Advanced Construction Technology System – ACTS

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ABSTRACT: The Advanced Construction Technology System (ACTS) is a computerized database for the classification, documentation, storage and retrieval of information about emerging construction technologies. ACTS consists of a custom MS Windows application, classification and keyword files, and a database of emerging technologies. It currently includes technologies that relate to civil, architectural, electrical, instrumentation, mechanical, and piping systems. Technologies have been classified according to the CSI Masterformat, indexed using a predetermined set of keywords, and described according to a standard format that determines the type, amount and organization of information about each technology. The ACTS project was supported by the Construction Industry Institute and the Construction Productivity Advancement Research program (CPAR) of the Corps of Engineers. Ultimately, it is anticipated that ACTS will be established as an ongoing information service to the US construction industry that will help contractors, designers, and owners identify and use emerging technologies to improve construction efficiency and effectiveness. ACTS has been developed in Actor, an object oriented general purpose language for MS Windows 3.x and is available from the senior author upon request.

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INTRODUCTION

The rising cost of construction is a subject of grave concern to U.S. industry. Excessive construction costs have eroded the construction industry's competitive position and have led to a decline in capital investment and the growth of manufacturing. A large number of projects have been abandoned and many are delayed because of shortness of funds. As a result, owners are more aggressively looking for more cost-effective design and construction, while contractors are looking into increasing productivity and efficiency to remain competitive.

The expedient introduction of new technology has been widely recognized as one of the most promising solutions to these problems because of the potential to enhance quality of the constructed product, to increase efficiency, and to decrease costs. New technology provides a driving force to change decisions at the design stage and operations at the construction stage. It has been identified as a significant factor influencing design and construction integration (Vanegas 1987) and its prudent deployment has a direct influence on the effectiveness of constructability input during design (CII 1986). Not surprisingly, it has also been identified as the factor that will determine leadership in the world construction markets over the next 20 years (Halpin 1989).

Construction lags behind other industries in developing, identifying and adopting innovative technology and has a history of long lead-times for technology transfer (CICE B-2 1982). The productivity growth rate of the construction industry from 1948 to 1981 was only 15%. This rise is much lower than that for other industries, such as manufacturing for example, which in the same period enjoyed a productivity growth rate of 132% (Sink 1985).

The ACTS project originated from a consensus that the construction industry needs a more structured and systematic means for the identification of innovative technologies that will speed up the process of technology transfer and promote efficiency and effectiveness. The project is a an industry-wide effort to identify, compile, and disseminate information on emerging construction technologies in selected areas that merit priority (CICE B-3 1982).

ACTS OVERVIEW

The Advanced Construction Technology System (ACTS) is a computer-based database for the classification, documentation, storage and retrieval of information about emerging construction technologies. ACTS consists of a custom MS Windows application, classification and keyword files, and the technology information stored in its database. It is similar to an on-line relational database that serves as an intelligent classification and indexing system for characterizing, storing, and retrieving detailed technology information. Its primary objectives are to allow the user to find all emerging technologies that relate to a specific domain or problem, and to provide sufficient information to make the initial and crucial decision as to whether a certain technology is of interest and should be pursued further.

The type, amount and organization of information about each technology in the ACTS database is determined by a standard format developed by the research team and the members of the CII Technology Survey Task Force. The system currently includes 397 technologies that relate to civil, architectural, electrical, instrumentation, mechanical, and piping systems. The identification and documentation of advanced construction technologies was accomplished through a joint effort by researchers at the University of Michigan, North Carolina State University, Purdue University, and Argonaut AEC, General Motors Corporation.

The ultimate objective of this project is that ACTS will eventually be established as an ongoing information service to the US construction industry that will help contractors, designers, and owners identify and use emerging technologies to improve construction efficiency and effectiveness.

ACTS has been implemented as a protected mode application for the MS Windows 3.x operating environment. It requires an IBM-compatible computer, with a 386 or better microprocessor, a minimum of 4 Mbytes of RAM and 3 Mbytes of hard disk space, a VGA or better display, and any pointing device (mouse) and printer supported by MS Windows 3.x. It is available from the principal author upon request.

