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A Programme of Research into Knowledge-Based Systems for the Building Industry

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Abstract

Since 1985, members of the Building Research Association of New Zealand and the Department of Computer Science at the University of Auckland have collaborated in investigating the suitability of knowledge-based systems technology for building industry applications. These investigations have principally concentrated on applications for code-of-practice compliance checking. Four such applications have been developed, two to a field trial level. In this paper we review the results of the collaboration.

Keywords and phrases: knowledge-based systems, code of practice compliance, research collaboration.

1. Introduction

Since 1985, the Design Software Research Group of the Department of Computer Science at the University of Auckland (DSRG) and the Building Research Association of New Zealand (BRANZ) have collaborated in a programme of research into knowledge-based systems (KBS) for the building industry. KBS technology presented BRANZ with a new means of providing useful information to the building industry. BRANZ was not alone in seeing the opportunity for KBS to assist the building industry. Eindhoven (1988), for example, lists a wide variety of groups working on KBS for the construction and design of buildings. Groups such as Sharpe, et al (1986), Maher and Fenves (1986), Fenves and Garret (1986), and Rosenman, et al (1986) have also shown a long term interest.

BRANZ personnel have much building knowledge expertise and information, as well as a good idea of the market needs for this information. This cooperative research has enabled BRANZ to keep abreast of KBS technology with relatively small in-house resources.

For DSRG the KBS area, being in its infancy, provided many research opportunities in fields such as programming language design, application development methodologies, and knowledge elicitation techniques. These opportunities, however, could only be fully exploited if sufficiently complex "real world" problems were available to test and drive the development of the tools and techniques. Hence the collaboration was a natural one, with BRANZ providing the "real world" problems and domain expertise to solve them, and

DSRG providing the application solutions and the KBS expertise used in developing them.

The relationship between BRANZ and DSRG continues to evolve. Beginning with the common interest in KBS in the *FireCode* project, the cooperation has expanded. Technology transfer between the two groups continues to be an important part of this collaboration.

In this paper we present the experiences and results of the collaborative programme to date, together with an outline of current research. None of the applications will be discussed in great detail as this has been done elsewhere. Instead we will concentrate on the overall strategies adopted and attempt to measure the success of the joint venture.

2. Initial Collaboration: the FireCode Project

2.1 Background

The collaborative programme commenced with the *FireCode* project (Hosking et al, 1987; Mugridge et al, 1988). The principal aim of this one year project was to develop a KBS to assist building designers to check that their plans meet the requirements of Parts 2 and 6 of *DZ4226: Code of Practice for Design for Fire Safety* (Hay, 1984), a draft New Zealand Standard.

Part 6 of DZ4226 contains provisions to ensure that a fire compartment contains adequate means of escape for all of its occupants. Hence, it specifies, amongst other things, minimum numbers of exitways and minimum widths and maximum lengths of exit paths for different configurations of building layout and usage. The principal aim is to ensure that all occupants of the building can be evacuated to a safe place within two and a half minutes. A major parameter used in calculating the limits is the *use class* of each of the areas in the fire compartment. The use classes are defined in Part 2 of DZ4226 and take into account factors such as the occupant density, the occupant mobility (are they wheelchair bound?), and the inflammability of any materials stored in the area.

The following factors were significant in the choice of codes of practice for the application domain:

- BRANZ advisory staff had found that queries regarding codes of practice were common. Hence code of practice based applications were likely to be particularly useful to the building industry.
- By its nature, a code of practice contains a distillation of domain knowledge in a written form. Hence it was felt that the knowledge acquisition exercise would be simpler for a code of practice-based application.

The following factors were significant in the choice of DZ4226 as the code of practice:

- Parts 2 and 6 of DZ4226 were quite complex, yet the complexity was primarily because of the highly conditional nature of their clauses together with the size of the code as a whole (Part 6 alone consists of 81 pages containing approximately 150 clauses and numerous tables). Rule-based programming seemed an obvious paradigm for representation. Conventional programming techniques appeared inappropriate as they would prevent a close correspondence between the clause structure of the code of practice and the implementation.
- DZ4226 was particularly well written from the point of view of explaining and justifying its requirements; an example clause illustrating this is shown in Fig. 1.

6.5.3.6 Separation of final exits: Where final exits in use class AL give access to the same safe place, at least two of the final exits shall be separated by a distance equal to 1 m per 100 occupants

C6.5.3.6 See D6.5.3.6. This refers to the total number of occupants of the storeys classified in the use class. The provision is to ensure quick dispersal, as otherwise final exits may get jammed by the crowd outside.

