Expert systems for detail design in building

T. Cornick
S. Bull
University of Reading (United Kingdom)

SUMMARY

Computer-Aided Architectural Design (CAAD) requires detailed knowledge of the construction of building elements to be effective as a complete design aid. Knowledge-based systems provide the tools for both encapsulating the rules" of construction - ie the knowledge of good construction practice gained from experience - and relating those rules to geometric representation of building spaces and elements.

The "rules" of construction are based upon the production and performance implications of building elements and how these satisfy various functional criteria. These building elements in turn may be related to construction materials, components and component assemblies.

This paper presents two prototype knowledge-based systems, one dealing with the external envelope and the other with the internal space division of buildings. Each is "component specific" and is based upon its own model of the overall construction. This paper argues that "CAAD requires component specific knowledge bases and that integration of these knowledge bases into a knowledge-based design system for complete buildings can only occur if every knowledge base relates to a single coordinated construction model".

INTRODUCTION

Building design is a "non-trivial" task and this fact is well demonstrated when attempts are made to model the process in a computer. The advent of the computer and its gradual uptake in the world of construction led many to believe (Broadbent, 1973 and Patterson, 1980) that its power to rapidly process information could lend itself easily to building design. Existing CAD systems offer facilities such as advanced draughting features, "walk throughs' and direct measurement - essentially thermal, structural and "crude" material resource calculation. Although these tools are powerful, they are far from being design aids and are therefore, for all intents and purposes, merely geometric models of construction.

Building design, like other forms of design, is regarded as a reasoning process during which requirements are analysed and solutions processed and evaluated against the requirements. This reasoning is based upon knowledge gained from experience, be it from an individual or an encoded publication concerning the particular subject domain. The complexity of building design arises from the wide range of knowledge domains involved. Building design reasoning is normally associated with the ability to apply "rules of construction" based upon production and performance implications. These implications, in turn, relate to the materials, components and component assemblies used to construct a building.

The AI (Artificial Intelligence) techniques made available by high level computing languages have been shown to help model rule based reasoning (Levitt, 1986). Such systems are referred to as knowledge-based systems. When CAD and KBS techniques are combined, a powerful tool is created for building design. This tool can be used to implement systems that reason (using the KBS) about geometric fonts (using CAD). Some research studies are addressing such aspects as eaves detailing (Radford, 1986), kitchen design (Oxman, 1987) and designing the structural font of high rise buildings (Maher, ????). In this paper we shall use the tent 'knowledge-based design system' to refer to systems with an explicit knowledge component, while the term CAD will imply to the drafting and measurement programs mentioned earlier.

This paper considers two pilot studies being carried out in collaboration with major U.K. building component manufacturers. Both these studies involved the implementation of knowledge-based design system that can provide detailed design advice as part of the component manufacturers marketing strategy. The first of these systems is concerned with brickwork cladding and the second is a system for metal stud partitioning. Both these systems manipulate geometric information and so CAD systems are used as man/machine interfaces.

This paper also contains a section exploring a major problem with existing knowledge-based design systems. This relates to the difficulty of integrating separate component specific systems into a complete building design system.

Finally, we will present our conclusion about knowledge-based systems in building design, together with our views on the future for CAD.

IBSCAD RESEARCH PROJECT

Background To Technology

A leading U.K. brick manufacturer, Ibstock Products Ltd, considered CAD for dealing with the generation of special shape brick components. These are required to suit complex brickwork assemblies, such as arched openings and splayed returns to window reveals, which are typical of current British architecture. Although in outward appearance modem brickwork cladding is comparable with its Victorian predecessor, the similarity ends there. Essentially, the technological problems that have to be resolved are related to material characteristics (there are over 80 different types of brick available), manufacturing implications, structural and performance criteria. The structural and performance problems have arisen as the role of brickwork has changed from purely structural, to one of a decorative external envelope for buildings. Modem brickwork must look good and provide proper thermal and moisture control.