ACTS DOCUMENTATION FORMAT

Technologies in the ACTS database have been documented using a standard format that prescribes the type of information that should be collected as well as its organization.

Conceptually, the ACTS standard format is similar to a database record definition. It includes 25 predetermined fields, each of which has a well-defined purpose for describing a particular aspect of the technology. Obviously, not all fields apply to all technologies. Also, information about emerging technologies simply may not be available to complete all fields. As a result, some fields may remain empty or may have to be completed as information becomes available. Appendix II shows the complete ACTS standard format with a detailed description of its fields.

The technology documentation format was originally based on the one developed for the Advanced Building Technology (ABT) Matrix (Ioannou 1988). This project was sponsored by CII as a pilot test for ACTS and concentrated on civil and architectural technologies. Because its format was most appropriate for building construction it was later modified and extended to accommodate a broader spectrum of technologies. The final ACTS format was developed through an iterative process of refinement based on suggestions and feedback from industry and academia.

The type of information collected and the degree of detail in the database were determined on the basis of experience and the industry's needs. Several objectives are satisfied by the suggested format. It provides information in a form that is sufficient, non-product specific, and readily usable in everyday practice. Most importantly, it provides enough information to make the initial and often crucial decision at to whether a certain technology is of interest and should be pursued further. This is of particular importance because, by definition, a database of emerging technologies cannot provide the spectrum of information necessary for detailed implementation.

TECHNOLOGY IDENTIFICATION

The ACTS database currently includes emerging construction technologies that relate to civil, architectural, electrical, instrumentation, mechanical, and piping systems. Technologies in ACTS are defined to be combinations of resources, methods, and environmental requirements and constraints that produce a construction product (Tatum 88). Since a primary objective was to concentrate on emerging technologies, the information about each technology is sometimes limited but will gradually increase as new technologies are researched, tried, and evaluated. Perceptions of what constitutes an emerging technology varied with different individuals and companies, depending upon whether a particular technology had been encountered previously, and was determined on a case by case basis. The selected priority areas for technology identification are those identified by the CICE B-3 report as having the greatest potential for improving construction efficiency and reducing costs: steel & concrete structural construction, electrical & instrumentation construction, and piping & mechanical construction (CICE B-3 1982).

The identification and documentation of advanced construction technologies was accomplished through a joint effort of four organizations over a period of two years. Emerging technologies in steel and concrete construction were identified by North Carolina State

University, electrical and instrumentation technologies were identified by Purdue University, mechanical and piping technologies were identified by the University of Michigan, and technologies for the mechanical systems of buildings were contributed by Argonaut AEC, General Motors Corporation. In addition, ACTS includes technologies identified by the University of Michigan as part of the ABT Matrix project.

The technology identification effort involved thorough searches of library indexes, research journals, conference proceedings, professional and trade magazines, patents, product catalogs and manufacturers' literature. Emerging technologies were also identified through questionnaires, site visits, request letters and phone calls to product manufacturers and suppliers, and communications with owners, designers, and contractors.

The information collected by each of the four organizations was initially screened and evaluated by members of the CII Technology Survey Task Force to assess its value and impact on construction. Every effort was made to provide impartial descriptions and to avoid focusing on proprietary products. After the initial screening, the documentation for each technology was prepared according to the ACTS standard format, and after a second review, it was classified, and entered into ACTS by the responsible organization. In addition to the technologies included in ACTS, individual reports summarizing the findings of each organization will be published separately (Chang et. al. 1992, Johnston et. al. 1992, Ioannou et. al. 1992).

