ARTIFICIAL INTELLIGENCE IN COMPONENT DESIGN

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Contents

1. Introduction
2. Characterization of the Design Process
2.1. Abstraction
2.2. Classification
2.3. Analogy
2.4. Error Handling
2.5. Hierarchical Knowledge Elicitation
3. Expert Systems, Expert Assistants and Expert Advisors
4. The task of "Designing a Component"
4.1. General Strategies
4.2. Problem Breakdown into Structural Elements
5. Selection and Design of a Feedwater Pump
5.1. The Physical Problem
5.2. Some Theoretical Considerations
5.3. Solution
6. Choice and Design of a Shell-and-Tube Heat Exchanger
6.1. The Physical Problem
6.2. Some Theoretical Considerations
6.3. Solution
Glossary
Bibliography
Biographical Sketch

Summary

Expert Systems (ES) constitute a particular application, of some of the techniques of Artificial Intelligence, aimed at the construction of “codes” (more properly, "automatic procedures") capable of *logically selective* rather than *deterministic* behavior. While the heart of such systems is their Inference Engine (i.e, the portion in which the rules are properly compiled and consulted to extract higher level information on the System's future actions), their indispensable input is a certain amount of knowledge about the universe they are supposed to interact with.

Such knowledge must be properly extracted, catalogued, possibly ordered, logically collected or re-fragmented, and systematically fed into a special data base called the Knowledgc Base (KB) of the ES. This chapter describes the principles of Knowledge acquisition and Knowledge Base assemblage, and discusses some of the problems that may arise with the collection, classification, and application of knowledge to design of

compressors.

1. Introduction

As of today, engineers use computers almost exclusively to perform system analysis tasks, and only rarely to tackle the crucial and sometimes mutually conflicting design decisions required by complex engineering projects. This represents a cost both in terms of economic implications and in terms of innovation drawback. A possible solution is to upgrade from CAD (Computer-Aided Drafting) to KAD (Knowledge-Aided Design, which we envision to embed CAD). CAD tools are primarily a drafting aid; they cannot be applied to other important aspects of the design process such as maintenance or fault diagnosis or design improvements. Presently, their only purpose is to produce detailed and/or assembly drawings of the components, even if lately they have been improved by the addition of capabilities like 3D representation and Finite Elements Analysis (FEA) pre- and post-processing, Generally, CAD analysis is a complement to numerical analysis, and the combination of the two allows for a better evaluation of the *structural* performance and of the mechanical properties of the proposed component.

