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Integrated Innovative Computer Systems for Conceptual Bridge Design

Systèmes innovants et intégrés pour la conception des ponts

Integrierte innovative Computersysteme für die Konzipierung von Brücken

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SUMMARY

The development of a suite of innovative, complementary systems for bridge design is described. The suite consists of four systems which cover conceptual design, a case-based database of existing designs, decision support for costing and aesthetics. The systems are linked through a dynamic database and all adopt a user-centred approach. The four systems are briefly described and their utility in practical bridge design is discussed. Also, the proposed method of interaction is discussed. The system's development is based on the authors' experience of the needs of practising designers.

RÉSUMÉ

Le développement d'une suite de systèmes innovants et complémentaires en matière de conception de ponts est décrit dans cet article. Cette suite est constituée de quatre systèmes qui couvrent: la conception, une banque de données de réalisations existantes, l'aide à la décision en matière d'estimation des coûts et l'esthétique. Les systèmes sont reliés entre eux grâce à une banque de données "dynamique" et chaque système a une démarche centrée sur l'utilisateur. Les quatre systèmes sont présentés brièvement et leur utilité pratique dans la conception de ponts est discutée. Le développement du système est basé sur l'expérience des auteurs et les besoins des praticiens.

ZUSAMMENFASSUNG

Die Entwicklung einer Gruppe innovativer, sich ergänzender Systeme für die Brückenkonstruktion wird beschrieben. Die Gruppe umfasst folgende vier Systeme: Konzeption, eine Datenbank bestehender Konstruktionen, sowie Entscheidungshilfen für Kostenberechnung und Ästhetik. Die Systeme sind durch eine dynamische Datenbank verknüpft und von benutzerfreundlichem Design. Die vier Systeme, ihr Nutzen in der Praxis und die angestrebte Methode des Zusammenwirkens untereinander und mit dem Benutzer, werden diskutiert. Die Entwicklung aller vier Systeme basiert auf den Erfahrungen des Autors mit praktizierenden Brückenkonstrukteuren.

1. INTRODUCTION

Many concepts and ideas have resulted from Artificial Intelligence research. How best to use these ideas to assist designers has grown into a major area of research. Initial efforts to achieve these aims were inflexible and fragile but more recent work is starting to overcome these problems; for example, the generic spatial reasoning system of Coyne and Subrahamin [2]. The authors have concentrated on the development of innovative systems for conceptual design which are of more immediate benefit, ([17],[11],[5],[8]). The research has progressed from the development of relatively large expert systems which covered the entire domain, to more flexible systems which aim to cover smaller, more focused sub-domains. Although the aims of these latter systems are more pragmatic and therefore easier to achieve, they could be criticised for being too limited in their coverage. To overcome this, the systems currently being developed are highly interactive, both with other complementary systems and with the user. The merits of this approach form a major part of the discussion in this paper.

The provision of sophisticated decision support software for designers is generally accepted as a desirable goal. A number of large scale projects whose aim is to create comprehensive design environments which incorporate CAD, various KBS, databases and analysis capabilities are either in progress or have been attempted. These systems offer the advantage of compatibility. However, to date, the success rate of these projects has been disappointing. Generally throughout the software industry, it is recognised that large systems are difficult to develop, demanding a disproportionately high number of man hours compared with the development of smaller systems [10].

The alternative to large complex projects is to develop separate, readiliy compatible systems which can be successfully linked. This leads immediately to the concept of linking technologies such as product models [18] which facilitate the transfer of information between different systems. However, the development of product models is still in its infancy and furthermore their development is a relatively involved process. These difficulties have hampered the acceptance of product models by the construction industry. Hence, funding is difficult to obtain and it is likely that progress will be slow. In the absence of such sophisticated methods of linking, it is pragmatic to develop methods which exploit the available technology and can therefore be more immediately employed. One such method is described here.

This paper briefly describes four complementary sub-domain design systems and the mode of interaction chosen by the developers. The application domain is the conceptual design of bridges. The subsequent discussion describes the underlying philosophy of the work, the linkages between the systems themselves and also between the system and the user.

