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BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND

A KNOWLEDGE-BASED SYSTEM ON THE SELECTION OF ADHESIVES FOR WOOD OR WOOD-BASED SUBSTRATES

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ABSTRACT

The knowledge-based system, "Adhesive", developed by the Building Research Association of New Zealand, selects adhesives for assemblies of wood and wood-based materials commonly used in the building industry. Information in a form suitable for the knowledge engineer was acquired from individual expertise and existing written adhesive selection standards. Refining and checking of the information within the system required good communication between the expert and the knowledge engineer.

Construction of the system was facilitated by the use of the CLASS language. The use of CLASS resulted in an object-oriented structure helpful for the development of the system and in simplifying maintenance.

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1. INTRODUCTION

The development of new materials in the building industry has resulted in the increasing use and acceptance of adhesives for many bonding applications. Unlike common mechanical fixings, adhesives have the potential to join materials with no concentrations of stress at focal points. They can have higher bond strength, give good seals against pressure and moisture, give good electrical insulation, and in some applications can be quicker than traditional fixing procedures. However, there are more variables to consider when using adhesives compared to traditional mechanical connectors. In particular, which adhesive should be used for a given application?

As part of its ongoing effort in developing knowledge-based systems (KBS) as a means for providing information to the building industry, the Building Research Association of New Zealand, (BRANZ) has spent some time in the development of a KBS for the selection of adhesives within building industry applications.

The BRANZ wood adhesive system is a material-selection type of KBS. It is designed to assist the user to select an adhesive for some predetermined application or combination of substrates (one substrate must be wood-based). A full set of suitable adhesives is displayed, depending on the application or substrate, and this can be refined by specifying certain characteristics of the adhesives. The adhesives are classified according to their chemical type rather than brand name. The users who can gain the most benefit from this system are those with some appreciation of chemical types of adhesive (e.g., epoxy).

2. ACQUISITION OF KNOWLEDGE

The acquisition of knowledge followed five stages. These stages form the five headings in this section, and appear in chronological order. There was some overlap in time between these stages, especially between refining information and checking information once it was in the KBS.

2.1 Information gathering by the expert

The expert had knowledge of the general area of interest, namely adhesives for wood and wood-based materials, and ready access to references.

An overview of the time resources available to produce this KBS led to an early decision to have adhesives classified by chemical class rather than by brand name. A KBS using chemical class classification (19 varieties for most wood adhesives) takes less time to create and maintain than a KBS using brand names (at least several hundred were known in New Zealand).

Some guidelines on the level of detail were obtained from the likely KBS users plus the message that BRANZ should include explanations and on-line help that would cater for the least technically literate of the likely users. The more technically literate users could always skip the help options and explanations.

Further guidelines on the choice of reference material were as follows:

(a) Applications that made sense to the users (eg. 'Wood beams' is probably not specific enough, while 'glued-laminated beam exposed to the weather' is specific enough to be useful.)

(b) Adhesive classes that are well defined (e.g., 'Formaldehyde-based' is not specific enough, but 'melamine-urea formaldehyde' is a suitable class.)

(c) An authoritative source that is accepted by a wide range of adhesive users.

It was decided to use wood adhesive standards as the main reference material because they satisfied the above guidelines and in particular, they are widely accepted in the building industry.

Any applications of interest to the New Zealand building industry that are not covered by these standards are covered by other sources. Examples of these applications are: on-site bonding of wood-based or kraft covered wallboard, and the manufacture of reconstituted woodboard (e.g., particleboard). The reference material used as information sources is listed in Appendix 1.

2.2 Transformation of information into a form suitable for the knowledge engineer

The information was transformed into large scale decision trees (initially taking up six pages of ruled A3 size paper). Extraction of information from the original sources was quicker from tables than from normal format text. Fortunately, the bulk of the information sources were tables (from standards), which speeded up the extraction.

As well as the basic KBS, the following features were included in the decision tree: introduction, scope, limitations, some help options, some warnings, advice on how to bond materials on-site, and explanations of common pitfalls. The decision tree was checked for technical accuracy before it was given to the knowledge engineer.

2.3 Absorption of information by the knowledge engineer

Before the knowledge engineer put the decision tree into the programming language, he made sure he understood the tree. He asked the expert to explain the reasoning behind the tree, the meaning of unfamiliar terms and words, and to explain apparent anomalies or gaps in the information.

