artificial intelligence and pattern recognition in computer aided design

edited by
j-c latombe

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ARTIFICIAL INTELLIGENCE AND PATTERN RECOGNITION IN COMPUTER AIDED DESIGN

Proceedings of the IFIP Working Conference
organized by Working Group 5.2, Computer Aided Design
Grenoble, France, March 17-19, 1978

edited by

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PREFACE

An important goal of Artificial Intelligence (AI) and Pattern Recognition (PR) is to make computers more useful by building systems that can perform intellectual tasks. Both fields have produced advanced scientific and programming tools, which already have some well-known applications is chemical analysis, medical diagnosis and industrial robotics. During the last five years, several projects have attempted to incorporate some artificial intelligence and pattern recognition capabilities into computer programs intended to aid design. Although this tendency has remained considerably more limited than the main CAD thrusts, for example graphics and databases, recently it has attracted increasing interest from the CAD community and it is more and more widely believed to become a major trend in the coming years. In view of this interest and in order to study the impact of AI and PR on CAD, the IFIP Working Group 5.2 (Computer-Aided Design), at the meetings in Austin and Visograd, decided to bring experts of these three fields together by organizing a Working Conference with the theme "Artificial Intelligence and Pattern Recognition in Computer Aided Design". This meeting, the third Working Conference of W.G. 5.2, was organized in collaboration with IAPR (International Association for Pattern Recognition) and was held in Grenoble, 17-19 March 1978. This volume constitutes the proceedings of this conference.

The appointed Programming Committee of the conference consisted of J. J. Allan (Southern Methodist University, Dallas, USA), K. BØ (University of Trondheim, Norway), C. M. Eastman (Carnegie Mellon University, Pittsburgh, USA), H. Freeman (Rensselaer Polytechnic Institute, Troy, USA), R. B. Kenyon (The Polytechnic of North London, UK), J. C. Latombe (Institut National Polytechnique de Grenoble, France), M. Nagao (University of Kyoto, Japan), M. Sabin (Kongsberg Ltd., Maidenhead, UK), T. Vamos (Computer and Automation Institute, Budapest), and E. A. Warman (Perkins Engines Ltd., Peterborough, UK).

The goal and the scope of the Working Conference was set as follows in the "Call for Papers" :

"The purpose of this Working Conference is to motivate and lay the basis for a promising new direction in CAD thinking by bringing together for the first time very skilled people from the AI, PR and CAD fields, and having them produce and discuss a compendium of papers about the current and potential impact and use of AI and PR theories and techniques on CAD. Analytical papers extracting principles from practical experience will be greatly appreciated....

The following list of topics, although not exhaustive may be helpful to guide authors :

- Identification of those CAD problems that require AI and PR for their solution.

- Application of AI techniques to design problem solving.

- Procedural and database representation of knowledge for the design problem and for the design solution.

- Problem recognition and classification, so as to select, for example, the appropriate representation/solution algorithm.

- Intelligent communication between CAD systems and users : quasi-natural languages, personalized response, sketch recognition, intelligent graphic recognition and generation packages.

- Control of information flow in CAD systems with multiple users and system components.

- Modeling of the design processes and design methodology.

Any design field (mechanics, architecture, ...) is acceptable as an illustration of these topics".

The conference gathered 54 participants coming from 16 different countries and distributed among CAD, AI and PR fields. Twenty papers were presented, including three invited papers introducing CAD, AI and PR by E.A. Warman, E. Sandewall and M. Nagao. The other seventeen papers were selected by the Program Committee among the 50 submitted proposals so as to provide an interdisciplinary view of the application of AI and PR to CAD and to stimulate broad discussions among the attendees. With two exceptions, each paper was individually discussed and, in addition, there were four general discussions.

This book contains the full set of papers presented at the conference augmented by their individual discussions and the general discussions. It provides new regards on many fundamental issues including CAD control structures, programming complexity in CAD systems, automatic problem solving, representation of large database of design knowledge, self-explaning systems, aesthetics versus performance aspects in CAD, and man-machine synergism. Originally, it was planned to divide the book into four sections : I - Presentation of CAD, AI and PR ; II - Automatic Problem Solving for CAD ; III - Design knowledge Representation ; IV - Man-Machine Communication in CAD. But later on, having got a better view of the papers and discussions, I found this division somewhat confusing and misleading. For example, G.J. Sussman's paper, which would have been put in Section III, addresses many issues that have considerable interest for problem solving. And some papers, like O. Akin's, would have been very difficult to classify. Since there was some kind of continuity among the discussions, I finally preferred not to divide the book into sections and to produce the papers and the discussions in an order that is almost the actual order of oral presentation. However, this order was based upon the above division into four sections, so that the original plan remains implicit throughout the book.

