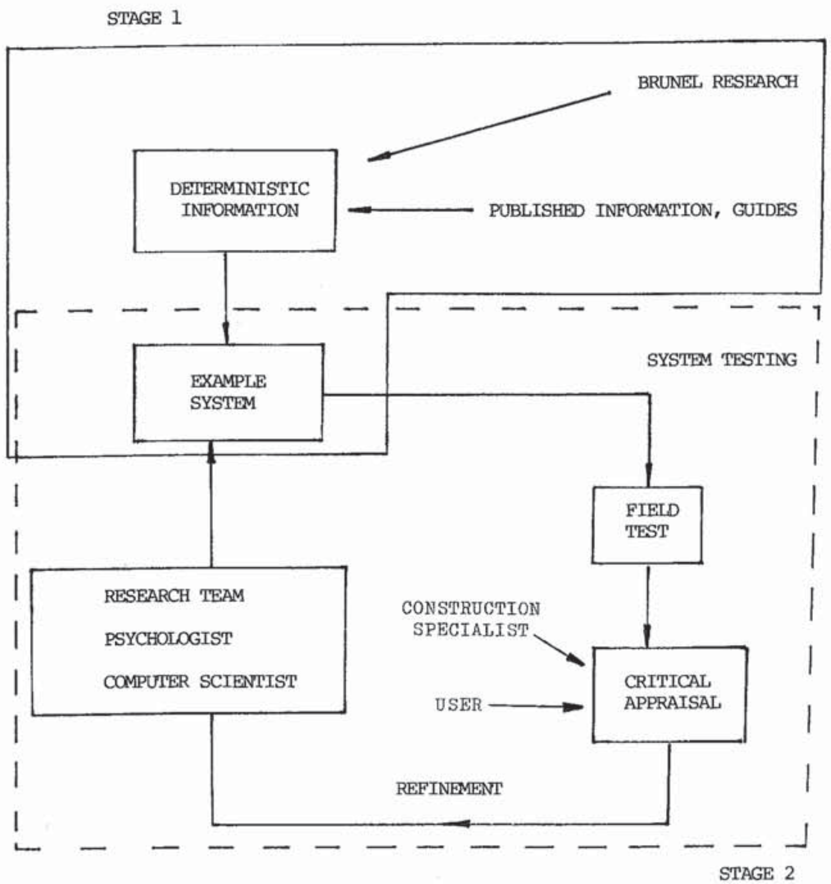

Fig. 1. Expert System Development Path

Optimization and Expert Systems in Building and Urban Design

R. Sharpe, J.F. Brotchie and B.S. Marksjö
CSIRO Division of Building Research
P.O. Box 56, Highett, Victoria 3190, Australia

KEYWORDS

Optimization, Expert Systems, Building Design, Computer-aided Design.

ABSTRACT

A centre for collaborative research on knowledge-based systems for computer-aided decision has been established at CSIRO Division of Building Research, Australia. The research is an extension of previous Divisional contributions to the mathematical basis for automated optimal design and planning with applications to urban planning, building and industrial layouts.

The research is focussed in two areas: (1) development of expert systems for design and planning and for transfer of building technology, and (2) development of intelligent optimization techniques as engines for CAD systems.

Expert systems being developed are based primarily on the Division's own expertise in the areas of building technology, e.g. sealants, water penetration, and of planning and design methodology, e.g. wind loading code.

Initial optimization research is focussed on seeking improved optima in non-convex quadratic programming problems such as the layout of systems and facilities, including hospitals, commercial buildings, industrial and urban layout problems. The use of the simulated annealing method (SAM) as an intelligent optimization technique (with colour graphics) for building layouts will be illustrated, and its potential for use as a simulated learning tool will be discussed.

Optimisation et Systemes Experts pour le Bâtiment et L'urbanisme

R. Sharpe, J.F. Brotchie and B.S. Marksjö
CSIRO Division of Building Research
P.O. Box 56, Highett, Victoria 3190, Australia

MOTS-CLÉS

Optimisation, Systèmes Experts, Conception du Bâtiment, Conception Assistée par Ordinateur.