2.4 Refining information in the knowledge-based system

The knowledge engineer redefined some pathways to suit the programming language and to make minor alterations to avoid redundancy. For example, if a number of applications resulted in the same set of adhesives, these sets could be generated as a whole unit rather than being generated by the addition of all the individual adhesives. However, the technical accuracy of the information presented in this new way was not always retained, and it had to be checked and altered by the expert.

The expert was involved mainly in a checking type of role in the refinements of the system, which are discussed under the later heading of "SYSTEM DEVELOPMENT". However, there were some late additions to the information used, and here the expert was also involved in the role of transforming the original information into a form suitable for the knowledge engineer.

2.5 Checking information in the knowledge-based system

Checking the information once it was in the KBS involved the greatest input of the expert's time and frequent communication with the knowledge engineer. The expert took about eight man days to check the system (this includes a relatively short time to make refinements) and one and a half man days to gather and transform the information into a form suitable for the knowledge engineer. The knowledge engineer took about 30 man days to understand and encode the information into a simple working system. Refinements and additions took about another 50 man days, this figure including time to document the technical details.

A large diagram was drawn of each pathway observed by a user. Each pathway was then checked on-line for technical accuracy and clarity. Version one of CLASS compiler had such a long response time between user input and KBS reply (several minutes) that the checking procedures were delayed until version two was in place. The latter version typically took less than several seconds response time.

3. SYSTEM OVERVIEW

The KBS on adhesive selection is written in CLASS, a language designed for knowledge-based systems, and much of its operation involves classification. (This language is described by Hamer, Hosking, and Mudridge elsewhere in this conference). The system consists of a main control class that provides introductory text, guides a session, and provides helpful hints at the end of a session. This control class is classified in two distinct directions.

In one direction the control class is classified according to the application the user is presenting to the system. This classification passes through several levels of specialisation, asking questions and generating results.

In the other direction the control class is classified according to all the adhesives the system regards as being suitable for the application that has been described. This provides the full set of suitable adhesives that can then be refined. Each of the adhesive classifications is checked according to specifications supplied by the user, and the successful adhesive classes form the result of the system.

4. SYSTEM DEVELOPMENT

The following section describes the development of this KBS from the initial prepared information sources through to the running system.

Having been presented with a decision tree describing the major decisions of the intended KBS the first practical approach was to encode this basic structure as a simple CLASS program.

The tree structure was based on the intended use of the adhesive, where the decisions involved questions such as:

Are the adherends : wood, chips, veneer ? Is the construction in a factory or on the building site ?

The CLASS program was based on a classification system according to the class of application. These questions were used to guide the classification process. The most specialised classes of application contained one or two rules and a procedure for presenting the results.

The simple system that resulted asked four or five basic questions about the intended application and printed out the chemical classes of the suitable adhesives.

Having checked that this simple system was accurate as far as it went, effort was directed at expanding and improving its simple solution. This involved several experimental approaches as the language being used (CLASS) was still under development and contained several 'grey' areas.

4.1 Extending the basic system

Simple extensions were the inclusion of such things as explanatory text at the start of a session, and that often seen question: "Do you require an introduction?".

Other ways of improving the system were to increase the amount of information given to the user as a result of a session. A large amount of information about the various adhesive types was available (Building Information Bulletin 246, see Appendix 1) and ways were looked at to include such information in the KBS. This information dealt with the adhesives individually, rather than with the applications side of the problem.

In deciding the best way to use this information these questions were considered:

What information is useful?
How much of this information is needed for the casual user?
Is the information ambiguous to the user?
How much difficulty is involved in encoding this information?
How many types of adhesive are needed to provide this information (for an average session) ?
Will the information be supplied to the user as an option?
Could information be incorporated in the decision making process (rather than as part of the result) ?
What ways could information be stored by the KBS?

This area of development was kept separate from the basic selection system above to narrow the field of concentration and to speed compilations. Once both areas were running satisfactorily then they could be combined into the current two stage system.

4.2 Developments - Stage 1

Most of the development of the basic stage 1 decision tree related to the questioning of the user and the explanatory text provided. Much time was given to making the questions as clear as possible to avoid any misunderstandings, while still not becoming too technical or too wordy.

Comments from the system to the user were included where the user should be informed about some of the assumptions made by the system.

For certain adhesive/application combinations it was necessary to generate a note of warning or explanation that was specific to only that adhesive in that application. In such cases the extra text was included with the adhesive class involved, to be displayed as necessary whenever the system mentioned the adhesive's name. An example of this type of adhesive is:
solvent_elastomers (Close contact type, Polychloroprene).

Help options were made available after each question, consisting of answers to the users prompts of "what" or "why". These options helped to explain the underlying reasoning behind the sequence of questions in the KBS.