The current research project is addressing both the problem of CAD generated special shapes (an ACROPOLIS system has been selected because of its inherent 3-d capability) and building a knowledge-based design system for evaluating brickwork proposals. The knowledge-based design system (known as BERT) currently uses AutoCAD for its graphical man/machine interface. Ultimately, BERT will be integrated with the special shapes system.

BERT - The Brickwork ExpeRT

BERT was designed according to the conventional knowledge based systems model of a central knowledge base, an environment in which the knowledge base operates and a man/machine interface. The motivation behind BERT was to investigate how far a knowledge base and a computer-aided draughting system could be integrated on a PC. The knowledge domain chosen was brickwork cladding and initial implementations of BERT focused on the problems of movement joints. A human expert was selected as the source of this information. BERT is implemented as a design advice system. Designers describe their construction, particularly the brickwork cladding and they possibly include a proposal for the movement joint layout. BERT comments on this design, pointing out problems and suggesting remedies. The designer may then incorporate these suggestions into the initial design and the whole process is repeated until either BERT accepts the design as being the best solution or the designer decides to ignore BERT's advice on the grounds that it is too pedantic.

In the following section, the component parts of BERT are examined and a sample interaction is provided to illustrate the system's expertise.

Input to BERT - graphical descriptions of brickwork cladding:

Knowledge about movement joints within brickwork cladding requires a large amount of spatial information, hence BERT uses a graphical man/machine interface to ease communication between designer and knowledge base. The computer-aided draughting package AutoCAD was chosen for two reasons: its macro language AutoLisp is very powerful and it has facilities for attaching attributes to drawings. The major disadvantage with AutoCAD is its limitation to 2 dimensions. However, when 3 dimensions are required a compromise is reached and a formalism known as "face representation" is used (Bowen et.al. 1986). This allows the user to input individual brickwork faces rather than a complete 3 dimensional building.

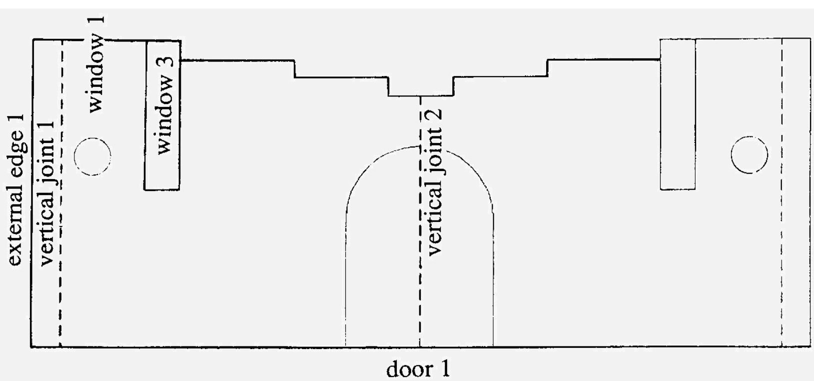

Figure 1 A building elevation using the face representation model

Examination of the knowledge domain seems to indicate that there are a finite number of building elements that can affect the layout of movement joints. These include brickwork edges, openings, downpipes, other movement joints and parapets. The user constructs a brickwork face by selecting a building element from a menu and then locates it within the drawing. Each brickwork face representation (see Figure 1) generally provides the following information:

- the outline geometry of the face
- the position, shape, size and classification of each element in the face
- horizontal and vertical cross-sections through the face, giving information on the spatial relationships between elements
- mid-points of brickwork piers and other areas of brickwork.

Finally, by relating the individual faces to one another the knowledge base can "understand" the whole construction.

BERT's knowledge base:

The deamon form of the procedural knowledge formalism was found to be the driving force behind the domain experts knowledge and so this was used as BERT's overall control mechanism. Hence, BERT may be regarded as a forward-chaining expert system.

BERT's movement joint knowledge base comprises three main groups of deamons. Group 1: provides general remarks on the movement joint layout proposal. Group 2: remarks upon the location of individual movement joints. Group 3: suggests possible improvements to a joint's location.

Other rules, such as those for printing results, are not considered as part of the actual movement joint knowledge.

Example of BERT's expertise:

Figure 2 shows an example result from a request for a detailed examination of vertical movement joint I on the face shown in Figure 1.