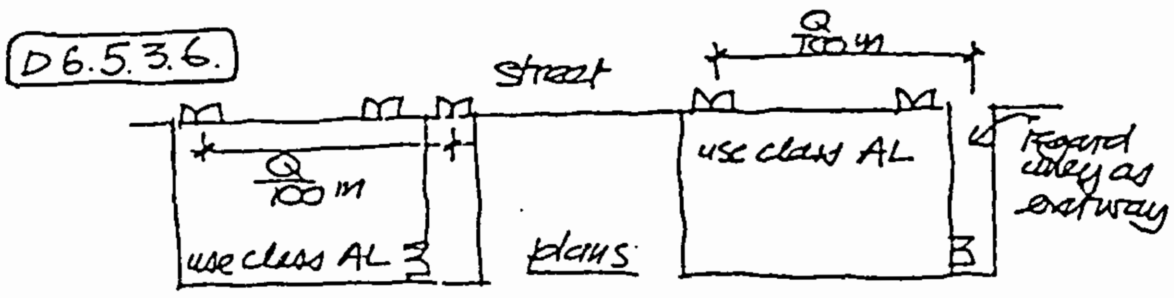

Figure 1: Clause 6.5.3.6 from DZ4226. Note the commentary C6.5.3.6 and the diagram D6.5.3.6.

In the words of the authors of the code:

> "Therefore, if this code appears more complex, at first sight, than its overseas cousins, it should be realised that one of the reasons for that is that it sets out to carefully explain "why"; and that another is that it also sets out to carefully explain the "need", and leave both designers and manufacturers to fashion the possible ways of meeting that need for fire safety." (Hay, 1984)

- A domain expert, one of authors of DZ4226, was readily accessible to DSRG.
- Parts 2 and 6 represented a relatively self contained subset of DZ4226. A system for assisting with these parts would be useful in its own right, yet could be incrementally extended to handle the complete code of practice. In addition, Parts 2 and 6 appeared to require little "common-sense" reasoning, although a spatial reasoning component provided an interesting challenge from a research perspective.

These factors correspond well with Prerau's criteria for selection of a "first" expert system application (Prerau, 1985).

2.2 The FireCode system

The *Firecode* system was developed to a research prototype level. Some parts of the initial target, such as full checking of plans against Parts 2 and 6 of DZ4226, were covered in full depth, while others received only superficial treatment. This combination of broad and shallow overall with some narrow areas covered in depth is a common way of proceeding in KBS prototype development (Hayes-Roth et al, 1983). Sufficient of the system was implemented, however, to demonstrate the feasibility of developing a production version of *FireCode*.

FireCode allows a designer to check either an entire building or individual components, such as one storey. Information is gathered using question and answer interaction, controlled by the system. At any point, however, the user can request an explanation as to why the current question is being asked (the current line of reasoning) or what the question is about (information about the item being asked about). In addition, the user can modify any previous answer permitting what-if style exploration. More complete descriptions of the *FireCode* system, including sample dialogues, can be found in Hosking et al (1987) and Mugridge et al (1988).

2.3 Class Language

Initially a fairly standard backward-chaining rule-based language with Mycin-style (Buchanan and Shortliffe, 1984) explanation facilities was developed to experiment with the representation of code clauses. This proved to be inadequate.

A special-purpose support language, *Class Language*, was developed in parallel with the *FireCode* project (Hamer, et al, 1989). This development was motivated by the research interests of DSRG and by the lack of suitable tools available under VMS. While this time would probably not have been justified in a purely development-oriented project, the research orientation of this project meant that a longer term view could be taken.

FireCode application had a considerable impact on the design of *Class Language*. In *FireCode* there is a need to incrementally refine a building model as information is gained about it; for example, the use classifications of areas, as defined in Part 2 of the written code.

The rule-based representation was embedded within an object-oriented framework in order to minimise redundancy, provide reasonable information hiding above the rule level, and explicitly model the aggregational and classificatory structures associated with building designs. Further details can be found in Hamer et al (1988).

The resulting blend of representational mechanisms naturally arose out of the needs of the application domain. *Class Language*, however, has proven to be fairly general purpose and has formed the cornerstone of all of our subsequent KBS work.

2.4 Lessons from FireCode

The *FireCode* project showed that code of practice interpretation held considerable promise as an area of application of KBS techniques. The ready-distilled information in DZ4226 certainly provided a good head start in knowledge acquisition. The domain expert was able to perform more of an advisory role, rather than being the primary source of information. In this respect, DZ4226 was a fortuitous code to start with as the large amount of explicit explanation and justification allowed us to readily infer not only what the code requirements were, but also an appropriate design/checking methodology for applying the code provisions.

The development of *FireCode* has had several helpful spin-offs. For example, a number of flaws were isolated in the code of practice (see, for example, Fig. 2). The discovery of these flaws provided valuable feedback to BRANZ and the domain expert (one of the code authors) on the quality of the code of practice. For reasons unrelated to KBS, the draft standard itself is unlikely to be adopted in its present form, but the feedback from building *FireCode* should be of value in future revisions.