Once the KBS was running, it became more obvious what refinements could help the user. The following extra options fell into this category. Existing electronic files of a glossary of terms for adhesives use and files of descriptions and characteristics of adhesives were copied into the KBS. (There were no transcription errors introduced by this method.) The original KBS asked questions about the final application that the adhesive would be put to and then gave a suitable set of adhesives. A second set of pathways was introduced so that the KBS could alternatively ask questions about the type of material to be bonded.

At the end of a session a menu of general topics on adhesives was provided to give a glossary of terms and to supply information on how to use adhesives on-site, safety, relative adhesive costs, surface preparation, and timber preservatives.

When users want to leave the KBS, they are given a summary of the application or materials to be bonded, the intial list of suitable adhesives, any refinements to this list and the new set of adhesives.

4.3 Developments - Stage 2

The information was encoded into CLASS in a form similar to that of its written form (i.e., tabular). Each of the eighteen types of adhesive were represented by a record type of structure containing descriptions of the various adhesive properties (and an example is given in Appendix 2).

Figure 1 depicts the stages specifying the input and output. The application class hierarchy shown in Appendix 3 has two parts, representing the two different methods that the user can employ to classify the adhesive. The user has the choice of classifying either by the materials that will be bonded together (e.g. timber to vinyl) or by the final product (e.g. door).

Figure 1   The basic information flow within the KBS.

```
USER INPUT                                                  SCREEN OUTPUT

General Job description =====> | Stage 1 |==========>Comments/Warnings
                                ---------
                                    ||
                                    ||===============>Adhesives Chosen
                         Adhesives  ||  Chosen
                                    \/

Specific Job/Adhesive ========>| Stage 2 |==========>Remaining Adhesives
    Description                 ---------
```

A class was constructed that contained rules and procedures that used this record structure for deciding if an adhesive was suitable or not. Each type of adhesive was represented by a separate instance of this class, with the same rules and procedures being common to all the types of adhesives.

This allowed the problem to be treated as if only one type of adhesive was having its suitability judged, a process that was simply repeated eighteen times with different data.

It was assumed that this area of the system would operate after the suitable range of adhesive types had already been selected by the first stage of the system, and would deal with displaying the results of a session as well as any further selection operations.

Initially, the extra information was provided as an option so that the final result of the session could be more than just the name of a type of adhesive. At this stage the adhesive class only displayed to the user the data it contained.

To further improve the system, the user was given the choice of using some adhesive properties as a means of refining the initial full set of adhesives. At the level of the single control class this would involve rules simply judging the adhesive as passed or failed, according to the values contained in the record structure that describes the adhesive.

In many cases, this refinement operation would be unnecessary or a hindrance and therefore it should be optional. Since there was no way of knowing in advance which adhesive properties a user would consider to be important, the user was provided with the choice of properties which were to be involved in the selection process. The inclusion of this choice removed unnecessary questions about adhesive properties.

Some of the adhesive properties could be quantified as single values, for example the resistance of the adhesive to temperature could be rated as being poor, good or very good. For such properties the adhesive class could compare the adhesive's rating with a value supplied by the user and so automatically reject unsuitable adhesives.

Unfortunately, many of the adhesive properties were of a more descriptive nature and could not be quantified in this way. eg. A description of the mixing method for the adhesive.

For such properties each available adhesive would, in turn, have the property description printed out, and the user would be asked whether to accept or reject the adhesive for further consideration based on this single property.

The advantage of this approach over simply giving the user all such information at the same time and asking them to choose the best of them, is that the area of consideration is narrowed down to one single property at a time which could be compared amongst the adhesives.

The properties dealing with the adhesive's resistance to temperature and moisture were already partly represented in the first stage of the system, where the application is being defined, by a question about the location of the bond. This rule was removed, and the decision left to the second stage of the system, along with the other adhesive properties.

The user interface rules and properties dealing with this area of the system were moved into an additional class as both an aid to maintenance and to make the control class more manageable.

At the end of any session the Class language provides a menu of options. This enables the user to quickly re-run the KBS, view the list of known values of variables (useful if the user wants to change questions), write a comment to BRANZ, or view a summary of the help options.

5. MAINTENANCE CONSIDERATIONS

One of the aims considered during the development of the system was to build a finished product that could be easily maintained and updated. Some of the features that assist maintenance are listed below:

(1) The information that the system uses about an individual adhesive is kept together in an ordered structure, and all such structures are kept together.