2. THE SYSTEMS

Four systems associated with different aspects of bridge design are currently being developed. These are described below. The first three systems are being developed in Microsoft Visual C++. A Case Based Reasoning system is also being developed, currently using Remind but it is anticipated that the final system will also be written in C++. C++ was chosen instead of a conventional AI language due to the greater power and flexibility available, albeit at the expense of increased programming effort for certain parts of the work. In particular, the version of C++ used offers considerable control over the user interface which past work [15] has shown to be important. In the original system of Moore [11], because of the limitations of the software used, it was not possible to incorporate graphics. Instead the user interface was text based. Tests of this software showed that designers prefer to reason about designs in a more pictorial way, presumably because such information can be more readily handled in short term memory. Thus, wherever possible, the systems provide information in a graphical format.

The domain of the work is small to medium span road bridges, as this is where the experience of the research group lies [11],[6]. In addition, as these are currently the most common form of bridge built in Britain there are large volumes of accessible data.

As with all of the authors' work, these systems are all being developed by collaborating closely with practising designers who are used to evaluate the work. This helps to ensure relevance as well as providing and ideas and impetus for further research.

2.1 System One: A Non Prescriptive Conceptual Design System

The original conceptual bridge design system [11] underwent extensive industrial evaluation. This revealed that the users did not feel in control of the design process because the original system was too prescriptive. Like many other KBS, the system controlled the decision making process . Also this form of reasoning resulted in a system which was inflexible, particularly when the user wished to incorporate non-standard, case specific information.

Despite these criticisms, the original system was, in principle, well received as it provided correct answers and useful advice. This was because, despite the style of user interaction being flawed, the knowledge base was sound. Based on an analysis of the reactions to this initial system, it was decided to replace some of the heuristics incorporated with more sophisticated forms of reasoning (as described in Systems Two and Three below) and for the initial conceptual design a far more flexible, user driven, knowledge-based system has been developed. This system solely undertakes conceptual design and does not venture into preliminary costing or member sizing as was the intention of the original system. These areas are now catered for by separate systems.

The new system has been developed from the initial knowledge base, although this has been rewritten in an object oriented format. In addition the entire structure of the knowledge base has been altered so that the "rules" are clustered in small groups with no more than 10 rules per group. Each group is associated with a daemon which only fires when the user violates certain constraints. Constraint violation can occur for a number of reasons, for example when the user chooses an uneconomic structural form or when there is a locational clash say between a water main and a foundation. Thus rather than controlling the design process, the knowledge base observes and interacts only when necessary via a message on the screen. On receiving a message, the user is left to decide what action (if any) to take. The initiative is left with the user because given the impossibility providing of knowledge bases to cope with every situation, one has to allow human judgement and common sense to be included in the design procedure. This obviously permits the user to make mistakes but is a vast improvement on current procedures where no checks are made. This style of user interaction we call non-prescriptive because the system does not prescribe an answer; it only suggests alternatives [7]. By leaving the user in control of the design, the benefits of computers are maximised (i.e. memory, computational power and reliability) without stifling the capabilities of human beings (creativity, flexibility and innovation) [8].

A further facility allows the user to access and amend the knowledge base through a purpose built knowledge manager. This is possible because the knowledge base has been fragmented into short and separate constraint trees, which is in turn possible because of the non-prescriptive nature of the interface. This facilitates access by expert bridge designers who are not familiar with the system, hence allowing design consultancies to modify the knowledge base to suit their own practices. Further work is in progress on allowing users to add to (rather than to amend) the knowledge base and progress to date is encouraging.

At present the system is undergoing its first design office trials. Initial findings show that the designers see a distinct role for the system, providing a quality assured design procedure. They particularly like the knowledge manager and those people who had used the previous system [11] are appreciative of the improved style of interaction.

2.2 System Two: A Preliminary Costing System for Bridges

Following the evaluation of the first bridge design system, it became apparent that engineering consultants found the costing of alternative bridge designs a major problem. Currently, bridge designers use very simple heuristics (typically a cost per m^2 of deck). Obviously such a method is very crude. When a more detailed search of the design space is required then the usual procedure is to design a limited number of bridge options in some detail, and take off quantities in order to cost them. This can take several man weeks, the amount of work involved effectively prohibiting a proper search of the design space. To overcome these problems, a design costing system has been developed. This provides an cost estimate which is far more accurate than that reached by using current heuristics by sizing the components of the bridge to a level of accuracy which is close to that achieved by using a full analysis. The system is then used to take off appropriate quantities to obtain a preliminary cost.