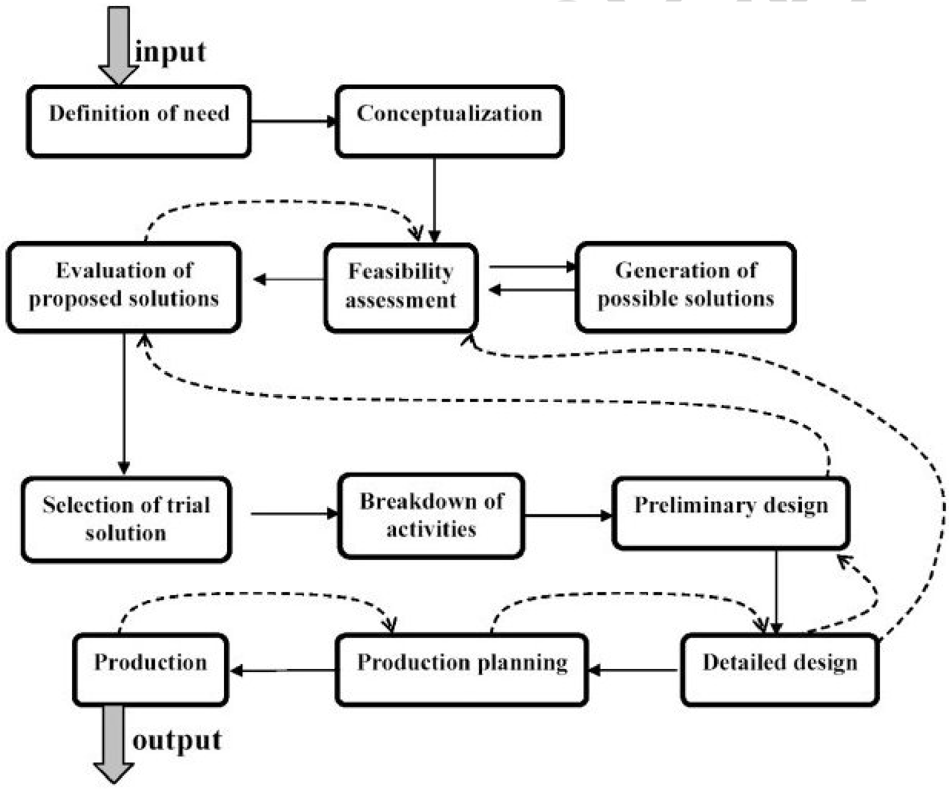

Figure 1: The logical steps of a design activity.
Dashed lines indicate possibility of backtracking

A KAD-tool should represent instead a real assistant to the design activity of an engineer, and as such it must deal with problems concerning the *functional* performance of a component. The process of designing an industrial component involves some creative contribution which goes beyond the proper assembly of subcomponents and brings an improvement over previous models. This is particularly important during the concept formulation stage. A good solution is often the result of a conceptual synthesis arising from past experience and a well structured knowledge base. This conceptualization of the design activity has been formulated in a widely accepted set of specifications, shown in the simplified flow-chart in Figure 1.

The adoption of KAD techniques can also enhance the degree of coordination among different design aspects by integrating the information acquired from different sources. KAD has been formally introduced in 1994. The main obstacle to the development of these techniques is their being based on a deep knowledge of the design activities: a breakdown of these activities focuses on each step involved in component design both as a single task and as part of a process, and it is obviously very difficult to acquire in a systematic way. As a result of this inherent difficulty, engineering companies have been reluctant to develop KAD tools, due to the large amount of time and resources needed to set up and validate the relevant knowledge base(s). Any component analysis must possess enough generality to retain its validity across a broad spectrum of applications: regardless of the nature of the equipment operation, a quite large number of factors must be considered in designing any unit. The most important consideration is often the selection of the type of unit that performs the required service in the most satisfactory manner. In developing the design, other criteria must be considered, such as the properties of the material used, cost, etc. In other words, a preliminary concurrent engineering modeling work needs to be developed in a sort of virtual desk where all the functional, production, maintenance and disposal requirements are analyzed and integrated into the final product. The output of this complex process will be the sought after "general component design tool".

In order to justify the need of Expert Systems to assist engineers in components design, it is important to remark that a design process is, in our technologically mature society, no longer a purely creative, but rather a well formalized process: most of the activities can be thought of as logical analogues of “Catalog and Handbook consulting", and recourse to "intuitive" creativity is either limited to details or shifted back to system level. Such a process is well-suited to be implemented into a knowledge-based system that can enhance both the engineer's choices and productivity. Furthermore, the advances in AI techniques and applications provide the possibility of building qualitative models that reproduce the creative steps as well, whose output represents the abstraction of possible solutions.

A design process starts with the *identification of a need* that can be satisfied by an engineering product. The recognition of a need may come from different sources: market analysis, solution for a technical problem, improvement of obsolete products, customer requests, upgrading of an existing product, conformity to new regulations, etc.

The *conceptualization* phase presents multiple alternative solutions, each of them focusing on one or more different aspects of the problem, like minimum cost, maximum performance, environmental issues, etc. These aspects can be viewed as constraints that the logical process of “component design" must abide by. A necessary initial step of every conceptualization is the building of a proper model of the component. It is also important to be capable of producing more than one solution as result of the conceptualization phase.

The *activities breakdown* phase subdivides at different levels the design process design activity into hierarchically ordered sub-activities.

The *preliminary design* phase provides a first-trial solution to the specific design problem. The overall system configuration is developed from general basic design concepts.

It has beenshown that most large design problems can be decomposed into sub-components ("design-in-the-small") and then integrated into the final system ("design in the large"). While such an approach is immediately applicable to Complex Systems (like Energy Conversion Systems), its application to simple components is more difficult, because of the large body of "modular knowledge" needed in this latter case. As an example, consider the choice of a feedwater pump in a modern large Steam Power Plant: once the design specifications are given, there are very few solutions available, and they can all be found in a "Pump-database" of rather limited extent. But once the pump has been *selected*, to *design* it is a different story: not only is the amount of required knowledge much larger in extent, but also the decision tree corresponding to the automatic drafting of the pump assembly has so many branches that an efficient scan becomes arduous (see Section 5 here below).

