19. N.J. Nillson, "Principles of Artificial Intelligence", Springer Verlag (1982).
20. F. Preparata, T. Yeh, "Introduction to Discrete Structures for Computer Science and Engineering", Addison Wensley (1963).
21. A.A.G. Requicha, H.B. Voelcker, "Solid Modeling: a Historical Summary and Contemporary Assessment", IEEE Comp. Graph. Appl. 2 no.2, (March 1982) pp. 9-24.
22. A.A.G. Requicha, H.B. Voelcker, "Representation for Rigid Solids: Theory, Methods and Systems", Computing Surveys, 12 no.4, (December 1980), pp. 437-464.
23. A.A.G. Requicha, H.B. Voelcker, "Boolean Operations in Solid Modeling Boundary Evaluation and Merging Algorithms", Proceedings of the IEEE, 75 no.1, (January 1985), pp. 30-34
24. R. Schenk, R. Abelson, "Scripts, Plans, Goals and Understanding", Lawrence Erlbaum Associates, Publishers (Hillsdale, New Jersey, 1977)
25. M.I. Stefik, "Planning with Constraint", Stanford University (1980).
26. P.H. Winston, "Artificial Intelligence", Addison Wesley (1984)
27. P.H. Winston and B.K.P. Horn, "LISP", Addison Wesley (1984).

A knowledge-based 'expert system' for brickwork cladding design & production

Timothy Cornick & James Bowen

Departments of Construction
Management & Computer Science,
University of Reading RG6 2BU, UK.

KEYWORDS

Expert System, Building Design, Component Assembly

ABSTRACT

Increasing use is being made of 'special shapes' for bricks and brickwork elements in cladding UK buildings. Certain colours and textures are also required for these proposed elevational forms. When selecting one or more types of brick from a wide 'material range', verification is necessary to ensure that structural and weathering criteria will be fully satisfied in any proposal. It is also necessary to know the implications for brick component manufacture and brickwork assembly of the particular shape/material combination proposed. This paper describes a computer aided design system which addresses both aspects of the task of brickwork design. There are two parts to the system. The first part is a 3-d graphics facility which allows the designer to visualize proposed elevations and details. The second part is an expert system which uses data about the characteristics of available bricks, information about the demands of the particular design context and experiential knowledge of 'good practice' in brickwork. This is to ensure the chosen design is functionally satisfactory and all the implications for manufacture and assembly have been considered. The system is being developed in conjunction with a major brick manufacturer, whose design staff are providing the experiential knowledge which is incorporated in the system using an expert system language.

Un 'système d'expert' à base informatique pour le design et la production des revêtements en brique

Timothy Cornick & James Bowen

Section de Construction et d'informatique, Université de Reading, Reading RG6 2BU, UK.

MOTS CLEFS:

Système d'expert, design de construction, assemblage des pièces.

SOMMAIRE:

On emploie de plus en plus fréquemment des briques et des élements de briquetage 'de forme spéciale' dans le revêtement des bâtiments en GB. En plus, certaines couleurs et certains grains sont nécessaires pour ces genres d'élévations proposées. Quand on choisit un type, ou plusieurs types, de brique d'une large 'gamme matérialle', il faut vérifier afin de s'assurer que les critères de structure et d'érosion de n'importe quelle proposition seront pleinement satisfaits. Aussi est-il nécessaire de constater les implications de la combinaison forme/matériel proposée pour la fabrication des pièces de brique ainsi que pour l'assemblage du briquetage. Cette communication propose un système de design géré par ordinateur qui s'adresse aux deux aspects du travail de design du briquetage. Le système so compose de deux parties. La première est une facilité graphique à 3 dimensions qui permet au dessinateur de représenter les élévations et les détails proposés. La seconde partie est un 'système d'expert', utilisant des données sur les caractéristiques des briques disponibles, des informations sur les exigences d'un contexte de design particulier, et une connaissance expérimentée du 'bon usage' dans le domaine du briquetage. Tout cela vise à assurer que le design choisi est conforme aux exigences fonctionnelles, et que toutes les implications pour la fabrication et pour l'assemblage ont été considérées. Nous développons ce système conjointement avec un important fabricant de briques dont les dessinateurs fournissent la connaissance expérimentée qui a été incorporée au système en utilisant un langage de programmation du 'système d'expert'.

