graph for each element produced.

The system is composed of the four following modules:

(1) Initialization Module - In the first module, the procedures that initialize the information contained in the system get under way. At this point information is supplied regarding the number of elements to be manufactured within the parameters of ideal efficiency for this process. This module receives information that enables the system to calculate the yield for the remaining modules. Here lists are utilized to store the necessary information for production programming for a pre-established period, according to production needs.

(2) Framework Module - This module covers the whole production planning for frameworks, beginning with the activity of cutting the screens. In this module, through procedures followed by technicians in ferrocement factories and modeled for the system, it is possible to obtain the programming for daily production, as well as for a 28-day period, and finally various graphs in which the comparison is established between the programming and the actual production of the frameworks for the elements.

(3) Molding Module - After programming the cutting activity, all the procedures that lead to the production of ferrocement are considered. The ferrocement is then to be joined to the framework, to obtain each pre-molded element. This module considers all the intermediary procedures until obtaining the elements that should be ready to be transported to the first treatment tank. In this module all the procedures are also considered which comprise the processes of the first and second treatment, the duration of these activities, and the transportation of the elements until they pass through the second treatment.
tank and proceed to the quality control division. In this case, it is possible to obtain the daily programming of ferrocement elements, the programming of these elements for a 28-day period and various graphs showing the comparative control between the programming and the results obtained for pre-molded elements.

(4) Quality Control Module - In this last module all the procedures followed from the treatment phase up to quality control, as well as the subsequent release of the elements for stock or shipment, are brought together. It comprises the final procedures and also presents the daily programming of the elements that are to arrive at the quality control sector. It shows the programming for a 28-day period, considering the production of the framework and the ferrocement of the two previously described modules and receives the information about the elements sent to quality control, providing several comparative graphs between the elements that reach quality control and their subsequent release.

The expert system we have developed was submitted to a series of tests and was shown to be suitable to the various situations studied. Specifically the system was tested in cases that showed special characteristics, in terms of the result itself, that is, cases in which the result to be obtained by the system was known beforehand, through the information in control reports. In those cases where the system was applied to known situations, with real data, extracted from the production processes under study, the result obtained was the same as the expected one.

Through the results obtained in the application of the expert system, access can be gained to a series of complementary procedures, making it possible to attain near-optimization in sequencing. These actions are determined by the results obtained in the various processes of the system and, through their interaction with the shop floor, yield important data for highlighting the production process or correcting incidental faults.

The system constitutes a very important aid in decision-making. Comparative tests between factory reports of the production that have already been obtained and the plans created by the system, show clear advantages for the latter, mainly when the programming is over a period of two weeks, inasmuch as they result in a better distribution of resources during the period and a better utilization of the resources in relation to production bottlenecks.
4. 1. The Organization of Frames

The system that was developed has an important part of its knowledge base represented by frames, that comprise the objects and have slots that contain the values utilized in the system processing.

Figure 2 shows the class editor of the object 'FRS' and the configuration of attributes that make up the frame of this object.
Figure 2 - Editor of the Object 'FRS' and Its Frame

4.2. The Use of Lists

Figure 3 shows an example of the list-type slot, in which values can be stored. In this figure there appear within the active window, the first rules that are chained forward and offer consultations regarding the Molding Module in the complete form, that is, for all the pre-molded parts manufactured.

All the programming for a 28-day period is stored in the lists. This type of procedure was aimed at making it easier to handle values in the system.
Figure 3 - Editor of List-Type Slot

4.3. Organization of Knowledge

The knowledge base contains a hierarchic structure where the frames of the preceding objects are inherited by their successors. However, the value of each slot can vary in the whole chain of objects.

An example of this hierarchy is shown in Figure 4, where part of the knowledge structure referring to the individual parts produced by the factory can be seen. The groups are divided according to types, and the parts are represented by their respective codes, according to the factory catalogue.
Another part of the system is composed of a group of objects that control the application screens, created for each specific case. In this group there is storage of all the information regarding the location and size of the pictures and graphs for presenting the information in system consultations.

The other two groups of objects are called List and Global and contain information regarding programming for a period of up to 28 days as well as the values needed for drawing up the graphs that provide a comparison between the programmed and the obtained results.

5. RESULTS OBTAINED

It is important to show a comparison between the result obtained in the application of the system to the problem under study, and the result found currently in the everyday routine of an industry that manufactures pre-molded parts of ferrocement in a series.