Aknowledgements

H. Freeman, H. Hatvany, U. Montanari, M. Sabin, M. Somalvico, and C. de Vanssay served as Session Chairmen. Their contribution to the quality of the discussions is very much appreciated.

Many graduate and ungraduate students helped in organizing the conference. M. Dymetman, M. Lopez, A. Lux and M. Vernet devoted much of their time in recording and transcripting all the discussions. They did a formidable work, without which producing this book would not have been possible. Miss J. Argento expertly typed all the discussions.

The IMAG Laboratory provided much assistance in organizing the conference. Financial support was provided by IFIP (International Federation for Information Processing), IRIA (Institut de Recherche en Informatique et Automatique), ADEPA (Association pour le DEveloppement de la Production Automatisée), IBM France and AF.MICADO (Association Française ayant pour MIssion la Conception Assistée et le Dessin par Ordinateur).

Finally, I would like to express my personal thanks to E.A. Warman (chairman of W.G. 5.2) and J.J. Allan (Vice-Chairman of W.G. 5.2) for their friendly assistance and their encouragements.

Grenoble
July 17, 1978

J. C. Latombe

CONTENTS

Artificial Intelligence and Pattern Recognition in Computer Aided Design, Latombe, ed.

COMPUTER AIDED DESIGN : AN INTERSECTION OF IDEAS

E.A. Warman

Perkins Engines Ltd., Peterborough, England

The design process is analysed and a general model of the Computer Aided Design process is constructed. Extending this model to incorporate the full requirements of a designer, shows that the incorporation of Artifical Intelligence Methodology into Computer Aided Design is a natural and expected development.

INTRODUCTION

This paper examines computer aided design from the view-point that it is a subject that has developed from the intersection of ideas derived from other sections of science and technology. Each of these sections have in addition to their part in computer aided design, an existance in their own right. It is this duality of use that tends to lead to confusion as to what constitutes computer aided design. Computer aided design is therefore neither graphics or applied numerical techniques or any other individual thing. It is the intersection of these and other ideas coupled with man, who acts as a composer for, and conductor of, an orchestra of diverse technologies. The objective of this conference is to examine the effects of adding the further intersections of artifical intelligence and pattern recognition to computer aided design, and to extropolate the use of such techniques upon the future form and nature of computer aided design, and computer aided manufacturing systems.

DESIGN ANALYSES

At its core, design is a creative process, but the creative core is surrounded by many other processes that enable the central design notion to be eventually realised in some material form. The many processes that are used to achieve the final realisation of the central idea are not used in individual isolation, but act upon one another. This process inter-dependance requires a design system to be interactive, capable of iteration and hierarchical. The features of interaction, iteration and multi level construction are exploited to varying degrees in all computer based processes that form part of computer aided design systems.

In order to gain an insight into the apparent diverse forms a computer-aided design system may take, the components of design will be first examined. In figure 1 is shown a concept of the design process. The creative process is fed with notion and needs, that are modified by constraints. The design throughout its production provides a modifying feed back.

Any design can be shown to possess three elemental aspects:- aesthetics, kinaesthetics and strenuosity. These aspects may be subject to calculative or intuitive processes in order to arrive at a complete design. Acting upon each of the three elemental processes are four modifying processes. These modifying processes are designated as Reduction, Simulation, Optimisation, and Modularisation. Finally there is an output that may immediately or eventually feed back and influence the notion and needs.

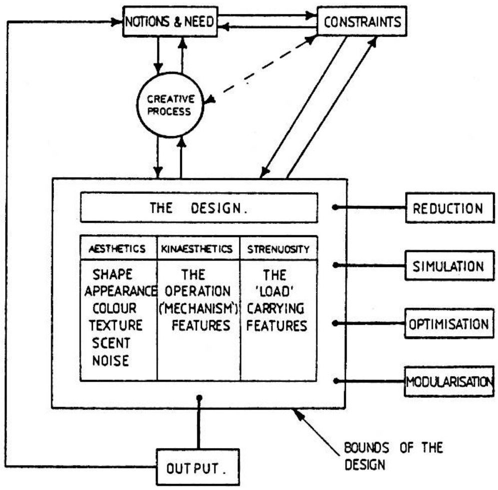

FIGURE 1 THE BASIC DESIGN PROCESS.