By combining improved estimating techniques, approximate contingency factors and heuristic replacement [8] with the power and speed of computers, an effective system which can rapidly and accurately cost a bridge has been produced. The system enables bridge costings to be produced in few minutes, which in turn provides the designer with a tool which can rapidly cost alternatives and assess the impact of small changes, thus enabling the design to be 'fine tuned'. This means that the designer is able to search the design space for an optimum solution. The principle of heuristic substitution and the developed system are described elsewhere [7] [14].

2.3 System Three: An Advisory System for Bridge Aesthetics

Another decision variable in bridge design is aesthetics. This is an area of engineering design which is highly subjective and therefore difficult to investigate. However, the need to elicit information and provide assistance to designers in this area was identified during the evaluation of Moore [11]. The knowledge base for this project is being developed with the help of a number of expert bridge designers and architects. The opinion of the general public is also being included, via sophisticated questionnaires. Some work in this area has already been undertaken, notably by Crouch [3] and the work of the authors has extended this.

The system does not aim to provide a definitive set of rules which must be adhered to for all road bridges. Instead, it provides advice and assistance with the benefits of visualisation. As with the costing system, this system enables the designer rapidly to evaluate options. It is important that the use of such a system should not lead to the standardisation of road bridge design, therefore it only provides suggestions for improving the aesthetics of a bridge and, as with the other systems in the suite, control of the design stays ultimately with the designer.

Initial evaluation has again showed that the system is liked by the reviewers and that they see a worthwhile role for the system.

2.4 System Four: A Case Based Reasoning System for Bridge Design

Case Based Reasoning (CBR) is an important new technology which allows the more effective use of databases; initiating problem solving techniques which are based on the utilisation of past, recognised solutions [16]. Engineering design is a complex task. However, previous research has shown that much of the design conducted on a day to day basis consists of modifying past designs; as this approach is economic. In the construction industry, there are large collections of design data which are traditionally stored on paper or more recently in computer aided design packages. When considering a new scheme a designer will typically want to locate previous designs which can be used as the basis for a new design. Currently, this process is done manually. Many design offices recognise the need for more efficient search and retrieval techniques and CBR presents a possible solution to these problems.

The project does not aim to compile detailed design information on all types of bridges. Nor does it aim to develop a design standard which removes the creative side of design. Inevitably, bridge designs are complex and to aim to store all information about them would be unrealistic. Therefore, a sub section of bridge designs are considered (small to medium span road bridges as mentioned above). In addition, the CBR system aims to capture conceptual design decision information as well as specific design criteria.

The project is still in its early stages, but industrial collaborators have already given a number of suggestions and bridge designs, which have provided the basis for the formulation of a prototype system which incorporates a preliminary case breakdown [13].

3. THE INTERACTION MODEL

The four systems outlined above are being developed as independent systems. However consideration has been given to their interaction to form a complementary set of design systems. The mode interaction of the systems is shown in Fig.1. Also shown is the proposed interaction with AUTOCAD. Further work has taken place to investigate linkages to packages such as MOSS which could be used to input directly topographical data. The initial findings are that information can easily be passed using file protocols such as DXF but obviously this involves a substantial loss of information. It is also recognised that Fig.1 does not show any links to analysis software. However previous work [17] has shown the feasibility of such links and no problems are anticipated in providing them.

It can be seen that the user can enter or exit the system at any point. For example, the user can enter the system at the conceptual design stage, create a design, cost it, obtain advice on its aesthetics and leave the system with the completed conceptual design, with the option of storing the new design in the CBR system. Alternatively, the user could retrieve a design from the CBR system and check its cost, receive advice on its aesthetics or both. These are only two examples of many possible modes of consultations. The proposed connections (shown by the arrows) have been deliberately limited, (that is, they are one directional in places), so that the prototype architecture is realistic in its aims.