SOMMAIRE

Un centre de recherche pour l'étude des systèmes informatiques à base de connaissances (knowledge-based systems) pour l'aide a la décision par ordinateur vient d'être établi par le CSIRO (Division of Building Research). Les recherches y seront une extension des précédentes contributions de la Division aux bases mathéthematiques de la conception et de la planification automatisées, avec application aux domaines de la planification urbaine, et de la répartition d'activites au sein d'un bâtiment ou d'un site industriel.

Les recherches porteront dans deux directions: (1) développement de systèmes experts pour le conception et la planification et pour le transfert des techniques de construction, et (2) développement de techniques d'optimisation intelligentes comme moteurs de systèmes de CAO.

Les systèmes experts en cours de développement sont basés sur la propre expertise de la Division dans les domaines des techniques du bâtiment (ex.: joints, infiltration ...) et de la méthodologie de la planification et de la conception (ex.: Code des charges de vent).

Les recherches initiales en matière d'optimisation viseront à l'obtention de meilleurs optima pour les problémes quadratiques non convexes, tels que la répartition optimisée d'activités (pour les hôpitaux, les centres commerciaux et autres problèmes de disposition urbaine on industrielle). On montrera ici l'intérét de SAM (Simulated Annealing Method) comme technique d'optimisation intelligente pour la répartition d'activités et on discutera de son potentiel en tant qu'outil d'apprentissage.

INTRODUCTION

A Knowledge-based Systems Research Centre has been established at CSIRO Division of Building Research to undertake collaborative development projects in computer-aided design and planning with industry and government. The research extends previous contributions to mathematical optimization in design and planning with applications to urban planning, building design and industrial layout planning.

Strong emphasis is being given to the development of computer software packages on microcomputer and super-mini computer systems, so that the software can be marketed to the building and planning industry at relatively low cost.

KNOWLEDGE-BASED EXPERT SYSTEMS

An Expert System is a piece of software containing knowledge on a specialized technical subject which attempts to perform at the level of a human expert. This software is able to interact with a user and can respond to questions on how a certain conclusion was reached or why certain information was requested from the user. The knowledge is usually expressed in the form of simple IF ... THEN ... rules, easy for a non-programmer to understand. The aim of expert systems is to make expert knowledge from individual experts and groups of experts more widely available. They also have an educational function helping to prime users before questioning experts.

Areas of potential application include (1,2):

- interpreting design codes, building and planning regulations,
- design procedures,
- construction management and operation procedures,
- fault diagnosis in buildings and other construction,
- scheduling of construction projects,
- monitoring site plant and equipment, and
- tender evaluation.

Research at CSIRO Division of Building Research is focussed on the development of the expert systems described below using Prolog, an AI (artificial intelligence) language.

The knowledge base for the expert systems has been accumulated by the Division and its staff over many decades, and also with its collaborators. Expert systems are seen as a potentially very powerful addition to the delivery of the fruits of research to industry and the community. They offer to fill a gap often left when human experts retire or leave, and also they should allow expertise to become more widely accessible via microcomputer and teletext networks. Unlike human experts, these expert systems could be made available on call. Assistance will also be given to industry to help it to consolidate its expertise into an expert systems form which can be more readily passed on to new employees.

Window water penetration expert system

A large multi-storey building may have up to 100 km of window framing and seals, most of which will be exposed to severe weathering conditions and occasional storms. Millions of dollars damage occurs annually due to water penetration through existing window systems in domestic, commercial and industrial buildings. New window systems are being continually developed using new materials and construction techniques, and the Division's expertise in drained-joint design (3) is being called upon to evaluate these systems and also diagnose faults in existing systems. A large full-scale test rig (SIROWET) has been developed and it is frequently used for testing building and window facades (at the time of writing it is being used on the New Parliament House, Canberra). This testing is very expensive, and obviously any computer expert system that can be developed (to test out design alternatives and thus reduce the need for extensive full-scale testing) will have substantial benefits, both in Australia and overseas. In addition, much of the window system expertise will soon be lost when the current CSIRO expert retires, so it is important to capture as much of this expertise in a more widely accessible form as quickly as possible.