In considering the application of computers to design, the elements of the design process can be related to particular computational aspects. Space does not permit a total study, therefore key features have been selected. The Strenuosity features of a design have been considerably impacted upon by the application of the finite element method (1) for the study of the structural aspects. Though the technique is used also for the study of such diverse problems as seepage under dams, electromagnetic field intensity studies and pressure distribution in bearing oil films. The finite element, finite difference and iterative methods for studying the 'load' carrying features of a design were only practically and economically possible through the application of computers.

Naturally the three elemental aspects act upon each other within any design, and the techniques employed to achieve these aspects also influence each other. Of the various aesthetic features that a design may possess, there is an obvious interplay between shape and strenuosity. The computer methods that are used to produce and manipulate shapes are also now being used to prepare mesh information for finite element investigations.

The study of shape production using numerical methods (2) and the techniques used to display shapes (3) are essential to some computer aided design systems. Shape production and display has absorbed (and will absorb for many years) a great deal of effort in the application of computers in design. Nevertheless this effort has produced new approaches to the production of shapes using numerically controlled machine tools, and has started to assist in obtaining an understanding of the creative aspects of design by observing the human attitudes toward the pleasing effect or otherwise of shapes.

The kinaesthetic aspects of design are concerned with the functional aspects, (called the principle by Krause and Vassilakopoulos (4)), of design. Dependant upon whether the design is mechanical, electrical or some other physical aspect in its formulation, a variety of techniques exist, for performing functional studies. Electrical and aerodynamic design, because of their more analytical background, are more fully treated, from the kinaesthetic aspects, at present by computer methods than mechanical based systems. It is speculative as to whether a general system will ever be developed for the kinaesthetics of a design.

The aesthetic aspects of design involve all of those features that act upon the human senses, and thus extend beyond the simple concept of shape. The advent of colour raster scan graphics is enabling some aesthetic judgements to be more rapidly reached than was possible through non-computer methods. Aesthetics of design will undoubtedly remain the prerogative of man rather than machine, in the final acceptance of a design, for many years to come.

Acting on the three basic aspects of a design are four processes (figure 1) of Reduction, Simulation, Optimisation and Modularisation. These processes, due to their numerical nature, have in many instances been the starting point for the construction of computer aided design systems. This action has again caused certain confusion as to what constitutes Computer Aided Design. Reduction is the process of "parsing" a design in order to reduce, for example, the kinaesthetic features into a more simple but equivalent form. Work to date on reduction has been based upon the application of techniques derived from the theory of graphs.

Simulation is the process of modelling the behaviour of a design and subjecting it to parametric studies (5).

Optimisation is the adjustment of the features of a design toward some economic factor, using the results obtained from simulation and reduction studies.

Modularisation is the division of a total design into sub-units that may be re assembled in different sequences to produce new designs.

The interplay between all of these techniques results in some form of output. In the non computer situation this output is usually a set of drawings. The application of computers has extended the range of immediate output to include tapes for numerical manufacturing processes, data files for bill of materials, piece part costs or manual machining operation sheets.

DEVELOPING THE C.A.D. MODEL

Having examined the design process, application areas for computers, and their interplay, a general model of a computer-aided design system will be developed.

Figure 2 is presented as a starting point. The original objective of this diagram was to illustrate the necessary separateness (6) of computer aided design software, the command language and the job control language.

The concept bounds equate to the notions and needs. The creative process is represented by the designer (and his interaction), and the 'program' is the computer based realisation of the three elemental aspects of design and the four modifying processes. The diagram is not however complete. Other than the designer, there is not any process for capturing and filtering information for immediate or future use, nor is there provision for making use of previously acquired information; either by the man or by the machine. If such processes are to be incorporated, as they are in non computer based systems, there is also the need for an interrogation system that can be used by both the designer and the design problem solving process. This extended model is shown in figure 3. This extension hints at the requirement for some sort of intelligence to be built into the system, and that it would be desirable if this intelligence had also a recognition component. The questions that arise are what, where and how this intelligence component should be incorporated.