This comparison is made possible by examining the production control reports and comparing them with the results of the system. Since the
programming in the factory in not documented at present, it is drawn up for the current period and does not extend for longer periods, unlike the system worked out in this study, that considers the production programming for a period of up to 28 days.

The program utilizes 471 functions and 170 rules to obtain the production programming.

The data available are based on information from the factory, obtained over the period studied, with the aim of getting a comparative picture.

In the case of the example- information on parts already assembled- it is an estimate and is based on control reports from the factory.

According to the graphs shown in Figures 5 & 6, the programming obtained by the system provides a better utilization of the resources available, through a more balanced allocation of these resources. Since factories of pre-molded ferrocement parts at present do not follow a previously established programming, plans are drawn up for the period itself, based on what is in stock and the number of parts needed to complete the order.

Figure 5 shows a graph for the period analyzed, drawn up according to the plans of experts from the factory. Discontinuity in the use of resources is shown in this graph.

Figure 6 presents a graph, with the aim of drawing a comparison. This graph was obtained by the expert system. Continuity in the use of resources is shown in this graph. These resources are used for a two-week programming period.
Figure 5 - Graph on the Level of Utilization of Man-Hour Resources, for the Programming Elaborated by a Factory for the Manufacture of Frameworks
6. ADVANTAGES OBTAINED THROUGH THE APPLICATION OF THE SYSTEM

The application of the system, presented in this paper, has made it possible to find a more economical production programming for the manufacture of parts for a building project in educational centers, allowing for the production of a greater number of parts in a shorter period of time, and with a fairly regular resource distribution during the manufacture of the parts needed for the construction of one or many educational centers.

The excessive and uncontrolled use of resources during the production period of ferrocement, in current factory processes, causes frequent delays in carrying out requests, causing damages and other problems. Nevertheless, this situation occurs continuously in industries of pre-molded parts, that do not avail themselves of the production systemization process. The results obtained by the expert system are also useful for eliminating this kind of delay.

Figure 6 - Graph on the Level of Utilization of Man-Hour Resources, for the Programming of the Manufacture of Frameworks, Obtained by the Expert System.
For programming the production of frameworks, good results were obtained by the system, reaffirming the efficiency of the systematization of molding procedures and leading to their subsequent inclusion in a knowledge base for the production programming of pre-molded parts for use in civil construction.

7. CONSULTATION SCREENS

The interaction between the system and the user is carried out through consultation screens, created for this purpose. These screens are denominated “sessions”, and three different sessions were worked out.

In drawing up these screens the first factor considered was that of a greater rapport between the user and the system’s consultation screens and then a more effective implementation of the resources of the computational tool utilized.

Figure 7 presents a screen with the results of a system consultation session. It concerns the production programming of frameworks for a period of 14 days.
**Figure 7 - Programming of Frameworks for a Period**

The system offers a comparative graph for all the parts, available to the user in his consultation sessions. The part is chosen in the square of options, as shown in Figure 8.
8. CONCLUSIONS

The expert system is an important resource in decision-making. The comparative tests that were made between the factory reports of production already obtained and the plans created by the system, point to advantages for the latter, mainly regarding programming for a two-week period, favoring a better distribution of resources over a given period and a better utilization of these resources in terms of production bottlenecks. The system permits expansion for other production lines and other groups of different elements, with some degree of flexibility and without many modifications on the basis of the original knowledge. The techniques of elicitation, used in the acquisition of knowledge have helped overcome the greatest difficulty in this research, namely, the participation of experts in the process, due to their lack of time for interviews and for telling how they have solved their problems, so as to promote verbal protocols.
The development of the computational system was subdivided into modules and they, in turn, were subdivided into stages that were rigorously programmed according to the basic idea of the production process of a factory of pre-molded ferrocement elements. This was done "a priori", that is, before developing the system, all the priorities, activities, resources and restrictions of production were determined and analyzed.

It is difficult to find mention in the literature of this type of production process. It is only for the ceramic industry that some important systems are shown.

The evaluation of the system focused on the validity of the model, i.e. the degree at which the outcomes of the system resembled the outcomes of the human expertise being modelled in the knowledge base. A prescriptive method of validation was devised specifically for this study, involving both experts that had provided expertise for the system, and external experts.

9. REFERENCES