ACTS DESIGN OBJECTIVES

Construction technology information systems have four critical characteristics - complexity, uncertainty, interdependency, and heterogeneity (Scott 1981, Tatum 1988). Complexity refers to the number of different items or elements that must be dealt with at the same time. Uncertainty refers to the variability of the items upon which the work is performed. Interdependency indicates the extent to which elements are interrelated. Last, heterogeneity refers to the contents of the construction technology information. Because of these characteristics the design of ACTS underwent a lengthy process of refinement over a period of almost 3 years. A total of four ACTS prototypes were developed during this period. Two of these were custom DOS programs written in object-oriented Pascal. One used a hypertext paradigm while the other was closer to a traditional object-oriented database. The last two were MS Windows 3.x applications, with the first written in Toolbook, a Hypercard-like environment, and the second and final version developed in Actor, a general purpose object-oriented programming environment. Several commercial software packages were also considered, including database systems, hypertext systems, and expert systems. These, as well as the first three custom implementations, were eventually rejected because they all failed to meet at least one of several basic design requirements, the most important of which are summarized below:

1. ACTS had to be very easy to use. If possible, the system should be completely mouse-driven so that the end-user would not have to type anything through the keyboard.

2. The administration and maintenance of the ACTS database should be equally user-friendly. Furthermore, the ACTS classification and keyword systems should be defined and entered into ACTS separately and be available for on-line use during the technology identification and documentation activities in order to eliminate clerical errors that might violate system integrity.

3. The user should never feel lost, as is often the case in hypertext systems, or have to memorize any commands. All available actions at any given point should be shown on the screen and be readily understandable.

4. The system should never appear to be in control of the user's actions. The user should not feel constrained by options offered by the system that relate to the subject matter being considered.

5. The ACTS software and its database should be independent of each other as much as possible. Major changes in one should require only minor changes in the other. This was particularly important with respect to changes in the database, the classification system, and the keyword system, as these were the subject of extensive scrutiny and were not finalized early on.

6. The ACTS software should be developed concurrently with the technology identification and compilation activities while the documentation format was not completely finalized. Several different teams should be able to perform these tasks and their work should be readily transportable to the final ACTS database.

7. The ACTS data structures, as well as its user interface, should not limit its future growth. All object collections (data tables), menus and listboxes (the basic mechanisms for user interaction) should be able to handle any number of entries.

8. The initial implementation of ACTS should be an open system that does not constrain its future capabilities. ACTS should be able to incorporate other types of information in the future, including vector and bit-mapped graphics, sound, and video, and should easily provide more sophisticated search and retrieval mechanisms if necessary.

9. ACTS had to be hardware-independent. It should operate on any IBM-compatible computer and should make full use of the available hardware, including memory, graphics adapter, monitor, and printer.

10. ACTS had to be completely self-sufficient. It should not require any software other than the operating system.

11. The initial release of ACTS should be distributed freely. It should not require royalties or licensing fees to any external software company.

Given the above set of objectives, at least three of the decisions concerning the design of ACTS become quite evident:

1. No general purpose commercial software could provide the necessary level of ease of use, the ability to customize and expand the system, and the decoupling of the program code from the database to facilitate concurrent development.

2. ACTS had to be developed for MS Windows 3.x, as it is the only widely available operating system for IBM-compatible computers that provides a graphical, hardware-independent application development environment with multimedia extension capabilities.

3. ACTS had to be developed as an object-oriented system. Two of the cornerstones of object-oriented programming, encapsulation and inheritance, provided maximum flexibility in the prototype stage by facilitating constant changes through loose coupling of the internal data structure and the overall database schema. Furthermore, this approach provided a solid foundation on which to base future enhancements by designing more specialized object classes.

Some of the most interesting and challenging design objectives for ACTS relate to information storage and retrieval. The issues and the corresponding factors that shaped the design of ACTS are presented below as guidelines for future work in the area of construction technology information systems.

Information Storage

One of the fundamental design decisions for ACTS was whether to store the documentation of each technology in a separate text file, or whether to follow the standard norm of storing all technologies in one large binary database file. Both approaches were implemented in the early design stages in order to evaluate their advantages and limitations.