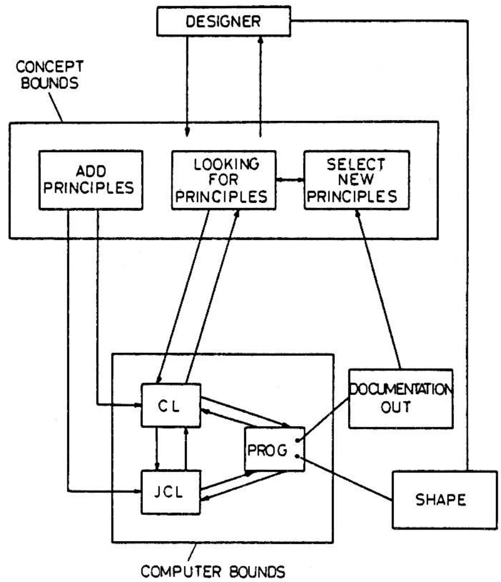

FIG. 2. BASIC CAD SITUATION

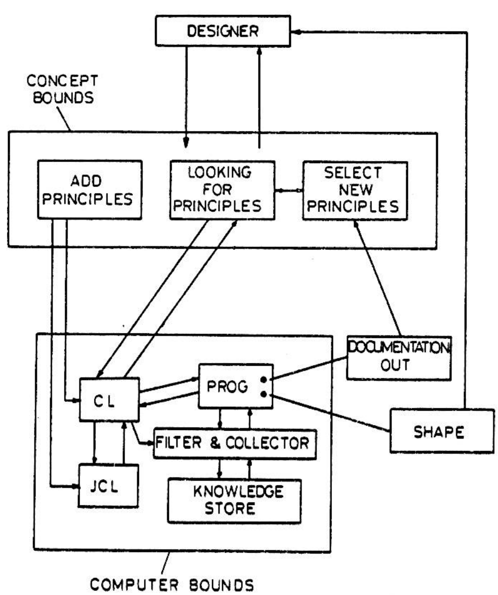

FIG. 3. ADDITION OF KNOWLEDGE STORE

Latombe (7) singled out three A.I. core topics, that in the terminology of figure 1 may be called processes. These processes interact with the creative process, and are designated, Perception, Knowledge representation, and Problem solving. Figure 4 shows the extended design process incorporating these features and figure 5 is presented as the end model of the computer aided design process incorporating some form of machine intelligence. Having demonstrated in a some-what primitive form that the integration of artifical intelligence into the computer aided design process is a natural progression, speculation as to the impact of this progression is now considered.

DIVIDING THE RESPONSIBILITY

The inclusion of A.I. techniques into the Computer Aided Design process requires a re-consideration of the responsibility apportioned to the man and the machine. The role of man in problem solving is still not entirely defined or understood. When machines are at a primitive level (8), no one worries about the operator, any discomfort is more than compensated for by the excitement produced by the new machine. The limits of system performance are set by the mechanisms. When however the machine becomes faster or more reliable, improvements are best achieved by studies of the operator. The introduction of artifical intelligence into Computer Aided Design systems is seen to be occurring at the point where the performance limits are being set by the operator and the tools provided for man-machine communication.

One of the prerequisites of a good designer is the ability to recognise situations, especially in a non-familiar context. Even in the Computer Aided Design environment, an operator with a well developed situation recognition ability will have a better performance than others who do not have this ability.

Should therefore such abilities be incorporated into comouter aided design systems ? In the elementary sense of working within parameter limits, simple situation recognition has been dealt with since the first program. As the complexity of the decision process increases, it becomes more difficult to decompose the decision steps into a programmable structure. The following discussion indicates a possible approach in such situations. An example of complex decision processes possessing a goal seeking element are routing algorithms.