2.4.3.1 Grading: The mobility which occupants are presumed to have in moving to escape from fire is based on the following assessments:

(a) Good, where occupants are fit, able, and free to move to exitways without assistance

(b) Limited, where:
(i) more than 5% of occupants are physically disabled but able to move of their own volition;
or (ii) more than 30% of occupants are between 2 and 3 years old.

(c) Poor, where:
(i) any occupant is involuntarily restrained from moving;
or (ii) more than 30% of occupants are bedridden;
or (iii) more than 30% of occupants are less than 2 years old.

Figure 2: Clause 2.4.3.1 from DZ4226. Note that although the categories of mobility appear to be well spelt out by explicit criteria, a closer examination reveals that these "criteria" are merely typical examples, and the code user must find the "best" match of his or her situation against these examples.

Technology transfer was another spin-off from this work. DSRG provided BRANZ with versions of *Class Language* as it was developed. BRANZ made use of these tools to develop KBS of their own (see below) which were then made available to DSRG. This provided useful feedback to DSRG on the language, such as features which BRANZ felt were missing from the language. The KBS themselves also provided useful feedback, with novel uses of language features (perhaps pointing to the need for new representational mechanisms) and testbeds for DSRG to try out new versions of the tools. Such feedback was extremely valuable to the development of later versions of *Class Language*. Our collaborative work has since placed much greater emphasis on such technology transfer.

One point that Prerau (1985) makes in his checklist for deciding the appropriateness of a KBS application is that it should be clear whether the application is to be a research system or a production system; one should not aim to do both. In this respect, we concur with Prerau. While the *FireCode* project was principally a research project, there was an underlying expectation that the system would eventually be developed for use by the building industry. This meant that some constraints were placed on the system design. For example, it was assumed that the system would need to be accessible from a variety of terminals via a dial-in packet switch line, meaning that the lowest common demoninator, textual interaction with simple character graphics, had to be chosen as a means of user interaction. This design choice limited the amount of effort directed into appropriate methods of user interaction. The limitation was probably unnecessary, as, by the time any development versions of research prototypes neared completion, better quality interfaces could reasonably be assumed.

Overall, the *FireCode* project was sufficiently successful to encourage the continuation of the collaboration. The focus was, naturally enough, further investigation of code of practice interpretation systems.

3. Other Code of Practice Systems

Three applications were chosen to extend the work begun with *FireCode*: *Seismic* and *WallBrace* were developed by DSRG, while *SubFloorBrace* was developed by BRANZ.

Seismic was intended to help designers to meet the seismic loading provisions of *DZ4203: 1986 General Structural Design and Design Loadings* (SANZ, 1986). *WallBrace* and *SubFloorBrace* were intended to assist designers to meet the wall and subfloor bracing provisions respectively of *NZS3604: 1984 Code of Practice for Light Timber Frame Buildings* (SANZ, 1984).

All three applications have moved beyond plan checking to provide design assistance. In *FireCode*, shortcomings in a plan just rated a simple message indicating the problem that was encountered and possibly some general methods the user could try to fix the problem. In varying degrees, the three new applications allow some forms of automated design assistance to allow problems to be corrected or avoided in the first place. In addition, the development of these three systems was expected to provide feedback to the further improvement of *Class Language*.

3.1 Wall and Subfloor Bracing

Light timber frame construction is the most common method of building residential dwellings in New Zealand, hence great demand for the systems was expected (Fowkes, et al, 1988). Being in a seismically active region, and also with parts of the country having high wind exposure, adequate bracing on timber framed structures is vitally important. Figure 3 illustrates some of the forces on various components of such a building.