A prototype expert system has been developed to graphically analyse such window systems and help designers quickly evaluate modifications (Fig. 1). The prototype, which runs on an IBM AT microcomputer, has proven the feasibility of the approach and is now being developed into a fully marketable system. This will require the addition of further expert knowledge and industry testing of the use of the system. The system will also be extended later to cover other types of joints in building facades designed to resist water penetration.

Sealant expert system

This is a classification type of expert system to advise which type of sealant is suitable for a particular application based on the types of surfaces to be sealed, the movement of the joint, the degree of exposure, the acceptable cost level and the form of the sealant (gun-grade, gasket, tape, etc.). Later the sealant expert system will be interfaced with the window and drained-joint expert system.

Wind loading code expert system

A new version of the Australian Wind Loading Code is being prepared and this provides an ideal opportunity to use an expert system to test the changes as well as helping code users to navigate a correct path through the Code. Extensive use is being made of colour graphics as a series of design pages. The system may be used by both inexperienced and experienced designers and the level of explanation is adjusted to the needs of each. The system gives a flow-chart of the logic of the Code and allows users to move freely between Code sections (4). Initial reaction from Code users has been positive and further collaborative development is under way.

Building damp expert system

This is a fault diagnosis system based on the work of Sachdeva (5). It allows problems such as condensation, wet surfaces, paint blistering, etc. to be traced to causes such as inadequate heating, ventilation, drainage, drying of construction materials, or broken pipes, damp-course failure, etc.

Other expert systems

In addition, small demonstration expert systems for parts of Building Fire Regulations and use of the Steel Design Code have been developed (6). Expert systems for assisting engineers to interpret and control the Melbourne water supply and sewerage systems, together with some to help the State of Victoria to develop a computer aided disaster management system to protect human life and buildings, are being investigated.

INTELLIGENT OPTIMIZATION

Reason for optimization

Optimization provides the mechanism for maximizing the cost effectiveness, effectiveness-in-use, or other measure of merit or performance of a system. An optimization technique thus provides an 'engine' for driving automated decision making - for design, planning, process control, or system management. It also provides a means of simulating the human decision-making process where utility maximization is the basis for those decisions.

Optimization also provides a means of predicting the most likely demand or outcome (e.g. using entropy maximizing theory), the best allocation of resources, the best description or classification of a system or its performance, or the best means of storing and retrieving information and presenting the results. It is thus one of the most widely useful of all generic tools. Its benefits are both direct and indirect, and the direct ones, at least, may be automatically assessed.

Applications of interest involve urban engineering, housing, other building facilities, communication, transport, solid waste disposal, power, water, sewerage, drainage infrastructure, or the integral of all of these. Also included are the industrial, commercial, residential, and community service systems they support.

Optimization techniques

The Division has been extensively involved in the development and application of optimization techniques to resource allocation, building and other facilities layout, urban and industrial location (7,8,9,10). Many of these problems belong to a class called NP-complete mathematical programming problems which are very difficult to optimize (11). Firstly their objective functions are usually non-linear (e.g. quadratic) and non-convex, with the result that multiple local optima exist and it is usually impossible to find the global optimum and also difficult to get close to it.

The most recent work has led to the development of TOPMET (10), an interactive colour graphics microcomputer model which uses the simulated annealing method (SAM) to optimize the placement of activities within a building, industrial complex or urban system. This uses an intelligent search process to solve the quadratic assignment problem (QAP) and this avoids getting stuck in local sub-optimum crevices. Solutions may be displayed in colour as shown in Fig. 2. The SAM method has also been successfully applied to the Travelling Salesman Problem (TSP) which is useful for solving routing problems in buildings and urban layouts. The latter may also be modified to solve the Chinese Postman

Problem (CPP) where links in a network must be visited (as opposed to nodes in the TSP).