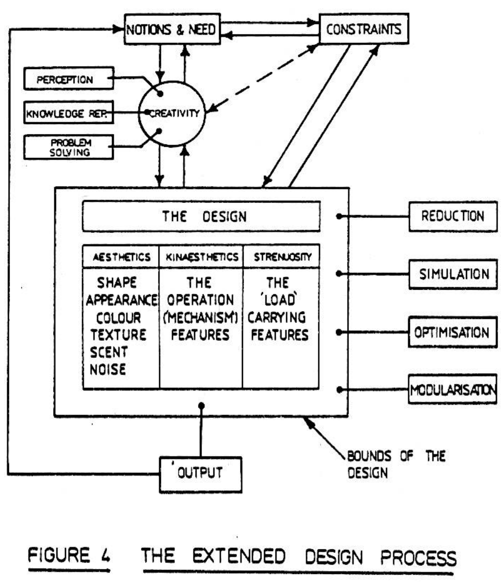

FIGURE 4 THE EXTENDED DESIGN PROCESS

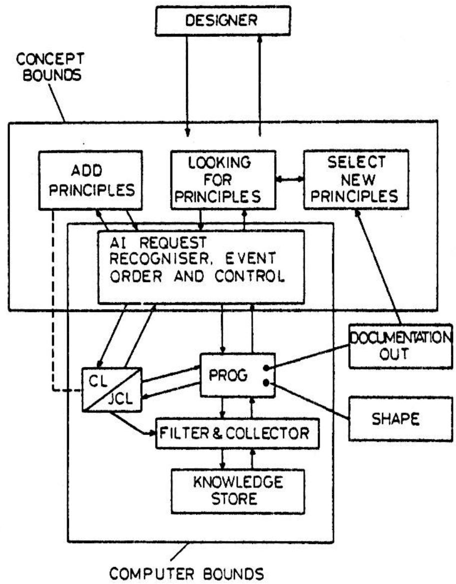

FIG.5 THE EFFECT OF INCORPORATING ARTIFICIAL INTELLIGENCE

These algorithms are used in a variety of Computer-Aided Design situations, from piping layouts, electrical cable layouts, Printed Circuit Board layout and other related systems. Connections between sets of nodes have to be established within certain pre-defined constraints. Many of the algorithms that deal with routing now allow for human intervention to deal with areas that the algorithms finds difficult to resolve. The fairly intelligent algorithm with a little human guidance appears to provide an economic solution to a difficult problem. Work still has to be carried out to determine the optimum man/machine mix for this type of problem and the advantages of being able to store the results of a man/machine interaction for future use. The approach however appears to have adequately apportioned the responsibility between man and machine and produced acceptable systems.

Similar methods of approach employing a man-machine mix for resolving complex descisions are being applied in space planning (9) tasks encountered by architects. When the program reaches an area of conflict the operator is requested for input. A vital fall-out from these systems is that the operator rapidly learns of the deficiences of the algorithm , and that in future program revisions this additional data becomes incorporated.

The majority of design work performed throughout the world is not the production of new creations but the modification and adaption of existing designs. In these cases, situation recognition is a major factor in the economic production of the new designs. "Have we made one like it before?" is a universal question that is asked in these situations. It is therefore conjectured that the extension of automated situation recognition to enable similar designs to be retrieved from data storage systems, will be a major component of future C.A.D. systems that utilise A.I. methods to the full.

QUESTIONS AND ANSWERS

Any interaction between a man and a C.A.D. system must involve a dialogue. This dialogue takes several forms in existing C.A.D. systems. These forms are varying relative to the level at which the interaction takes place. For example the dialogue may be; pictorial based upon tactile input, through a conventional keyboard, or even verbal in some experimental systems. The more complex the dialogue required, the more necessary it becomes to use natural language forms in which to conduct the dialogue.

The artifical intelligence studies in the use of natural language for interrogating data bases (10) are now at a sufficient state of development for incorporating into Computer Aided Design systems. The relevance of the use of natural language becomes important in uncertainty situations, and these can occur at any stage of a design process. Natural language interfaces bring into communication with computers, not experienced computer science practitioners, but casual users, whose interaction with the system is irregular in time. It is also predicted that the use of natural language in computer aided design systems will assist in the educational problems related to the use of C.A.D. systems by mixed ability personel (11).

There are at least two kinds of information needs related to design:-

i) The overview and awareness of the working environment of the design.

ii) The special interest problem relating to a particular aspect of a design.

The expansion of these needs related to the user, system and its properties is shown thus:-

Two kinds of design information needs

Awareness and overview	Special interest problem solving
Type of Query	
What is the present state of art of my design area? Most important problems, solution methods and results. Spread of papers on topics with trend production.	What is the answer to my specific question ? All relevant parts, data, text or pictures.
User Behaviour	
User devlops his own opinions by browsing through references.	User carefully studies all relevant data and documents.
System Properties	
Reply with a representative set of design references is sufficient.	High recall ratio with excellent fact precision is required.

Information needs again illustrate the interactive and hierachical structure of the design process and that any attempt to incorporate natural language question and answers systems into C.A.D. systems must reflect the structure of the design process. It must even allow for the very experienced user to be able to by-pass full natural language interrogation in order to achieve higher response rates (12).

Implicit in the C.A.D. requirement for the use of natural language is the ability of the language processing system to produce and execute programs that arise from questions that require such action in order to provide design relevant answers.