(2) The rules and procedures dealing with acquiring information from the user are kept in separate classes from those that apply the information.

(3) Meaningful property and procedure names are used throughout the system to make understanding and/or debugging easier.

(4) Rules and procedures that are common to many classes are kept in a single class that is shared between the common classes. This allows changes that apply to them all to be made only in one place.

(5) Using the classification system, the rules and procedures dealing with the different areas of operation are sorted into separate 'classes' of operation, which can then be dealt with independently.

6. SOFTWARE TOOLS

As in any major programming effort, a powerful editor was essential to speedy development of the system.

The compiler was under development during construction of the KBS. The improvements led to a greater appreciation of the importance of features such as: speed; error explanation/recovery; and interaction. For example, the later compiler enabled an acceptable real time response to user replies of several seconds, but the initial compiler gave a response time of several minutes.

A special version of the runtime system was designed for the knowledge engineer, and this had special features for debugging such as "Trace". This feature allowed the engineer to follow the runtime execution of the system, and displayed the current rules and procedures being used.

Once the system had reached an operational stage it was helpful if the business of loading, checking, compiling, and linking could be done automatically, and preferably in the background.

7. FUTURE CONSIDERATIONS

One interesting point that came up during the development was how some areas of operation were essentially doing database manipulations, which was not easily accomplished in a system such as CLASS. Of particular note was the information concerning individual adhesive types, and the rules that operated on this information.

If the system was tied into a separate database then such information could be kept and updated independently of the rulebase that forms the KBS. In fact, the system can, in principle, be tied into a separate database using the next version of CLASS which will have a database interface facility.

8. CONCLUSION

The development of the system has proved to be very beneficial in the further development of CLASS language especially in the knowledge engineering environment (e.g. for debugging and compiling) and in the integration with the database.

This prototype material selection system is more useful than the hardcopy information that it is based on, because it guides the user to the relevant factors, presents the user with relatively simple questions a step at a time and allows feedback from the user.

9. ACKNOWLEDGEMENTS

The authors wish to acknowledge the invaluable guidance and advice given by A H Dechapunya and the overall direction given by R S Whitney of BRANZ.

APPENDIX 1

INFORMATION SOURCES FOR THE KNOWLEDGE-BASED SYSTEM

Most information was obtained from:

British Standards Institution. 1979. Adhesives for construction. Part 1: Adhesives for use with flooring materials. BS 5442. London.

British Standards Institution. 1979. Adhesives for construction. Part 3: Adhesives for use with wood. BS 5442. London.

Gaps in the information derived FROM the above sources were filled FROM :

Standards Association of New Zealand. 1987. The manufacture of glue laminated timber. NZS 3606. Wellington.

Standards Association of New Zealand. 1978. Finger-jointed timber. NZS 3616. Wellington.

Building Research Association of New Zealand. 1985 Adhesives for Use with Wood and Wood-based Products. Building Information Bulletin 246. Judgeford.

Building Research Association of New Zealand. May 1986. Coming Unstuck? Build Issue No 65, page 1. Judgeford.