Using individual text files, one for each technology, allowed the creation of documentation files prior to the completion of ACTS by using ordinary word-processors and the subsequent publishing of reports outlining each research team's findings. It also made it much easier to merge the work of the various research teams into a global database. However, it also required a unique file-naming scheme, an intelligent mechanism for keeping track of unused or deleted file-names, more disk space, and resulted in a documentation subdirectory with a very large number of files. Using a single large binary database file to store all technologies did not have these shortcomings but was much more difficult to manage during the development of ACTS. It made it difficult to merge the databases created by the various research teams and would have prevented them from easily publishing their work separately. Furthermore, it would have probably locked the system into a proprietary file format

Closely coupled with this issue was the choice to store the documentation of each technology as one entity, as opposed to treating it as a traditional database record and breaking it down into individual fields. Most of the fields in the standard ACTS technology documentation format contain variable-length text and thus have no preset limits (field size). The breakdown of the available technology information into fields, the exact wording used, and thus the field size depend on the nature of the technology being documented and the individual compiling the information. Because of the variability of field sizes, it is obvious that fields could not have fixed storage requirements. Similarly, their contents could not be viewed in a reporting form of predetermined size on a computer screen. Instead, the contents of the various fields had to be presented using scrolling listboxes arranged within a larger scrolling record form. This approach, however, made reading the documentation of a technology on a computer screen very cumbersome. In addition, the traditional database record approach was not only more complex but yielded no benefits in information search and retrieval. This should have been expected, as technology documentation cannot be easily standardized, and thus record retrieval based on field contents (using string search) had very poor results. In contrast, storing the documentation of each technology as a separate text file had none of these shortcomings and was easy to read both on-line and in printed form.

Based on these findings, the documentation of ACTS technologies had to be saved in individual text files to allow maximum flexibility in identifying and compiling the information before ACTS was completed, publishing the results as separate reports, and gathering the files into a global database. This decision necessitated that ACTS be able to manage a large collection of text documents each describing one technology. The obvious problem was how to structure ACTS so that it would be an easy to use, efficient, effective, and yet flexible document storage and retrieval system.

Technology Classification and Indexing Versus Full-Text Search

An obvious approach was to base ACTS on a full-text search and retrieval system. Full-text search uses the power of the computer to search every character of every word in every sentence in every document. When information is needed from the stored document collection, the computer is instructed to search and retrieve all documents containing certain specified words and word combinations, possibly using logical operators and word-proximity rules. On the surface this approach appears to be very effective as well as efficient. It makes full use of inexpensive computing power and avoids the effort needed for indexing and classification of technologies.

Unfortunately research has shown that the effectiveness of full-text search is hampered by loose document structure, the inability of the computer to draw semantic inferences based on the linguistic meaning of document contents, the use of synonyms, the possibility of misspellings, long document contents, and a large number of documents (Blair 1985). In Blair's work, the effectiveness of full-text search was measured by the success of information retrieval as quantified by its precision and recall. Precision is the ratio of the number of relevant documents retrieved, to the total number of retrieved documents. Recall is the ratio of the number of relevant documents retrieved to the total number of relevant documents in the database. Tests of a commercial state-of-the-art full-text search and retrieval system on a mainframe using a database of legal documents were shown to have an average precision rate of 79% and an average recall rate of only 20%. This means that 21% of the documents retrieved were not relevant to the subject being searched and that about 80% of the relevant documents in the database were missed entirely. It is interesting to note that the actual users of this particular system had never realized the ineffectiveness of their searches and believed that they were working with at least a 75% recall rate. Blair's study illustrates that full text-search is not as effective as most people think, and that the cost of classifying and indexing the information in the database is indeed worthwhile given the resulting savings in end-user's time and the improved precision and recall of information retrieval. Furthermore, the speed and effectiveness of document retrieval systems can be greatly improved by reducing the number of logical decisions required of the user (Blair 1984).

The above results were of paramount importance in the design of ACTS. By definition, the information contents of a database on emerging technologies are not known a priori to the end-user. As a result, ACTS should be able to provide a very high recall rate and should also convince the end-user that this is in fact the case. These requirements were met by using a hierarchical technology classification system, and by indexing the technologies with keywords selected from a large predefined set.