The use of natural language with the design process also leads naturally to the programming of industrial Robots for use in the subsequent Computer Aided Manufacturing process (13). Natural language question and answer processes are thus seen to be implicit in any future development of C.A.D. systems.

SEEKING A SOLUTION

The act of design, from the previous considerations, implies a goal seeking process aimed at a solution that fulfils some notion of an optimum.

Design problems are non trivial with respect to the quantities of variables that have to be considered. The interactions between these variables are also complex. In order to arrive at an optimum, (not necessarily THE optimum) parametric studies have to be undertaken. Design problems are generally too complex for the classical methods of optimum value determination to be used. Thus design studies are approached using the computer in the same manner as conducting experiments on real hardware (14).

This method of approach enables use to be made of the techniques of experiment design and analysis. A typical example is the method of evolutionary operation (15).

These methods of experimentation control are suited to either man or machine implementation and may be wholly man or machine controlled or a mixture of both. Evolutionary operation is naturally suited to automatic tracking techniques developed for Robotics, and is yet another example of the natural absorption of A.I. techniques into Computer Aided Design.

The problems raised however are not of the implementation of these techniques into Computer-Aided Design systems, but that of capturing data released by their use. This problem is more difficult than the data base interrogation and information retrieval task. This increased difficulty is due to the dilemma of whether to capture all data, apply a filtering process, condensation process or a mixture of each. There is also the balance of **costs**, in that a problem common in normal design practice is again reached; it may be more economic to repeat a design analysis rather than retrieve previously obtained data.

THE OUTER LIMITS

The future possibilities for Computer Aided Design are so vast that at present any prediction of future developments would have a degree of correctness. One aspect of design is showing however that functional modelling techniques do have, at present, some limitations. The solution has been to take the Computer-Aided Design into the real design. This move to provide a better design solution is illustrated in figure 6. The component

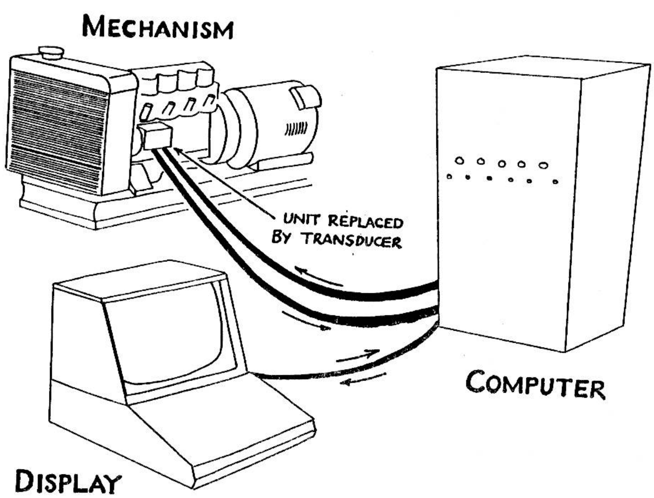

FIG.6 DESIGN BY INTERACTING WITH MECHANISM

under design is replaced by an actuator. The operational characteristics of the actuator is controlled by the computer. The design performance is also monitored by the computer. The designer interactively adjusts the actuator signal until the machine produces a satisfactory performance. This method takes into account the entire compliance of the real design, a situation that in many instances is difficult to model. To date this technique has been successfully applied to carburettor design, and cam mechanisms for textile machinery (16).

In a similar way machines have been coupled into the design process in order to provide a better appreciation of the design aesthetics by manufacturing small samples. Two examples of this approach are to computer controlled Jacquard loom (17) and the high speed polystyrene foam cutter at Cambridge University (18). These examples are not intended to be full computer aided manufacturing systems, but to provide a method of prototype production, that provides the designer with a better appreciation of his work.

CONCLUSIONS

The analysis of the design process and its extension into Computer Aided Design has shown that the incorporation of Artificial Intelligence methodology is a natural and expected development.

Having shown that Computer Aided Design is a working interaction of many ideas, the incorporation of the further intersections of Artifical Intelligence and Pattern Recognition thus impact many aspects of the Computer-Aided Design process. The effect of these additional ideas also depends upon the particular design application.

If figures 2, 3, and 5 are observed, an aspect that is beginning to emerge is that the systems design for C.A.D. systems needs to be considered from the bare machine upwards. Why for example could not Artifical intelligence methods be used to provide a combined command Language, Job Control Language and knowledge collection and filtering system as a single concept, rather than building up on unsuitable foundations ?