Adding further intelligence

It is planned to add the logical inference aspects of expert systems into the optimization process to allow qualitative or implicit constraints to be incorporated. For example, the building regulations may specify that work places or residential accommodation within a building must have certain access, ventilation and lighting requirements, and that various activities should be either close to each other or separated. Explicit constraints could be automatically inferred from such rules which the user may supply in advance, or interactively during the optimization phase.

Simulated learning is also possible during the optimization process as the relationships between groups of activities are tested and found to be weak or strong. Caching techniques (10) may be used to establish these and also preferred locations of activities.

CONCLUSION

The development of knowledge-based expert systems and intelligent optimization techniques offers exciting new ways to improve building planning and design processes and to disseminate accumulated expertise more widely.

ACKNOWLEDGMENTS

The assistance of Dr J.V. Thomson, Dr J. Holmes, Mr N. Brown, Mr J.Y. Le Texier and Mr G. Carroll in developing the expert systems is gratefully acknowledged.

REFERENCES

1. D.M. Wager, Expert systems in the building and construction industry, (Construction Industry Computing Association, UK, 1984).

2. B.S. Marksjö, Expert systems in the building and construction industry, Paper presented at COMTEC Seminar, Adelaide (available from CSIRO Division of Building Research, Melbourne, 1985).

3. N.G. Brown and E.R. Ballantyne, Watertight or weatherproof - application of drained joint principles, *Building Forum*, 5(1), pp. 2-8 (1973).

4. J.Y. Le Texier, A. Doman, B.S. Marksjö and R. Sharpe, Use of Prolog with graphics including CAD, Proc. Ausgraph 85 Conference, pp. 81-85 (1985).

5. P. Sachdeva, DAMP - a diagnostic system for architectural moisture damage problems, *Australian Computer Journal*, 17, pp. 27-32 (1985).

6. B.S. Marksjö and M. Hatjiandreou, Developing knowledge-based systems for building design approval, National Engineering Conference, I.E. Aust., pp. 206-210 (1985).

7. J.F. Brotchie, A general planning model, *Management Science*, 16, pp. 265-266 (1969).

8. R. Sharpe, Optimum space allocation within buildings, *Building Science*, 8, pp. 201-206 (1973).

9. J.F. Brotchie, J.W. Dickey and R. Sharpe, TOPAZ - General planning technique and its application at the regional, urban and facility planning levels, (Springer-Verlag, Heidelberg, 1980).

10. R. Sharpe, and B.S. Marksjö, Facility layout optimization using the Metropolis algorithm, *Environment and Planning B*, 12, pp. 443-453 (1985).

11. J.F. Brotchie, M. Georgeff, R. Sharpe and B.S. Marksjö, Introducing intelligence and knowledge into CAD, Paper presented at 1st International Conference on Applications of Artificial Intelligence to Engineering Problems, Southampton, April 1985.

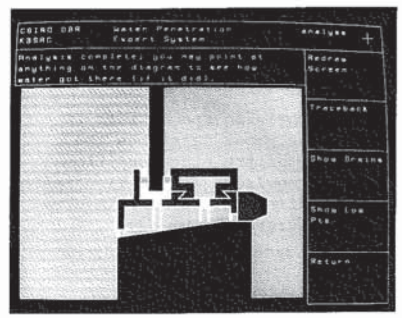

Fig. 1 Window water penetration expert system showing rain penetration through sill of a fixed aluminium window.

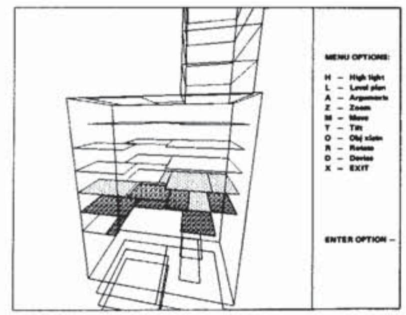

Fig. 2 Three-dimensional display of TOPMET results.