Standards for Computerized Construction Information Systems

Several standards for computerized construction information systems were investigated as part of the ACTS project. Recent efforts towards the computerization of construction information can be divided into two groups. The first focuses on the standardization for data exchange between computer applications for design, production, and maintenance of discrete products, including products for the Architecture, Engineering, and Construction (AEC) industry. The second focuses on the implementation of construction information systems.

Standardization efforts for product data exchange include STEP (STandard for the Exchange of Product model data), PDES (Product Data Exchange using STEP), and Productmodeling. STEP is a project of the International Standard Organization (ISO) aimed at capturing and transferring all product data (Howard 1991). PDES is the U.S. organizational activity in support of the development and implementation of STEP (NCGA 1991). Productmodeling is a research project of IBBC-TNO in the Netherlands and is part of the work on STEP (Gielingh 1986). These efforts focus on the description of geometry, topology, technique, and the representation of a building or its parts, as well as on the exchange of administrative data.

A second type of effort focuses on the implementation of construction information systems based on different classification systems. Examples include the Construction Criteria Base developed by the National Institute of Building Sciences (NIBS), the Electronic Sweet's Catalog, the computerized R.S. Means estimating programs, and the Building Product Model of the RATAS project. Of these the most ambitious effort is the RATAS project, conducted during 1987-88 in Finland, which aimed to develop a national system for computer-aided design in the construction industry (Bjork 1989-1, 1989-2). The kernel of the RATAS project is the “Building

Product Model", a functional description of a building in computerized form based on a five-level abstraction hierarchy: "Building", "System", "Subsystem", "Part", and "Detail".

Classification Systems for Construction Technologies

Three coding standards were identified as suitable for use in ACTS for classifying construction technologies: the Masterformat and Uniformat used in the U.S., and the European CI/SfB coding system.

The 16-division Masterformat of the Construction Specifications Institute (CSI) is a hierarchical system of numbers and titles for organizing construction information (CSI 1988). It provides a standard information filing and retrieval system that can be used for organizing information in project manuals and specifications, for organizing cost accounts and cost data, and for filing product information and other technical data.

Since its introduction in 1963, the Masterformat has been widely accepted as an industry standard in the United States and Canada. It has been adopted by the Associated General Contractors (AGC), the American Institute of Architects (AIA), the National Society of Professional Engineers (NSPE), and others in the United States and Canada in the form of a document entitled "Uniform System for Building Specifications." It has also been officially adopted for all construction work by the U.S. Army, Corps of Engineers, the U.S. Navy (NAVFAC), the National Aeronautics and Space Administration (NASA), and by numerous other public and private agencies. It has been used since 1986 by McGraw-Hill Information Systems Company as the basis for the Sweet's Catalog Files of construction products and it has also been used since 1987 by the R.S. Means Company for coding their construction cost data publications. In addition, the Masterformat has also been used for coding product literature, such as the CSI Spec-data product information sheets, for organizing specifications and construction bids, as in the CSI Manu-Spec system, and in commercial cost estimating and cost accounting computer systems.

The Uniformat (GSA 1975) is issued by General Services Administration (GSA) and uses a functional breakdown of a building into subsystems. It includes 12 major divisions which are then broken down into two sublevels, and unlike the Masterformat, it is not materials oriented. In current design practice the Uniformat is used primarily for functional breakdown at the early planning and design stages. Information at the detail design and construction phases is typically organized according to the Masterformat.

The CI/SfB coding system (RIBA 1969) is based on the SfB system used in Sweden since 1950 as a national method for organizing official and centrally produced construction industry specifications, price books, and building product data sheets. After many modifications, a new version of the SfB system, now called the CI/SfB system, was introduced in 1969 and has since been adopted by many European countries including the U.K. and the Netherlands, and is being considered as a standard for all countries in the European Economic Community. The CI/SfB coding system includes four main tables: the building environment table, the elements table, the construction forms and materials table, and the activities and requirements table. One characteristic of the CI/SfB system is that each table can be used either independently or together with other tables. This characteristic makes the CI/SfB system more flexible than other coding systems, since it allows it to cover technology information from generic to specific forms.