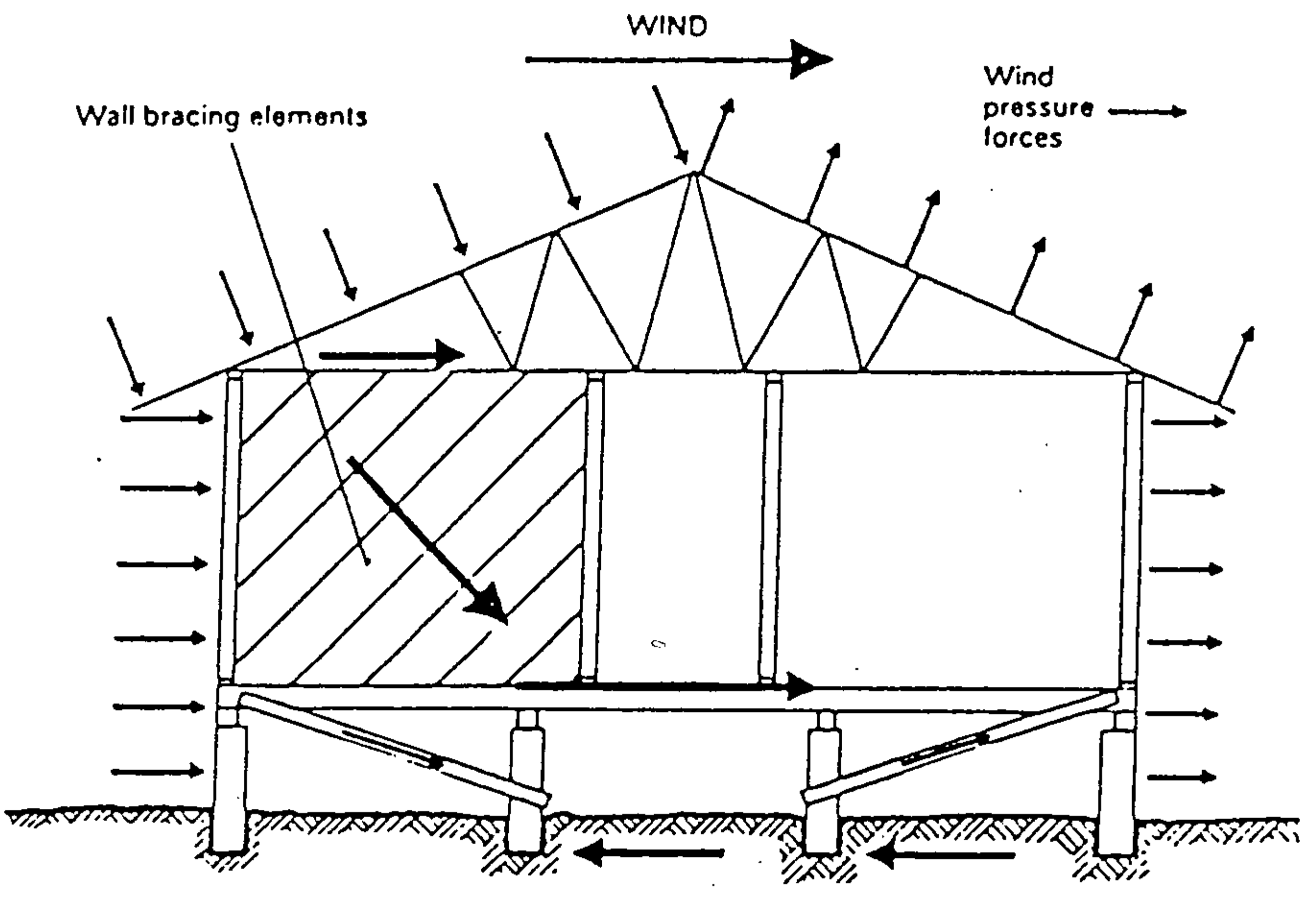

Figure 3: Action of Wind Forces on a Building

The sections of NZS3604 relating to each of the applications were quite small, much shorter than Parts 2 and 6 of DZ4226, and seemed on the face of it to be fairly straightforward and explicit. In addition, BRANZ had developed manual worksheets for builders to use in calculating loads, etc for the purposes of checking the wall bracing code provisions. Both these projects are concerned with bracing, so it was expected that there would be some cross-fertilisation between them, thus assisting in the technology transfer aims of the collaboration. One slightly unusual aspect of the *WallBrace* project was that the domain expert was based at BRANZ, some 600 km from DSRG, with only limited opportunity for face to face interviewing.

The *Wallbrace* and *SubFloorBrace* projects each consisted of two parts: a development-oriented checker and a research-oriented design aid. The developmental aim was to develop applications that could eventually be made available online for checking proposed designs for compliance with the wall and subfloor bracing requirements of NZS 3604 (SANZ, 1984). The research component was concerned with the provision of advice and assistance in the design of bracing to meet the standard.

The *WallBrace* checker has been completed to the field prototype level (Mugridge and Hosking, 1988). From building plan information supplied by the user it calculates the design loading, based on both seismic and wind forces, in two orthogonal directions. It then checks that sufficient bracing has been added to both external walls and internal bracing lines, to satisfy NZS3604 requirements. Inexperienced users are provided with some assistance with designing the bracing line layout.

While the coverage of the requirements of the written code is fairly complete, there are some restrictions on building configurations; for example, attics are not handled. It is worth noting that the code of practice itself does not cover all of the building configurations within its stated jurisdiction. The lack of coverage caused the majority of work in the development of *WallBrace*. This effectively involved reverse engineering the unstated assumptions the code authors had made and then developing appropriate strategies, based on safe building practice, for handling situations when those assumptions were violated.