INTRODUCTION

Knowledge-based expert systems are currently being considered for building design and construction management. Their ability to cope with 'concepts, ideas, judgement and experience' as opposed to just 'numerical descriptions or procedural representations'(1) makes them suitable for many building applications with which traditional computing techniques cannot cope. Typical problems being addressed range from space arrangement in design (2) to crane positioning in construction (3) and in both these situations the 'knowledge' requires 'graphical' representation for presentation. Another important area in building where 'judgement and experience' is required is in detail design when components are selected and assemblies determined to suit a particular proposed scheme design. Problems of building failure stem from a misuse of materials and components in detail design because all the implications of performance and production in assembly are not known. The need for a comprehensive knowledge base in building technology has been cited as a requirement for construction research (4) and in the author's opinion, individual knowledge-bases for specific components (preferably integrated with graphics) are vital in future computer-aided design systems for buildings (5).

A SPECIFIC COMPONENT KNOWLEDGE DOMAIN

There are two main reasons why building component assembly lends itself so readily to the application of knowledge-based expert systems. Firstly, buildings comprise 'exceedingly diverse materials/components' (6) and unless their individual 'rules' are observed in whole assemblies - a risk of failure exists. Secondly, each material/component presents a comparatively narrow domain of knowledge in building design, which is suggested as pre-requisite for developing 'knowledge-based' expert systems (7). Two things are important in the development of these types of computer-based systems. In the first instance, their integration with graphics must be seriously considered because in practice assembly detailing is designed largely on the basis of visualization. In the second instance, it is important that they can be related to scheme design decisions, (ie, overall building form and material finish) and to other specific component 'systems' for the assessment of whole building elements. With the continuous improvement of micro-computer hardware and software - and the consequential wider use of CAD because of lower costs - the development of these systems specifically for micro-computer applications must also be considered (8).

Under the influence of the 'Post-Modern' architectural style and for obvious weathering advantages, polychromatic and 'special shape' facing brickwork is now widely used for all types of 'non-domestic' building in the UK. Its detailed construction application is however fundamentally different from that of facing brickwork in historic buildings which modern design is trying to emulate. The main distinctions are that the facing brickwork is separated from the main building structure by a cavity which often contains insulation, a large range of material types may be used in a variety of locations, 'pre-assembled elements may be used instead of insitu construction and unique shaped brick components are often required on a project by project basis. In order to design the 'brickwork', mortar jointing and metal supporting and tying materials must also be taken into account. As a specific domain of building knowledge to be studied, modern brickwork cladding therefore offers a 'traditional' material whose building characteristics are well understood but an 'innovative' assembly situation in which problems of performance and production could still occur. Existing brickwork 'knowledge' can be found in mainly two sources - encoded in standards and codes of practice (9) and in the experience of those who give specialist advice in support of marketing bricks as a building product (10).

Brickwork was therefore selected as a specific component for knowledge-based expert system development with micro-computers because:

1. As a widely used building material, the developing system could be readily tested in practice.

2. The fundamental knowledge is widely accepted and readily available because of 'traditional' use (but 'modern' methods of assembly can present problems.)

3. Detail design requires a high degree of visualization, and in particular 3-d for special shape assembly, so that 'knowledge/graphics' integration is important.

4. The combined knowledge-base and graphics facility would make a high demand on computing power for integrated processing and therefore provide a good test for micro-computer applications.

It is also suggested that the fundamental mechanisms developed in a computer-based system for brickwork could be used for other specific building components (eg, blockwork, windows, steel frame, etc). Ultimately a suite of knowledge-based expert systems could be developed for a range of specific components and integrated through a 3-d 'modelling' graphics facility. This would be supportive of the method in which buildings are usually designed in that building forms (ie, plan sections and elevations) are first defined and materials and components selected to suit them (11).

THE IBSCAD RESEARCH PROJECT

A pilot study (12) showed that there was sufficient complexity in the material/shape relationship between a large range of brick types and special shape requirements to warrant a 'knowledge-based' expert system approach to brickwork cladding. A three year research project was commissioned, jointly funded by the Government and a leading facing brick manufacturer (13) to develop the system. This arrangement meant that the 'experiential knowledge' of the various experts within the company - as well as the 'knowledge' in a new masonry code of practice - could be incorporated within the system which could be tested in practice in the company's numerous design centres. Advice is given in these design centres to potential customers on the detail design of brickwork cladding in support of marketing their own brick products. The developed system will therefore have to survive in a very demanding environment, and also provide an effective means of controlling and co-ordinating design advice throughout the manufacturer's organization. How much the system will eventually control

brick production in the factory and brickwork construction on the site are issues that will be raised by its very existence within the manufacturer's organization. As the research project began with the manufacturer's desire for CAD graphics in their design centres to aid their design advisers in solving 'special' shape problems the work contains two distinctive but related parts.

1. <u>Graphics Facility</u> The manufacturer was very concerned with the image presented to clients and there was a need for highly manipulative 3-d graphics so existing CAD systems were examined for customization potential.