This suite of systems will be supported by a dynamic 'database' of the information accumulated during a consultation (Fig.1). This facilitates the transfer of information between the interacting systems as well as providing an easy to access record of previous user input, enabling them to 'tweak' the input data to see the affect of changes in the design criteria. From this it can be seen that the systems will operate on an equivalent basis, with the user maintaining control over the entire consultation. The architecture adopted is reminiscent of a blackboard principle [1]. It also exhibits some properties of agents [4]. However, it differs markedly in that there is no central controller or system 'manager' as is the common case with these alternative architectures. Instead, the user takes control of the consultation and acts as the suite manager. The aim of the arrangement is to provide decision support for the user, with the user controlling the interaction and the design process. This maintains the sense of user control, which previous research has shown to be important [8].

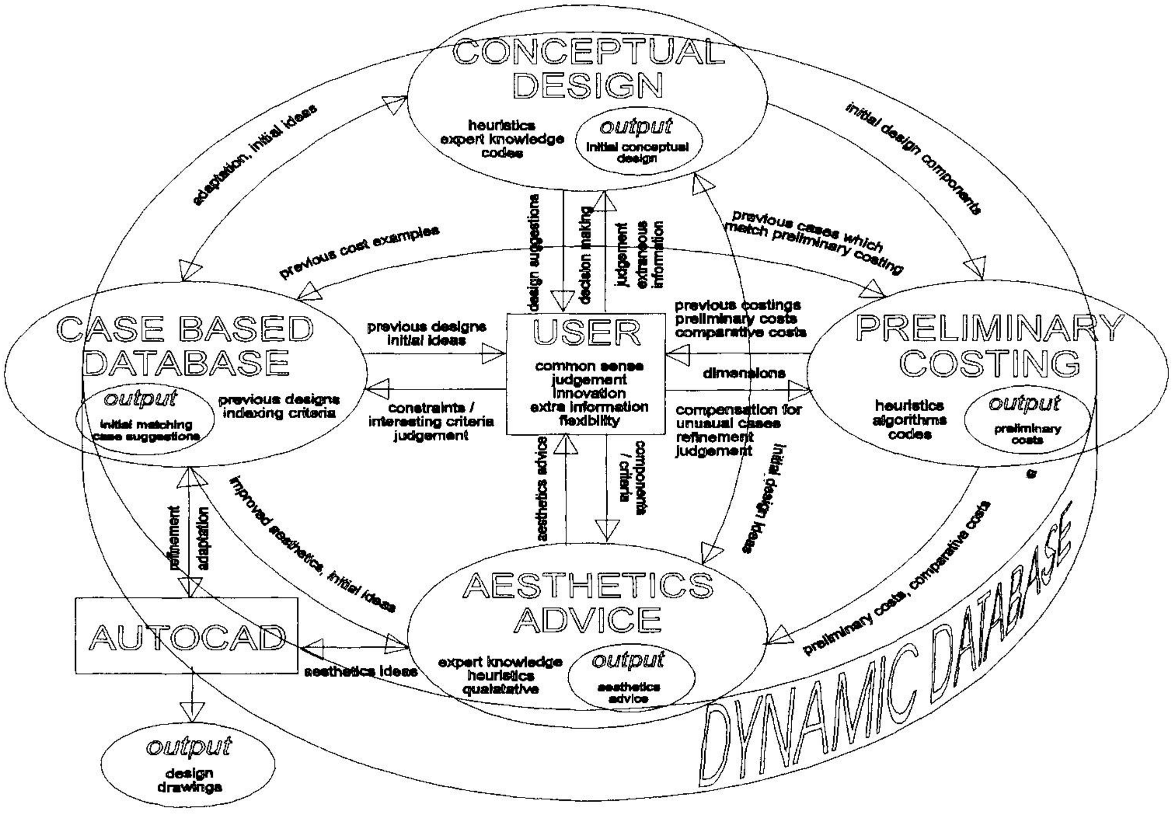

Figure 1

The mode of ineraction adopted allows the user to supplement the areas in which the computer systems currently deficient, such as common sense, judgement, innovation and flexibility: all qualities which computers currently find hard to emulate and which are recognised as being important in design . As discussed above, the philosophy of the research at Cardiff is to support designers in areas which they find difficult, leaving them to cover tasks which come naturally and which are difficult to incorporate in computer programs. Using the user/designer as a system component enforces this philosophy and ensures that the systems operate successfully whilst maintaining their support role. This user centred approach is felt to be vital for the future success of design systems. The authors believe that there is the temptation in AI to "over-automate".