The *WallBrace* and *SubFloorBrace* checker systems have been internally audited by BRANZ and are soon to undergo field trials at building inspectorates in two New Zealand cities. The results of these field trials will be used to further develop the systems prior to wider release. These systems will add to the usefulness of the online information service provided by BRANZ and therefore provide further incentive for builders, designers, and administrators to access the system.

WallBrace design extensions have been completed to a research prototype level. These extensions allow *WallBrace* to take a building layout and allocate bracing automatically to each external wall or bracing line to satisfy the code provisions. Design extensions to *SubFloorBrace* are under development.

3.2 Seismic

Seismic was, from the outset, more open-ended and speculative than the other two systems. The code of practice was fairly large, being similar in size to DZ4226 but much less explicit in providing rationale and justification. Hence, it was expected that much more emphasis on knowledge acquisition techniques and much more use of the domain expert's time would be needed than in the *FireCode* project. It was unclear at the commencement of the project how much of the application could feasibly be developed in the year available.

Seismic was developed to a preliminary research prototype stage, providing incomplete coverage of the target domain (Hosking et al, 1988). As expected, time spent on knowledge acquisition dominated other aspects of system development. In particular, much time with the expert was spent learning the construction design techniques which are assumed but not explicitly stated by the code authors. Knowledge of these techniques is essential to understanding how to use the code of practice; they form the major portion of the *Seismic* system. For the expert, a valuable spinoff was the formalisation of this methodology which could be used independently of the KBS.

Given the necessary emphasis on knowledge acquisition in the *Seismic* project, some time was spent investigating appropriate techniques for knowledge acquisition. The use of video for recording interviews, different interviewing techniques, and appropriate intermediate representations for communicating between the expert and the developers were all explored (Hosking, et al, 1988).

3.3 Lessons

The size of the code of practice being modelled is not a good indicator of the size of the application system nor of the amount of time needed for development. This disparity arises when parts essential to the interpretation of the code are left out. This is particularly obvious in the case of *WallBrace*, where the NZS3604 code provisions are quite concise, yet the developed application is the largest of all we have developed. The (unstated) assumptions made by the authors of NZS3604 led to large gaps in its jurisdictional coverage. These only became obvious with our formal approach to knowledge acquisition and system development.

A code of practice interpretation application consists of not only the code provisions, but also a model of the system being tested together with a suitable methodology for applying the code provisions to that model. The codes of practice we have based our work on vary considerably with respect to how much of the latter two are included and in what way. DZ4226 is fairly comprehensive in coevering all three aspects, NZS3604, somewhat less so, while DZ4203 does not go beyond the direct code provisions.

In all of the code of practice systems we have developed, the formalised approach to examination of the code has lead to the discovery of flaws, inconsistencies, and omisions, such as the gaps in the *WallBrace* coverage and the example from DZ4226 shown in Fig. 2. Tables in particular were often found to be flawed in one way or another (Mugridge and Hosking, 1988).

Two of the codes we have examined have been draft standards; we hope to have some influence on their modification. Much could be gained by including personnel with KBS development experience on any team developing a new or revised code of practice. Their formalised approach to knowledge acquisition and representation should assist in minimising the types of errors that we have found. In addition, if they concurrently develop a code interpretation KBS to be released with the code of practice, adoption of that code by the industry is likely to be much more rapid. The collaboration between Standards Australia and the CSIRO Division of Building Construction and Engineering in the development of Windloader while concurrently revising the draft Standard on which it is based is an encouraging start in this regard (Marksjö et al, 1988).

As expected, the application development has resulted in useful methods of applying *Class Language*, together with highlighting areas in which the language was obviously deficient. These deficiencies are being addressed in our current work, as described in Section 5.2.

The decision to make a clear separation between research and development applications was endorsed. The *Seismic* project was able to side-track into potentially interesting areas of research, such as the exploration of knowledge acquisition techniques, without having the pressure of producing a completed product to inhibit it. The major benefits of the *Seismic* project came from the technology discovered during development rather than the final software system produced.

The *WallBrace* and *SubFloorBrace* projects were much more strictly controlled, with any research by-products being a bonus rather than an aim. The by-products were the design extensions and the feedback on the development of *Class Language*. Nevertheless, these two projects have illustrated that the supposedly simpler applications still have considerable challenge.

4. Diagnostic and Material Selection Systems

In addition to the code of practice interpretation systems, several diagnostic and material selection KBS have been developed, all to a research prototype level. These applications form a subsidiary, but valuable, stream of interest and deserve a brief description.

The DAMP system diagnoses the cause of moisture related problems in residential dwellings. This application was developed by BRANZ, originally as a joint project with the Victoria University of Wellington (Sachdeva, 1985) but later reimplementated using the support languages developed by DSRG (Trethowen, 1987). Related applications have been developed by Allwood (1985) and Sharpe et al (1986).