2. <u>Knowledge base</u> The knowledge of brickwork is not necessarily directly dependent on graphical input and output for representation so the knowledge-based expert system is being developed independently of the 3-d graphics facilities.

It was also decided, as a marketing policy, that the 'expert system' should support rather than replace the human brick adviser in the design centres and that the graphics faclity - particularly 3-d - would be the most important part of the system to the customer. The initial stages of the research has however shown both the possibility and usefulness of integrating the knowledge base with 2-d graphics.

THE GRAPHICS FACILITY

The pilot study showed that certain graphical routines were required if a computer-based system were to work to the manufacturer's advantage in the design centres. They were as follows:

1. The storage of special shaped components which could be called up to fit a special shaped assembly detail - in order to determine if 'standard' special shapes could be employed to suit a particular situation.

2. The automatic generation of a 'special' special shaped component when a particular assembly detail was proposed - in order to determine the size and shape of the brick components for manufacture.

3. The automatic generation of quantity and shape of bricks contained in an arch on elevation when its geometry has been defined - in order to determine whether joints of bricks should be 'tapered'.

4. The automatic adjustment of a proposed elevation to a brick dimensional discipline when a particular bond has been defined - in order to determine a correct relationship between scheme and detail design and quanficiation of brick components.

It was also important that any general CAD system could be customized for ease of use because of the intermittent use by the brick adviser in the design centre (ie, this was not to be a drawing office situation where the system would be continually used) and speed of processing and image of display was of a high quality suitable to a client advice service.

The results of the graphics facility study so far are that:

1. A true 3-d modelling system provided the only effective basis for the graphical routines requires as 2-d draughting systems - even with a 3-d viewing - could not readily cope with transferring stored components into defined assemblies in a three dimensional mode.

2. The required speed of processing and quality of image display for varying and reviewing components in an assembly could not be achieved with current micro-computer based CAD systems.

3. Colour graphics would be useful only for distinguishing materials in a brick assembly and the facing surface of a special shape brick component and not for portraying the real colour and texture of a particular brick.

A CAD system that runs on a mini-computer has been initially selected and is to be purchased by the manufacturer for customization. Although both 'surface' and 'solid' modelling systems could be considered desirable for certain aspects of brick design, true 3-d modelling, with hidden line removal seems to offer the best all round approach for investigating brickwork - from component to elevation. However, the ability to surface model brick components in some detail will have ultimately to be considered as probably an additional module to the main system.

THE KNOWLEDGE BASE

The development of the knowledge-base is providing an opportunity to study the fundamental knowledge of a particular aspect of building technology. This essentially entails the ability to understand how the basic characteristics of a material or component will influence the production and performance of an assembled element as part of a whole building. 'Production' can be taken to mean the manufacture of a component in the factory and the assembly of the component - with others - into the building element on site. 'Performance' can be taken to mean the various aspects of durability (eg, weathering, thermal fill etc) of the component when formed into an assembled element as part of a building over a period of time. Knowing the interaction between them is important to construction management.

A multi-formalism Artificial Intelligence language (14) is being used by a 'knowledge engineer' to represent such knowledge acquired from the manufacturer's experts in such a way that it can be 'executed' by a computer. The first expert being interviewed is a design adviser who discusses with clients how the architect's proposed elevations can be achieved by applying good practice 'rules'. These 'rules' are based upon his experience and a code of practice for masonry. In order to begin the work it was decided to concentrate on a particular aspect of brickwork design in order to establish a pattern for knowledge acquisition, representation and presentation. Two important issues were to be decided during the first period of study. They were:

1. Should the system 'generate' brickwork design from the 'rules' or 'verify and suggest improvements' to a proposed brickwork design?

2. What sort of relationship would be the most useful between 'knowledge-base' and 'graphics facility' with particular reference to 2-d and 3-d viewing?

One of the major problems that can occur with facing brickwork is thermal expansion, so 'rules' for the location of movement joints regarding size and shape of a brick clad elevation were the first set of knowledge to be incorporated in the system. The result of applying these 'rules' could be best expressed by lines on a drawn elevation and it was possible to make the computer rule base issue commands to the graphics system to generate lines in particular locations. Although the rule base system could, therefore, 'generate' movement joints for elevations which had not been considered with respect to this criterion, it was decided that the rule-base should verify lines already drawn. This was because:

1. The most likely situation in practice is that the building designer would have already considered movement joint location in conjunction with other elements.

2. Examining a raw elevation for the 'optimum' positioning of movement joints, is an image recognition task which would require more computing power than can be delivered by the present generation of micro-computers.