GYPCAD RESEARCH PROJECT

Background To Technology

British Gypsum Ltd, (manufacturers of plasterboard products and suppliers of metal stud partitioning) is considering the use of computers to help respond to customer requirements for "standard" and "special" performance criteria from their products. These criteria include fire resistance, sound insulation, structural stability, minimum thickness and maximum height. In the case of metal stud partitions, a wide range of values for the criteria can be obtained by altering the design specification with regards to the number, types and location of components. For example, the number of partition boards used affects the overall structural stability, fire resistance, thickness and height. Each design specification -combination of components - has material cost and construction time implications.

At present, British Gypsum provides two pools of information that help customers to select the partition system that suits their specific application. The first of these is a publication that contains a catalogue of design specifications and associated performance values. A second pool of knowledge is

Face: 6
Name: vertical-joint-I
Position: 1000mm right of external-edge- I

Comment
12625mm left of vertical-joint-2
The gap of 12625mm between vertical-joint-I and vertical-joint-2 exceeds the maximum permitted separation (12000 mms). A vertical joint is required within this area. However, if a brick type with a smaller coefficient of expansion were selected, this problem would not arise.

Suggestion:
New Position: 3150mm right of external-edge-I
Reason: This location is at the middle of a pier. Placing a movement joint at such a position is usually aesthetically pleasing.
Reason:
No further joints are required to protect the adjacent areas of brickwork.

Figure 2 An example of a consultation with BERT

available for detailed information. This comprises a number of human experts, each of whom has specialist knowledge about a specific aspect of partition design. These experts provide information that is in addition to the catalogue and, where necessary, they can propose new design specifications to suit "special" performance criteria.

The current research project has examined both pools of information about metal stud partitions and is now addressing the problem of developing a knowledge base to completely embody this information. A knowledge-based design system has been implemented to demonstrate the feasibility of this proposal. The system currently works in a purely textural mode. However, plans are underway to expand this system and incorporate a graphical facility which both accepts information graphically (as working drawings) and produces drawings of design specifications.

GERT - A Metal Stud Partition Expert

GERT has knowledge about the domain of metal stud partitions. GERT has two main functions: it is a component selection system and an automated component designer. We shall discuss these two roles as if they were separate, although in reality component design occurs as a result of the component selection system failing to find a suitable standard component.

Component selection:
GERT has access to a catalogue of all British Gypsum's standard metal stud partition systems. Each partition system is described according to a number of elementary parameters. These include the number of partition boards, the type of board, the metal stud size, cross section and gauge and whether the system has a cavity fill. Each partition system also has a set of characteristics, such as thickness, height, weight, fire resistance (in hours) and sound insulation (in dBs). When a user makes a request for a partition system he does so by specifying the characteristics that he wants the system to meet.

GERT processes a user's request by finding all of the partition systems in the catalogue that match the user's specification. If there is only one suitable system this is selected. Otherwise, the alternatives are compared and the one that is deemed cheapest is selected. Most of the component selection task is pure data-base retrieval, however, the factors that govern cheapness are expressed in a rule based form. Thus, GERT exhibits intelligent data-base retrieval.

Component design:

If the British Gypsum metal stud catalogue does not contain a partition system that matches the user's specification, GERT proceeds into component design mode.

Knowledge about each of the subcomponents of metal stud partitions is used to generate new designs. This knowledge includes, for example, the rule:

> *the use of two partition boards, instead of one, increases the maximum system height by 1200mm, increases the sound insulation by 12dB and doubles the fire resistance.*

Once again, if a number of suitable partition systems are generated then they are compared and the cheapest is selected.

User Specification:

* Maximum Thickness -	200 mm	*Height -	9600 mm
* Weight -	unknown	*Fire Resistance -	1 hour
* Sound Insulation -	52 dB		

Additional Requirements:

Does the partition have a ceramic tile covering? ---- yes
To what height do the ceramic tiles come? - 3000 mm
Will the partition be subject to moisture? - yes
In what type of building *will* the partition be used? ---- unknown

Selected Partition: 2 layers of 12.5mm wallboard each side of 0. 55mm gauge 146mm fully boxed studs, no cavity mat and stud centres of 600mm.