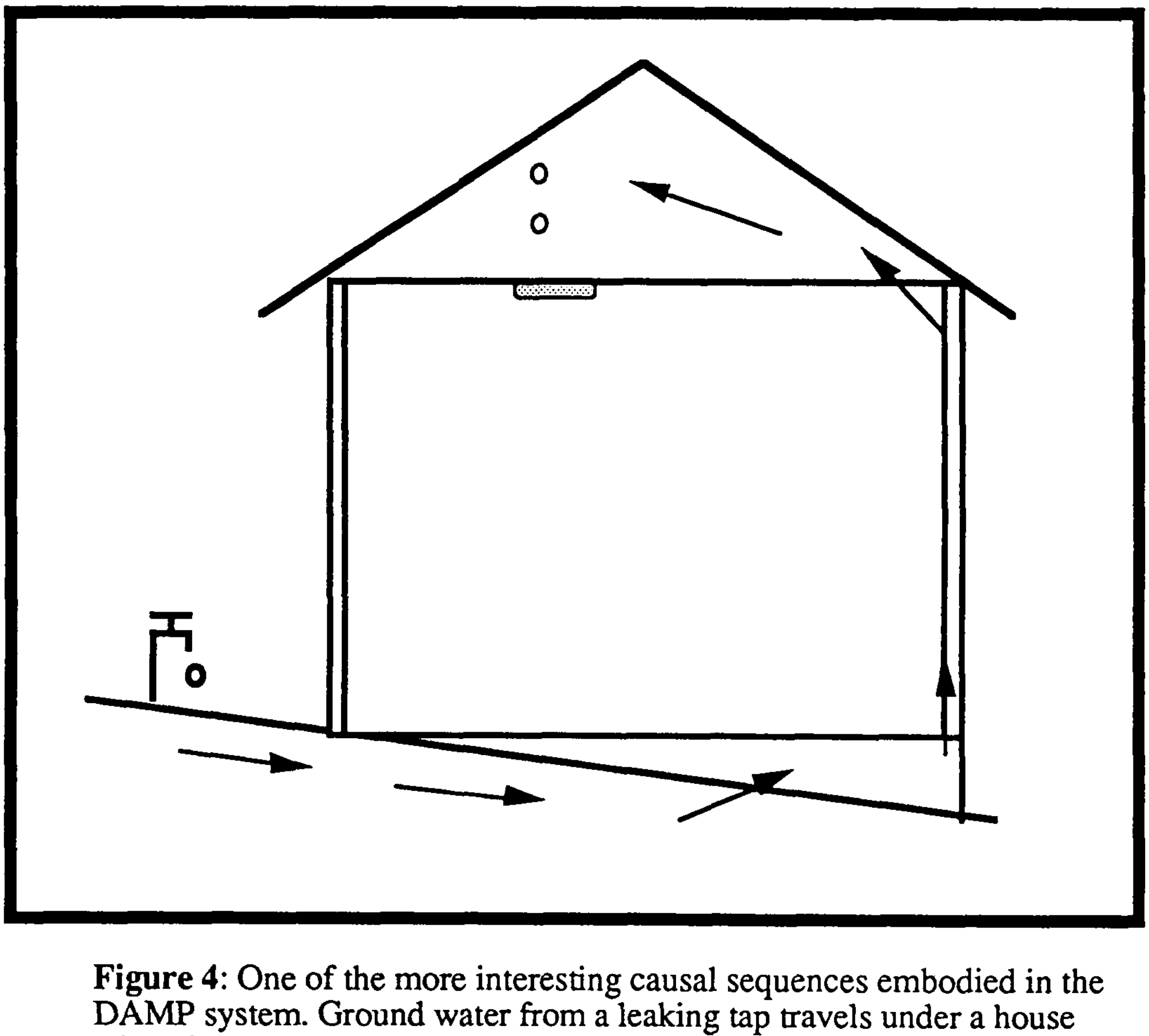

Figure 4: One of the more interesting causal sequences embodied in the DAMP system. Ground water from a leaking tap travels under a house where it evaporates. The stucco wall construction provides a convenient path for sun aided convection to transport the moist air to the roof space. In the evening the moist air condenses on the cold roof. Water then drips onto the ceiling, causing a stain.

DSRG have since used the DAMP system as a basis for investigating causal qualitative reasoning (Hosking et al, 1987; Crase, 1989). Figure 4 shows one of the more interesting causal chains embodied in the DAMP system.

SEALANT (Dechapunya and Whitney, 1988) and ADHESIVE (Fromont and Watkinson, 1988) are materials selection systems developed by BRANZ, assisting users to select appropriate sealants and adhesives for building applications. These systems are primarily classificatory, and hence were conveniently implemented using *Class Language*. DSRG has made use of the ADHESIVE system as a basis for preliminary explorations of the use of *Class Language* for developing design-oriented systems (Fromont, 1989).