The CSI Masterformat was finally selected as the technology classification system for ACTS because of its widespread use and recognition as a standard within the U.S. construction industry. This selection was subject to considerable scrutiny and discussion among the academic and industry members of the CII Technology Survey Task Force. In order to ensure its completeness and depth in all subject areas, particularly mechanical, electrical and instrumentation, the Masterformat was compared to three proprietary coding systems developed by individual contractor members of the CII, to CI/SfB, and to alternatives proposed by academia (Ioannou 1990, Tatum 1988). In the end, however, it was recognized that ACTS should initially follow a well established industry standard as this would be critical to the system's success. The implementation of the Masterformat within ACTS is quite independent of the software, and can be easily extended in the future if necessary.

ACTS CLASSIFICATION SYSTEM

Technologies in the ACTS database are classified according to the CSI Masterformat, a hierarchical classification system based on decimal five-digit codes and associated titles.

At the top of the Masterformat hierarchy are the General Divisions. Each Division is broken down into several Broadscope Sections, and each Broadscope Section may be subdivided into several Mediumscope Sections. Each of the General Divisions, 1 through 16, is identified by the first two digits of the CSI five-digit code (e.g., 03000-Concrete). The CSI number for a Broadscope Section begins with the first two digits of the corresponding General Division. The next two digits identify the particular Broadscope Section (e.g, 03200-Conrete Reinforcement). Each Broadscope Section may include several Mediumscope Sections identified by the last two digits of the CSI number (e.g., 03240-Fibrous Reinforcement) . It should be noted that the fourth digit may sometimes be used to identify a Broadscope and sometimes a Mediumscope Section. Some of the smaller Broadscope Sections do not contain any Mediumscope Sections. The Masterformat defines a total of 269 Broadscope Sections and 967 Mediumscope Sections, for a grand total of 1253 five-digit codes.

Each technology in the ACTS database must be classified so that it belongs to exactly one Broadscope or Mediumscope Section. The documentation of a technology is stored in a file in the ACTS subdirectory whose filename has the form ACTccccc.nnn. The string "ccccc" represents the five-digit code of the corresponding Broadscope or Mediumscope Section. The extension “nnn” is an indexing number beginning with “001” for the first technology of the corresponding CSI number. By using letters as well as digits within the file extension, ACTS can accommodate up to 46,656 different technologies within each CSI code. A complete listing of the CSI Masterformat as implemented in ACTS can be found in Appendix II of the ACTS User’s Guide (Ioannou 1992-1).

The entire Masterformat hierarchical structure has been coded and included in ACTS to provide a very effective storage and retrieval mechanism. Selecting a General Division from a scrolling list immediately presents a list of the associated Broadscope Sections. Similarly, selecting a Broadscope brings up another list of the associated Mediumscope Sections as well as a list of all technologies that belong to the selected Broadscope or any of its Mediumscope Sections. This list of technologies can be narrowed down by selecting one of the listed Mediumscope Sections. Selecting any of the retrieved technologies brings up its documentation in a separate window and allows the user to examine its contents.

ACTS KEYWORD SYSTEM

In addition to the complete CSI Masterformat classification system, ACTS includes a standard set of 9,247 predefined keywords. Most keywords are associated with a single Broadscope Section, even though there are exceptions. Keywords that span the boundaries of the Masterformat classification system are associated with several Broadscope Sections. Appendix III of the ACTS User’s Guide lists the complete set of keywords in alphabetical order and shows the corresponding Broadscope Section(s) for each one. Appendix IV of the ACTS Administrator’s Guide is an inverted index that lists the 269 Broadscope Sections in numerical order each followed by the associated keywords in alphabetical order (Ioannou 1992-2).

Each technology in the ACTS database may be associated with an unlimited number of keywords that best describe its nature, application, materials, methods, etc. This association of technologies and keywords is the basis for another search mechanism in ACTS. The user can select any of the keywords assigned to technologies in the database from an alphabetical list and the system will immediately retrieve all associated technologies. Selecting any of the retrieved technologies brings up its documentation in a separate window and allows the user to examine its contents.