There is a potential disadvanatge to the above approach because the user exhibits such human failings as inconsistency but the supporting systems have been designed to help to mitigate such problems and it is believed that the gains far outweigh the losses.

4. TRANSFER OF INFORMATION BETWEEN THE SYSTEMS

The manner in which information is transferred between the various systems in Fig. 1 requires careful thought to ensure flexibility whilst avoiding excessive complexity. Given the inadequate development of suitable advanced coupling technologies such as product models, it was necessary to devise a schema which satisfies current needs and allows for future expansion. The importance of the inter-system linkages and the user interaction is such that a great deal of effort has been expended in planning and forethought. It is not possible to present all this work here but an outline of the approach can be given.

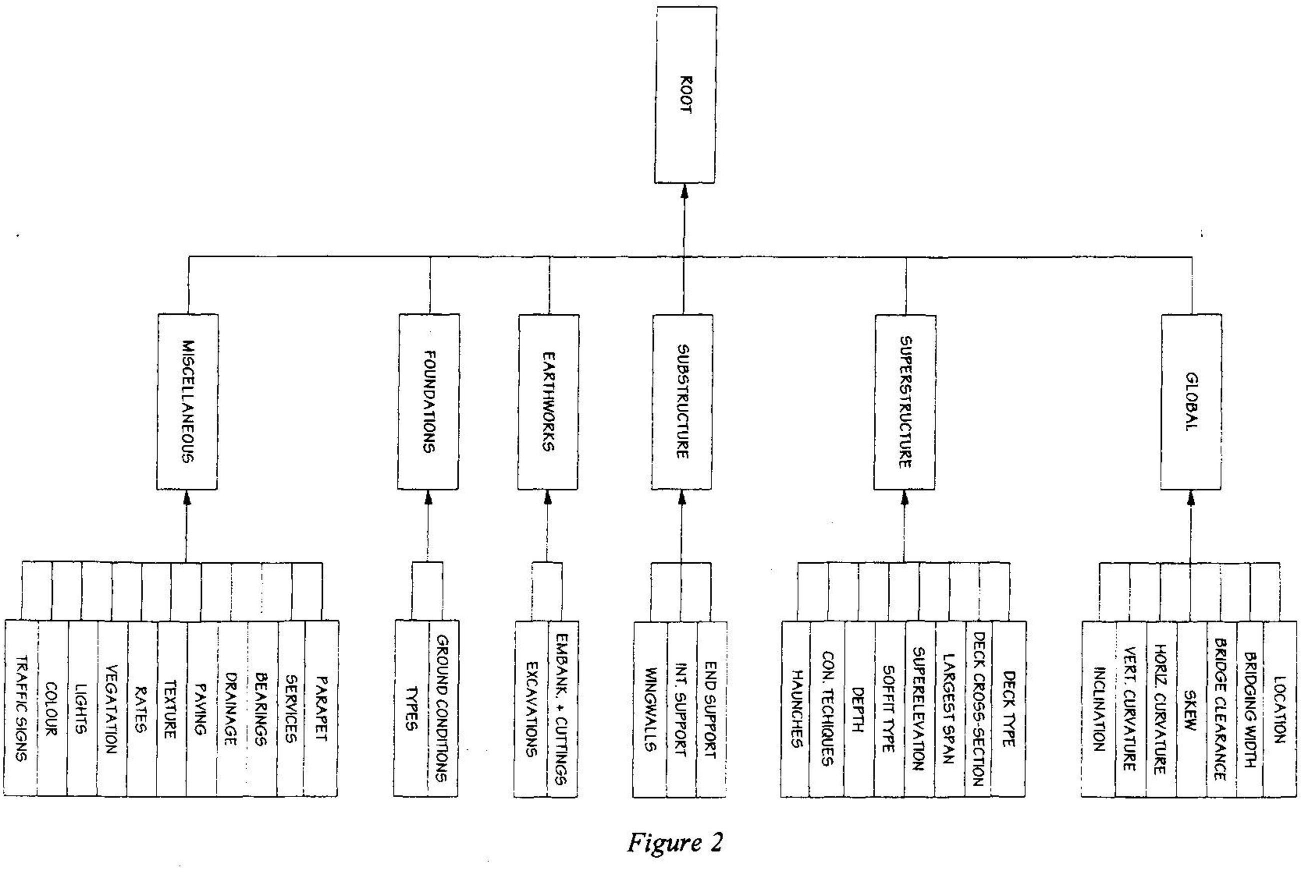

Figure 2

CATEGORY	INPUT	SYSTEMS	TYPE OF INPUT
Topological	Location	1,(2),3,(4)	*descriptive*
	Bridging Width	1,3,(4)	*descriptive*
	Clearance	1,3,(4)	*numerical*
	Skew	1,2,3,(4)	*angle*
	Inclination	(2),3,4	*angle*
	Horiz. Curvature	1,2,3,4	*radius*
	Vert. Curvature	(2),3	*radius*
Super Structure	Deck Type	(1), 2,(4)	*descriptive*
	Largest Span	(1),2,3,(4)	*numerical*
	Deck Depth	1,2,3	*numerical*
	Width	(1),2,3,4	*1,4 - descriptive* *2,3 - numerical*
	Constr. Technique	1,2,(3),4	*descriptive*
	Deck X Section	2,(3)	*descriptive/numerical*
	Soffit Type	1,(3)	*descriptive*
	Superelevation	(2),(3),4	*angle*
Sub Structure	End Support Type	(1*),2,3,4	*1,3,4 - descriptive* *2- descriptive/ numerical*
	Wing Wall Type	(1*),2,(3),4	*1 - angle* *2 - descriptive/ angle* *3,4 -descriptive/angle*
	Int. Support	1,2,3,4	*1,4 - descriptive* *2,3-descriptive/numerical*
Earthworks	Embank / cutting	1,(2),3,4	*1 - descriptive* *2,3,4-descriptive / numerical*
Foundations	Ground Conditions	1,2	*1 - descriptive* *2 - numerical*
	Type	(1*),2,4	*descriptive*
Miscellaneous	Bearings	1,2,4	*descriptive*
	Services	(1),(2),4	*descriptive*

Table 1: Summary of Input Study

The information which needs to be transferred between the systems has been studied using a variety of techniques to show the types of information that are involved and the possible modes of interaction between systems. Firstly, the input and output of each system was listed. The outcome of the study of the input is summarised in Table 1. Numbers 1,2,3,4 represent the systems as described in the previous sections. Only those data used by more than one system are shown. The numbers in brackets indicate that the input is optional as opposed to essential (again enhancing the flexibility of the systems). The numbers showing an asterisk (*) indicate that the user can choose whether to input his/her own criteria or to let the system make the choice.