All three of these systems illustrate the cross fertilisation permitted by the collaboration. The KBS technology used in the development of these systems originated in DSRG, the development of the systems was performed by BRANZ, the availability of the completed systems to DSRG allowed further research to proceed which otherwise would not have been possible.

5. Current Work

Work is concentrated on the user interface and on developing techniques for design assistance and partial automation of the design process. There are three main areas.

5.1 Bracing Applications

Design aspects of the bracing packages *WallBrace* and *SubFloorBrace* are being developed further. As mentioned in Section 3, the checking parts of the existing systems are undergoing field trials. The results of these trials will direct further development.

RoofBrace, a system for assisting with the design of roof bracing, is now under development by BRANZ. This suite of three bracing packages will eventually provide an integrated system for checking the bracing requirements of a light timber framed building.

5.2 Class Language

A major upgrade of the *Class Language* support environment is underway. This includes reimplementation of the runtime environment in C, together with the extension of the external interface capabilities of *Class Language*. One aim of the latter is to provide an integrated X-Window interface to *Class Language*. A database interface is also planned, allowing ready access to, for example, existing materials databases.

Improvements to the language for design-based applications are being investigated, based on our experience with *WallBrace* (Mugridge, et al, 1989).

5.3 Thermal Design

ThermalDesign will assist in designing the thermal insulation in residential dwellings to meet the requirments of *DZ4218: 1987 Minimal Requirments for the Thermal Insulation of Residential Buildings* (SANZ, 1987). To facilitate technology transfer, *ThermalDesign* is being developed as a research prototype level by DSRG, with further development being undertaken by BRANZ.

ThermalDesign will make use of the *Class Language* X-window interface to provide a direct manipulation front-end. In the process of developing this front-end, we plan to investigate the appropriateness of direct-manipulation strategies for the various phases of thermal insulation design, such as plan entry and wall design. Use will also be made of the database interface provided by *Class Language*.

6. Summary and Conclusions

When we embarked on our collaborative programme, the principal aim was to evaluate and hopefully exploit the potential of KBS techniques as a means of providing information and services to the building industry. In this section, we evaluate the success of the programme and summarise the lessons learnt.

The various applications developed to date strongly support the view that code of practice based KBS show a most promising potential. The most practical realisations of that view, the *WallBrace* and *SubFloorBrace* systems, are under field trial in the building industry. To some extent, therefore, the jury is still out. We are confident, however, that any problems in the systems' acceptance will be due to readily correctable presentation techniques, rather than the underlying KBS methodologies used.

From a technology point of view, the KBS approach to problem solving is emerging from an initial bout of "religious" fervour. It is now apparent that KBS techniques have their place as one of the many technologies in the software engineer's bag of tricks. More emphasis now needs to be placed on the integration of those techniques with the other contents of that bag. Witness, therefore, the current integration of *Class Language* with user interface and database management systems.

Focussing on the collaboration itself, the technology transfer objectives have been successfully fullfilled. BRANZ now has considerable KBS expertise, allowing them to embark on ambitious projects, such as *SubFloorBrace* and *RoofBrace*, on their own. The "market pull" provided by the "real world" applications has enabled DSRG to produce truly useful tools and techniques that would not otherwise have been developed. The reverse technology transfer, discussed in the previous sections, has also been an important contribution to the success of the collaboration. In summary, the collaboration has allowed BRANZ and DSRG to make the most of limited resources available to develop an ambitious and successful programme of research and development.

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References

Allwood, R.J., Shaw, M.R., Smith, J., Stewart, D.J., and Trimble, E.G. (1985) "BREDAMP - an expert system to diagnose the causes of dampness in buildings", Technical Report, Department of Civil Engineering, Loughborough University of Technology.

Bassett, M. (1988) *ALF Design Manual: Aid to Thermal Design of Buildings*, BRANZ Technical Paper P28.

Buchanan, B.G., Shortliffe, E.H. (1984) *Rule-Based Expert Systems*, Addison-Wesley, Reading, Massachusetts.

Crase, S.A. (1989) "Building with Knowledge Lego", New Zealand *Interface*, April 1989, pp21-23.

Dechapunya, A. H. and Whitney, R.S. (1988) "Knowledge-based systems for building technology in New Zealand", *Proc Symposium on knowledge-based systems in civil engineering*, Monash, August.

Eindhoven (1988) "List of expert systems for construction (and design) of buildings, Parts 1 and 2", Technical report, Technische Universteit, Eindhoven.

Fenves, S.J., Garrett, J.H. (1986) "Knowledge based standards processing", *International Journal for Artificial Intelligence in Engineering*, 1 (1), pp 3-14.