Additional Advice: To help support the load of the ceramic tiles and maintain partition rigidity, it is advisable to reduce the stud centres to 400mm. Additional Advice: To help the partition withstand moisture, it is advisable to use moisture resistant boards in place of the wallboard.

Figure 3 An example of a design specification produced by GERT

Figure 3 shows GERT's output for a specification that does not match any of the partition systems known to the British Gympsum catalogue. However, it must be stressed that this is an example and has not been validated by British Gypsum, neither has the knowledge used to generate it.

An additional knowledge base has been incorporated to augment the choice of a suitable partition system. This knowledge base reasons about how the partition selected will perform within its environment. For example, if tiles are going to be hung on one side of the partition, then it is advisable to introduce intermediate studs, thus maintaining rigidity. GERT also considers the type of building that the partition is destined for. This additional knowledge base has the power to veto a partition by calling for alternatives. Hence, if a system is discovered to be unsuitable for its application, a better one is found.

A COMPONENT SPECIFIC CONSTRUCTION MODEL

Ultimately, the construction industry is looking for knowledge-based design systems that aid the design of whole buildings (Wix, 1986) and not just individual elements, as in the case of BERT and GERT. Such systems would allow designers to manipulate the spatial arrangement of their buildings, while maintaining compliance *with* the rules of component assembly. Detail design could be automatically verified, thus production requirements would become more immediately understood (Atkin, 1987). The benefits of this are that all the 'technological" factors would be taken into account at the same time, thus avoiding the need for later changes to suit component details. For example, during the conceptual stages of building design the proposed form could be automatically assessed for compliance with brickwork cladding rules. If the form was deemed unfavourable, then appropriate actions could be taken at a far earlier stage in the design than at present.

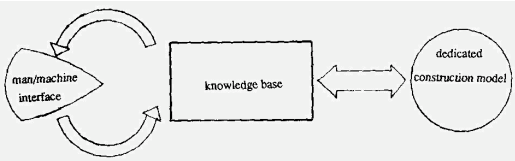

Figure 4 A traditional tripartite knowledge-based design system

So far, knowledge-based design systems have been developed using a simple tripartite model. Each knowledge-based design system comprises a single knowledge base, an environment - we shall refer to this as the construction model - and a man/machine interface (see Figure 4). As an outcome of the BERT and GERT projects we believe that the construction industry should not use this model as a basis upon which to design future knowledge based systems. This belief stems from a number of factors, however, for the purpose of this paper we shall present just two.

1. Few knowledge-based design systems can interact with one another. Knowledge-based design for whole buildings involves the interaction of a large number of different knowledge domains (each knowledge domain possibly being represented by a separate knowledge-base). For this type of interaction to be possible, there needs to be a central construction model of the design from which each knowledge base can obtain information. This model would need to be general enough to encompass all the possible aspects of building design, yet detailed enough to provide a complete description with respect to each. The problem with existing knowledge-based design systems is that each one is based upon its own highly specialised construction model, and this contains only that information relating directly to the knowledge base. None of these models are general enough to be used as the basis for a knowledge-based design system for complete buildings.

2. A large factor included in the development time for knowledge-based design systems, is related to the implementation of the construction model. In the case of BERT, this was found to involve approximately one third to one half of the project. Since a generic construction model has not been designed, each development project must, presumably, waste a similar amount of time. The solution to this problem is to design a generic construction model that can be used as the basis for all future knowledge-based design systems.

The above two factors clearly illustrate the need for a new type of construction model. This new model we shall call the coordinated construction model.

The Coordinated Construction Model

Figure 5 shows a schematic representation of a knowledge-based design system using a central coordinated construction model. This should be compared to the traditional tripartite system shown in Figure 4. The system shown in Figure 5 incorporates the idea of multiple knowledge bases which are each connected to a central coordinated construction model. One should note the position of the graphical man/machine interface which is regarded as a knowledge base in its own right. The reason for this is apparent if graphics are seen as a representation of the ability to manipulate real objects, which is itself constrained by the laws (rules) of physics. Hence, the man/machine interface is a knowledge base in the domain of physical manipulation.