Many of the items in the input column are single facts or datum but others are more complex. For example deck type can describe the material(s), the form of construction and the shape of the cross section.

Table 1 is also interesting as it shows the overall data requirements for the domain. The data which are common between the systems are, as one would expect, topographical and basic dimensions. There are some variations in format between the different systems but these are fairly minor and should be easy to cope with. In addition to table 1, a series of Venn diagrams showing the overlap of information between various system combinations have been created. Space limitations preclude their inclusion but they have proved to be useful for planning modes of interaction and also they provide a new insight into the design domain structure. To further clarify the workings of the linked systems, a number of tree diagrams (or basic semantic networks) have been created to represent the hierarchy of the domains studied and their inter-relationship. An example of these is shown in Fig. 2.

5. FUTURE WORK

In the immediate future, work will concentrate on developing the individual systems and with an increasing emphasis on the dynamic database. The industrial evaluation of the systems has commenced and it is anticipated that this will produce some changes and new ideas which will be included in the development of all the systems. As well as evaluating the systems, opinions will be sought on the interaction between the systems. Depending on these findings, and in conjunction with the development of the component systems, the interaction architecture shown in Fig. 1 will be further developed.

As has already been mentioned, further additions to the above four systems are planned and work has already started on knowledge acquisition for a foundation design system. Further systems are also planned but as yet funding for these is not available. Further work on linkages to external software is also planned but as the research element in such work is minimal, it is not planned to go beyond feasibility studies.