In the end, the application of ES to component design can be thought of as the transformation of a list of activities into a decision tree. The most powerful characteristic of such an approach is the capability of ES to handle incomplete and inconsistent data, which make them suitable to:

- Solve problems normally solved by human experts
- Find solutions to non-conventional problems (provided sufficient expert knowledge is available)
- Find solutions to incomplete or ill-structured problems
- Quickly produce prototypes
- Provide explanations for the different design choices

2. Characterization of the Design Process

Before selecting a KAD system, it is of fundamental importance to clearly formulate the logical path(s) one wishes to follow. The most commonly used methods are:

- Abstraction (for ill-structured problems)
- Classification (for well-structured problems)
- Analogy (comparison with other solutions of similar problems)
- Error Handling
- Hierarchical Knowledge Elicitation

2.1. Abstraction

This is the process the designer adopts to focus on the most important aspects of the final object. The technical specification of a component is the result of a search in a very large and complex set of incomplete alternatives and therefore most of the problems are ill-structured: the solution relies on the designer's capability of inferring properties that are independent of the application domain.

In such an environment, the Expert System can act as an "advisor" that simply lists possible alternatives and constraint violations and leaves the human expert with the task of selecting the most appropriate solution(s). The extent of the search in the domain space can be reduced by heuristically pruning partial solutions that are clearly not acceptable.

Another way to conceptualize the design process is to reproduce *sentence construction process*: both activities possess a syntax consisting of vocabulary of primitive elements and a grammar that specifies legal configurations of elements as well as semantics (functional mapping of inputs and outputs). For instance, the "correct" structure of a type of sentence is "noun-verb-predicate, and the “correct” structure of a certain sub-process is stream1-componentA- stream2".

A procedure that enjoys a good degree of success in structural and mechanical design is based on the same principles that guide Fault Diagnostics: it is possible to construct the expected performance curve of the component (or of an assembly of components) under its operating conditions and use it as a reference in the analysis of the design of a new component. Any deviation -both quantitative and qualitative- from the expected curve points to a fault in the component operating conditions. The resulting diagnosis process creates a set of specific rules that can be implemented into the broader knowledge base for further use in future component design process. An example could be like this: IF *the value of the design parameter T is too high* THEN *contact pressure in part A is too high*. The suggestion to be introduced into the broad knowledge base would be: "*Reduce contact pressure between part A and part C*”. Notice that this is the same logical path applied (at system level) existing Inverse Design methods.

Yet another, very interesting, way to perform component design is to reproduce a reverse fault diagnosis procedure, in the form of a series of "what if?": the task reduces to an iterative process that searches for a series of successive solutions to the problem "what component must be inserted to avoid a failure in satisfying design requirement number *j*?” and looping over the entire set of design constraints and specifications.

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Biographical Sketch

Roberto Melli is a Researcher at the Department of Mechanical and Aeronautical Engineering of the University of Roma 1 "La Sapienza" (UDR1), Roma, Italy.

He received a Masters degree in Mechanical Engineering from UDR1 in 1974. From 1974 to 75, he was a Research Assistant at the Chair of Machines in the same university.

As a faculty member he lectures on Machinery and Energy Systems Design in Nuclear Engineering Masters level courses.

His research activities are equally divided in two main fields:

1) Energy Systems Simulation and Design

2) Applications of AI-related techniques and procedures to the Design, Synthesis and Optimization of Energy Systems

His publications include more than thirty journal articles (mostly on international refereed Journals in the field of Energy). He published one book on AI applications for the types of NOVA Science, USA.

Within his 24 year diverse management experience, ranging from founder and co-owner of a process engineering consulting firm as a consultant for AGIP S.p.A. and AGIP Petroli designed an all energy (electrical and mechanical) system for Agip Petroli's new employee recreational facility at its new headquarters in Rome showcasing the effective deployment and use of solar energy. Led a 2 year, 30 person project to design and construct China's Rural Energy Resources Training Center in Beijing and coached/mentored Chinese counterparts in designing, building and deploying systems to convert renewable energy into usable energy. Produced prototypes and simulation models for training purposes and provided much needed knowledge transfer to the Chinese Government in availability and use of various energy sources.

In the late 90s he developed an extensive experience in the application and use of expert systems for energy management applications