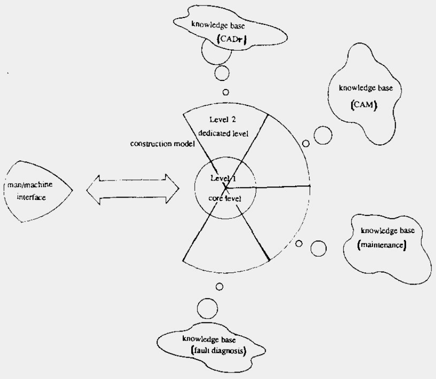

Figure 5 A knowledge-based design system using a central coordinated construction model

An examining of the coordinated construction model in more detail, suggests that it should consist of two levels. Firstly, the core level, which should be a data- base which describes the building design. The core level will contain descriptions at many levels of abstraction, and this will allow the coordinated construction model to be both general (high-level abstraction) and detailed (individual component descriptions). The second level of the model will serve as the interface between model and knowledge bases. Hence, this level will be segmented amongst the various knowledge bases as appropriate.

CONCLUSIONS

A system can only design if it understands the true physical nature of building elements. CAD systems will become aids to design only if they start modelling more *than purely* geometrical information. A number of component specific knowledge-based design systems have been developed that employ CAD as a man/machine interface. These system use their own, highly specialised, models to represent buildings. This means that, although they do aid design at the component level, they cannot be used for designing whole buildings. Knowledge-based design systems that aid whole building design must model the interaction of building elements and therefore they must reason in multiple knowledge domains.

The next steps in the development of knowledge-based design systems will need to address the problem of how the numerous component specific systems can be integrated into a single whole building design system. This must involve answering the questions: "What is the role of CAD - is it purely a draughting aid or should it represent the physical nature of elements ?'; "How can we model whole buildings ?"; 'How can we integrate different knowledge bases into a single system ?".

This paper has addressed the subject of design, however, this is not the only domain of knowledge in the construction industry that can be computerised. Computer-aided manufacturing, computer-aided process planning, scheduling, building maintenance and fault diagnosis are all domains of knowledge that reason about buildings and require construction models. A truly coordinated construction model must be capable of providing all of the relevant information needed by each of these knowledge domains.

Finally, if it is possible to integrate design, manufacture, maintenance and fault diagnosis into one knowledge-based system then it might be possible to incorporate feed-back. The results of a construction failure would be examined and used to update the designer, thus alleviating the fault from future projects.

REFERENCES

Atkin, B.L. CAD Techniques Opportunities for Chartered Quantity Surveyors , Surveyors Publications, London, (1987).

Bowen, JA T.C. Cornick and S.P. Bull, 'BERT - an expert system for brickwork design', in Research and Development in Expert Systems HI , by M. Brammer, Cambridge Press, (1986).

Broadbent, G. Design in Architecture, John Wiley and Sons, Chichester, (1973).

Fawcett, W. Linking Graphics and Inference Centre for Configurational Studies, The Open University, Milton Keynes, (1987).

Lawson, B. 'Integrated CAAD for building design', Construction Computing , (winter 1987).

Maher, M.L. and J.S. Fenves, HI-RISE An Expert System for the Preliminary Structural Design of High Rise Buildings ,Dept. of Civil Engineering, Carnegie-Mellon University.

Oxman, R. and J.S. Gem, 'Using an expert system for design diagnosis and design synthesis', Expert Systems The International Journal of Knowledge Engineering Vol.4, no.1 (Feb. 1987).

Paterson, J. Architecture and the Microprocessor , John Wiley and Sons, Chichester, (1980).

Radford, A.D. and J.R. Mitchell, 'Automated architectural detailing : a knowledge-based approach', Proceedings of the 10th. Triennial Congress of the International Council for Building Research Studies and Documentation Vol.2, Sessions 4,5 and 6, (1986).

Wix, G. Proposed Pilot Studies on the Definition of the Requirements of a Coordinated Building Model, BSRIA, (May 1986)