APPENDIX 2

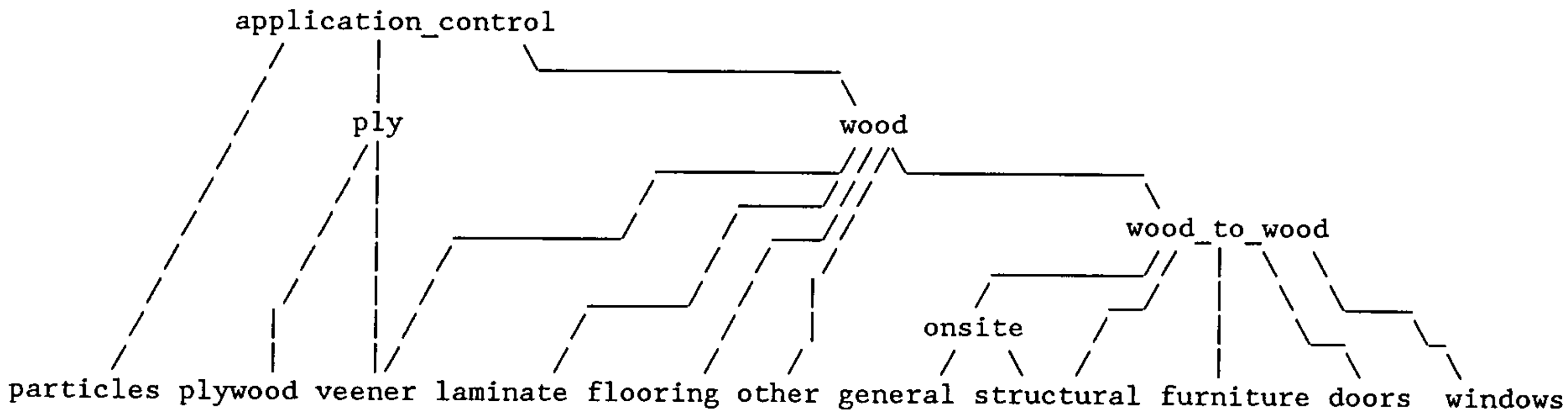
AN EXAMPLE OF THE DATA STRUCTURE OF AN ADHESIVE TYPE

```
urea_formaldehyde : adhesive_type := new(
      user :=                        users_selection,
      system_comment :=              urea_formaldehydeNB,
      name :=                        'Urea Formaldehyde',
      availability :=                retail,
      description_line :=            'Thermosetting Synthetic Resin; white
                                     to cream
                                     (liquid/powder)'&
                                     'hardener (liquid/powder)',
      preparation_line :=      'Resin mixed with hardener(and water for
                                     powders)
                                     extender mixed with liquid.'&
                                     '(Synthetic Resin and hardener can be
                                           applied to separate faces)',
      storage_life_comment := 'Up to 12 months; no limit for hardener',
      max_storage_life :=      twelve_months,
      assembly_time :=         'At Room Temperature; 30 mins
                                 (hot mixes longer), Pot life; 5 hrs',
      curing_comment :=        '2 to 24 hrs at Room Temperature under
                                 pressure'&
                               'several minutes above 80 degC (or RFC)',
      adhesives_minimum_cold_curing_time := hours,
      adhesive_is_suitable_for_heating := true,
      gap_filling :=           poor,
      gap_comment :=           '(Can be improved by additions)',
      moisture_resistance :=   moderate,
      moisture_comment :=      'to poor (Not recommended for warm, moist
                                           conditions)',
      temperature_resistance :=     moderate,
      temperature_comment :=   '(up to 65 degC)' ).
```

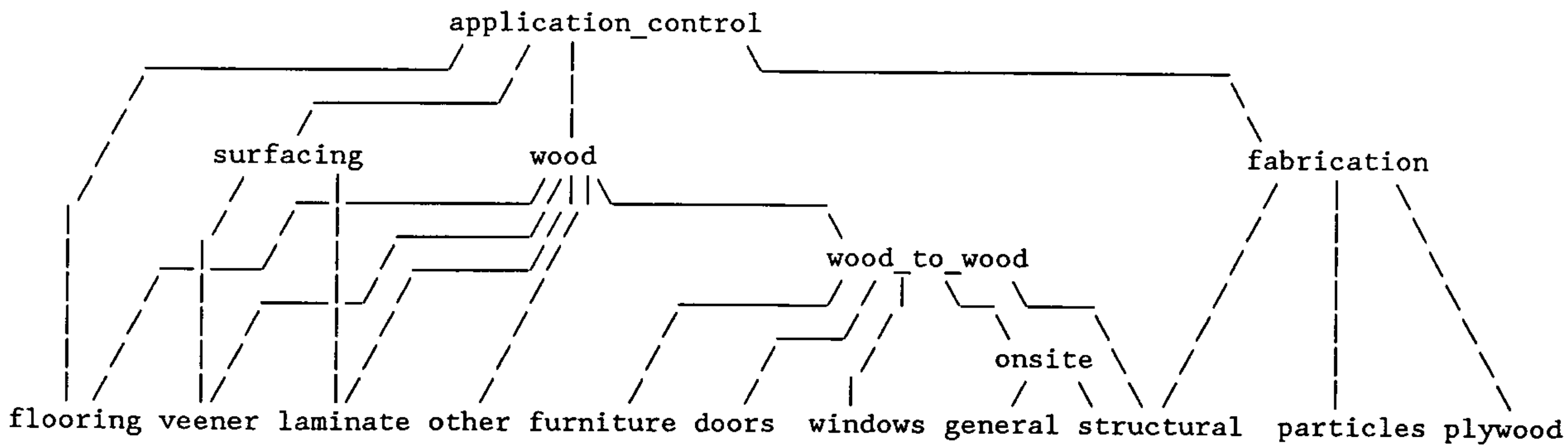
APPENDIX 3

ADHESIVE CLASSIFICATION STRUCTURE

Classification By Materials:



Classification By Application:



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