Fowkes, A.H.R., Sharman, W.R., and Dechapunya, A.H. (1988) "The development of marketable knowledge-based systems", *Proc 3rd New Zealand Expert Systems Conference*, Wellington, New Zealand, May.

Fromont, C.J. (1989) "An investigation of knowledge-based design", MSc thesis, Department of Computer Science, University of Auckland.

Fromont, C.J., and Watkinson, P.J. (1988) "A knowledge-based system on the selection of adhesives for wood or wood-based substrates", *Proc The 3rd New Zealand Expert Systems Conference,* Wellington, New Zealand.

Hamer, J., Hosking, J.G. and Mugridge, W.B. (1988) "The evolution of Class Language", *Proc The 3rd New Zealand Expert Systems Conference,* Wellington, New Zealand, pp40-57.

Hamer, J., Hosking, J.G. and Mugridge, W.B. (1989) "Object-oriented representation of codes of practice", submitted to *Australasian Conference on Expert Systems in Engineering, Architecture & Construction*, December, Sydney, Australia.

Hay, R.D. (Ed) (1984) *DZ4226: Code of Practice for Design for Fire Safety*, Standards Association of New Zealand, Wellington, New Zealand.

Hayes-Roth, F., Waterman, D.A., Lenat, D.B. (1983) *Building Expert Systems* Addison-Wesley, Reading, Massachusetts, United States of America.

Hosking, J.G., Mugridge, W.B., and Hamer, J. (1987) "A knowledge-level analysis of the DAMP problem", *Proc of the 10th New Zealand Computer Conference*, Christchurch, New Zealand, R29-40.

Hosking, J.G., Lomas, S., Mugridge, W.B. (1988) "The development of an expert system for seismic loading", *Proc Knowledge-Based systems in Civil Engineering Symposium*, Monash University, Melbourne, Australia.

Hosking, J.G., Mugridge, W.B. and Buis, M. (1987) "FireCode: a case study in the application of expert system techniques to a design code", *Environment Planning and Design B*, Vol. 14, pp267-280.

Maher, M.L., Fenves, S.J. (1986) *HI-RISE: A Knowledge-based Expert System for the Preliminary Structural Design of High Rise Buildings*, Report No. R-85-146, Department of Civil Engineering, Carnegie Institute of Technology, Carnegie-Mellon University, Pittsburgh, Pensylvania.

Marksjö, B., Sharpe, R., Holmes, J,. Fitchett, P., Ho ,F. (1988) "Windloader KBS - from prototype to the market," *Procs. Symposium on KBS in Civil Engineering*, Monash University, Clayton, Victoria, Australia, 1988.

Mugridge, W.B. and Hosking, J.G. (1988) "The development of an expert system for wall bracing design", *Proc The 3rd New Zealand Expert Systems Conference*, Wellington, New Zealand, pp10-27.

Mugridge, W.B., Hosking, J.G., Buis, M. (1988) "FireCode: an expert system to aid building design", Chapter 40 of Newton P, Taylor M A P, Sharpe R (Eds), *DESKTOP PLANNING: Advanced Microcomputer Applications for Physical and Social Infrastructure Planning*, Hargreen, Melbourne, 1988.

Mugridge, W.B., Hosking, J.G., and Hamer, J. (1989) "Knowledge representation issues in a system for wall bracing design", in preparation.

Rosenman, M.A., Coyne, R.D., Gero, J.S. (1986) "Expert systems for design applications", *The Second Australian Conference on Applications of Expert Systems,* New South Wales Institute of Technology, Sydney, pp74-91.

Prerau, D.S. (1985) "Selection of an appropriate domain for an expert system", *AI Magazine*, Summer 1985, pp26-30.

Sachdeva, P. (1985) "DAMP - a diagnostic system for architectural moisture damage problems", *Australian Computer Journal*, **17**, pp27-32.

SANZ (1984) *NZS3604: 1984 Code of Practice for Light Timber Frame Buildings*, Standards Association of New Zealand, Wellington, New Zealand.

SANZ (1986) *DZ4203:1986 General Structural Design and Design Loadings for Buildings*, Standards Association of New Zealand, Wellington, New Zealand.

SANZ (1987) *DZ4218: 1987 Minimal Requirments for the Thermal Insulation of Residential Buildings*, Standards Association of New Zealand, Wellington, New Zealand.

Sharpe, R., Marksjö, B.S., Thomson, J.V., Wilson, D. (1986) "Expert systems applications in building and construction", *Proc. 1st Australian Artificial Intelligence Congress* (Melbourne).

Trethowen, H.A. (1987) "The knowledge base - will the frog turn into a prince:?", *Proceedings of the Second New Zealand Conference on Expert Systems*, University of Auckland, Auckland, New Zealand, pp103-111.

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