The next section of 'rules' that has to be considered is the brick dimensional discipline of the elevation - as movement joints have to occur at brick joints - and then the structural stability implications of areas of brickwork left between movement joints and other opening and pier elements.

So far the study has shown that:

1. Simple 'rules' - position of movement joint - become complex when other 'rules' have to be taken into account, brick dimensional discipline and structural stability of areas of brickwork.

2. Certain 'rules' are best understood by the user through known graphic conventions - eg, a vertical line close to a rectangle as symbol means that a movement jointis close to an opening in reality. This knowledge integration between graphics and knowledge can be achieved in the system being constructed because the graphics system in use, AUTOCAD, can produce on demand, textual descriptions of its drawings. These textual descriptions can then be assessed by the knowledge base rules.

3. Movement joint 'rules' can be related by and large to 2-d graphics and 3-d graphics are not required. By storing textual attributes in AUTOCAD even the difference between an internal and external corner on elevation can be determined. Also communicating with a 3-d graphics package may yet prove very computationally expensive.

Building the knowledge base, with the aid of an expert, demonstrates that the rules are not absolute and uncertainty prevails. Correctness of answer depends on circumstances and existing encoded knowledge - ie, in code of practice - is superficial compared with expert experience applied to a particular situation, eg, code only states maximum distance between movement joints. Detail design by computer would appear to be best, a verifier - rather than generator - of proposed solutions required in the scheme design.

CONCLUSIONS

The three major issues that are being addressed in this research are therefore:

1. In modern building technology how can the various scattered sources of knowledge of component assembly be integrated and formally represented for scheme proposal analysis?

2. In computer aided design how can non-geometric data for design be integrated with graphics having regard to the usefulness of 2-d or 3-d representation.

3. In knowledge engineering what are the features required in A1 programming languages intended for use in CAD of buildings and how best can communication be achieved between textual design rules and graphical representation of the results of applying these rules.

References

1. J Gero, An Overview of Knowledge Engineering and its Relevance to CAAD, CAAD Futures, Delft, (1985).
2. E Shaviv, Layout Design Problems and their Systematic Approach, CAAD Futures, Delft (1985).
3. C Gray & J Little, A Systematic Approach to the Selection of an Appropriate Crane for a Construction Site, Construction Management & Economics 3 pp 121-144 (1985).
4. W Atkins, Latent Defects in Buildings: An Analysis of Insurance Possibilities, A Report for Building EDC (1985).
5. T Cornick, The Design Process, An Architect's View, ESCAD '85 Workshop, University of Reading (1985).
6. B Martin, Chapter 6, Building, Standards and Building (RIBA Publications Ltd, 1971).
7. R Allwood, Report on Expert System Shells Evaluation for Construction Industry Applications, University of Loughborough (1985).
8. B L Atkin, T Cornick and E M Gill, CAD on a Micro: How Far Can we go? Construction Industry Computer Conference, CICA UK (1986).
9. Code for Structural Use of Masonry, Part 1, BS 5628 (British Standards Institute, 1985).
10. B Hall, Brickwork Design Magazine 2 (Ibstock Building Products, April 1985).
11. G Broadbent, An Environmental Design Process, Design in Architecture (John Wiley and Sons, 1978).
12. T Cornick & J Bowen, A Computer-Based System for the Selection and Production Control of Brickwork (SERC and Ibstock Building Products,'85)
13. J Bowen, A Multi Formalizm Programming Environment for Knowledge Engineering and Expert Systems, Reading (1986).

Expert Systems prototypes applied to the Building field

Bertrand Delcambre et Delphine Halleux

Centre Scientifique et Technique du Bâtiment (C.S.T.B.)
Etablissement de Sophia Antipolis
Boîte Postale 21
06562 VALBONNE CEDEX, FRANCE

KEY WORDS :

C.A.D., Expert Systems, Prototypes

Summary :

New information processing techniques gathered by the name of Artificial Intelligence will probably come to maturity in the years 1985 to 1990. They will contribute to extend the Computer-Aided Design concept exclusively restricted today to an algorithmical approach. In particular, Expert Systems are relevant to a more efficient reasoning by computers than men on a bulk of statement knowledge. Their interest is also due to their structure and using mode. So, it is logical to think that the building field will be favourable for Expert Systems for numerous applications : aided choice, agreement with rules, elaboration of solutions, diagnosis, plan management ... At this time, some attempts have been successfully performed by French teams or architects, engineers and computer scientits. For his part, C.S.T.B. has started the development of prototypes for aided choice applications ; choice of technical solutions in accordance with technical and economical constraints and/or regulations. This first attempt has been conducted with the aim of testing the Expert System approach relevance in the building field, and estimating the performance to be expected with these new tools from the hardware and software points of view.