6. CONCLUSIONS

A suite of systems for the design of bridges has been described. The systems all deal with sub-domains of the overall design problem which is essentially the conceptual stage of the design process. The interaction between the systems is being designed in such a way that the user effectively forms an integral part of the set up. This is felt to be of paramount importance, offering greater flexibility and maximising the strengths and abilities of the designer and the current computing technology.

A study of the data requirements of the various systems has been outlined. This is part of ongoing work into the formulation of a dynamic database which will be used to control and facilitate the interaction between the current systems and future systems. Linkages to other common design software have been investigated and it is not anticipated that these will present any significant problems although with current technology the types of data which can be exchanged are somewhat limited. However it is felt that despite these limitations, such linking has much to offer and to wait until more sophisticated methods are available would waste the benefits of current technology.

7. REFERENCES

1. CORBY, O., Blackboard architectures in computer aided design. Civ Eng Systems. Vol. 4. pp 14-19/1986.
2. COYNE, R.F. AND SUBRAHAMIN, Computer supported creative design: a pragmatic approach, In Gero, J.S. & Maher, M.L. (eds) , Modelling creativity and knowledge-based creative design, Lawrence Erlbaum, USA, 1993.

3. CROUCH, A.G.D., Bridge aesthetics - a sociological approach, Civ. Eng Trans, Inst. Engs. Aust., CE16(2), 138-142/1973.
4. HUANG, G.K. AND BRANDON, J.A., Agents: Object Oriented Prolog for Co-operating Knowledge Based Systems. Knowledge Based Systems 5, (2), 125-136/1992.
5. HOOPER, J.N., A Knowledge Based System for Catchment Planning. Ph.D. Thesis. University of Wales, 350pp, 1994.
6. MILES, J.C. AND MOORE, C.J., An expert system for the conceptual design of bridges. in Topping, B.H.V. (ed), AI Techniques and Applications for Civil and Structural Engineers, CIVIL_COMP Press, Edinburgh, UK, 171-176, 1989.
7. MILES, J.C. AND MOORE, C.J., Conceptual Design: Pushing Back the Boundaries with Knowledge Based Systems. In: Topping, B.H.V. (Ed.): AI and Structural Engineering. Civil-Comp Press/1991.
8. MILES, J.C. AND MOORE, C.J., Practical Knowledge Based Systems in Conceptual Design. Springer Verlag,250pp, 1994.
9. MILES, J.C., MOORE, C.J. AND EVANS, S.R., Deriving Rules for Bridge Aesthetics. Civil-Comp '93. Edinburgh. August 1993.
10. MONTGOMERY, A., Combining SE Discipline With AI Creativity, in Software Engineering and AI, IEE (London), Digest 1992/087, 1/1-1/5/1992.
11. MOORE, C.J., An Expert System for the Conceptual Design of Bridges. Ph.D. thesis. University of Wales. February 1991. 350pp/1991.
12. MOORE, C.J., EVANS, S.N. AND MILES, J.C., Establishing a Knowledge Base for Bridge Aesthetics. To be Published in Structural Engineering Review/1994.
13. MOORE, C.J., LEHANE, M.S. AND PRICE, C.J., Case Based Reasoning for Decision Support in Engineering Design. IEE Colloquium on Case Based Reasoning. London. March/1994
14. MOORE, C.J., MILES, J.C. AND PRICE, G.E., Computational Decision Support and Heuristic Substitution in Preliminary Bridge Costing, In Smith, I.A.C.,(ed), IABSE Colloquium, Bergamo, 1995.
15. PHILBEY, B.T, MILES, C. AND MILES, J.C., The development of an interface for an expert system used for conceptual bridge design. In:Topping, B.H.V(Ed.): AI and Struc Eng, Civ-Comp Press, 87-96/1991.
16. SLADE, Case Based Reasoning: A Research Paradigm. AI Magazine 1991. pp 42-55.
17. SOH, C.K. (1990): An Approach to Automate the Design of Offshore Structures. Ph.D. Thesis. University of Wales. 330pp/1991.
18. WATSON, A. AND BOYLE, A.,Product Models And Application Protocols, in Topping, B.H.V. (ed), Information Technology for Civil and Structural Engineers,121-129/1993.