Since each keyword is also related to one or more Broadscope Sections, the assignment of keywords to a technology creates an indirect one-to-many relationship between the technology and the associated Broadscope Sections. It also creates a one-to-many relation with the technologies that have been assigned the corresponding Broadscope of Mediumscope numbers. ACTS exploits this powerful mechanism to expand the list of technologies in a search in order to ensure a high degree of recall. This capability is most useful when the user does not know the appropriate CSI Broadscope Section in which to search for technologies. In this case, a reasonable selection of a keyword is sufficient to identify the correct Broadscope Section(s).

ACTS LOGICAL SYSTEM DESIGN

Figure 1 shows the ACTS logical schema in relational database form. This figure uses rectangles to represent data tables and arrows to show the type of relations necessary for implementing ACTS. The “Broadscope/Keyword” and the “Act/Keyword” tables contain the “junction records” needed to establish many-to-many relationships between Broadscope Sections and Keywords, and ACTS (Technologies) and Keywords. Even though similar, the ACTS data structure is not identical to the one in the figure. ACTS uses advanced objects that can store unlimited fields per record and thus does not require junction records. In fact, ACTS is superior to commercial databases in that its data files are in text format and thus completely transportable, and in that it has a more powerful and yet simpler user interface.

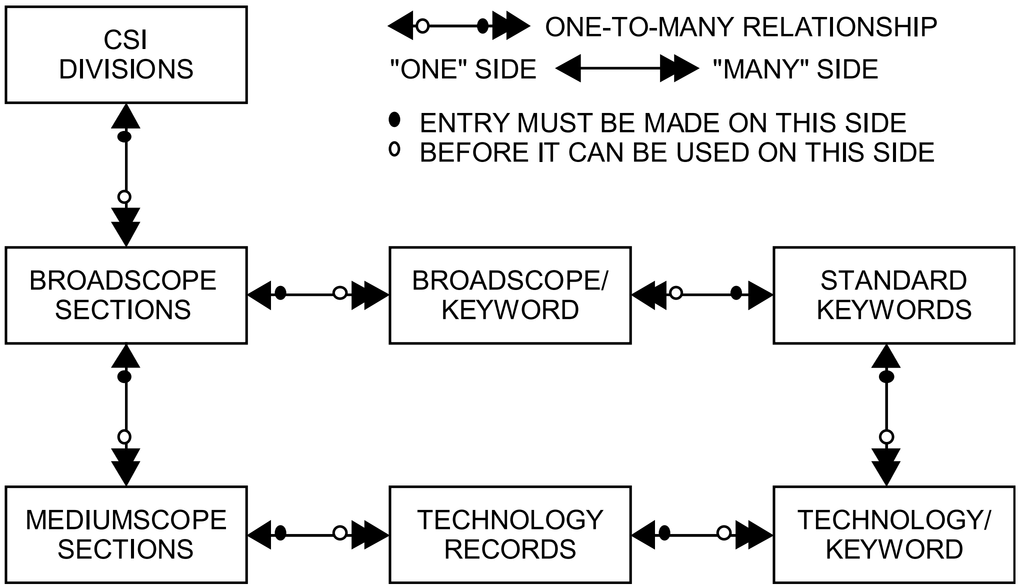

Figure 1 – ACTS Logical Schema

ACTS Operating Modes

ACTS operates in two distinct modes: “User” and “Administrator”. The “User” mode is the default and allows searching the ACTS database without changing it. The “Administrator” mode allows making changes such as adding, editing, or deleting technologies, CSI numbers, and keywords. It is possible to switch from one mode to the other without exiting the system. In order to safeguard the integrity of its database, however, ACTS requires a password to switch to “Administrator” mode.

The need for two separate modes of operation are central to the ACTS design. Casual users should be able to search the ACTS database but should not be allowed to change any of the contained information. This is the purpose of the “User” mode. The “Administrator” mode allows changing the database and is intended to be used by the ACTS maintenance organization.

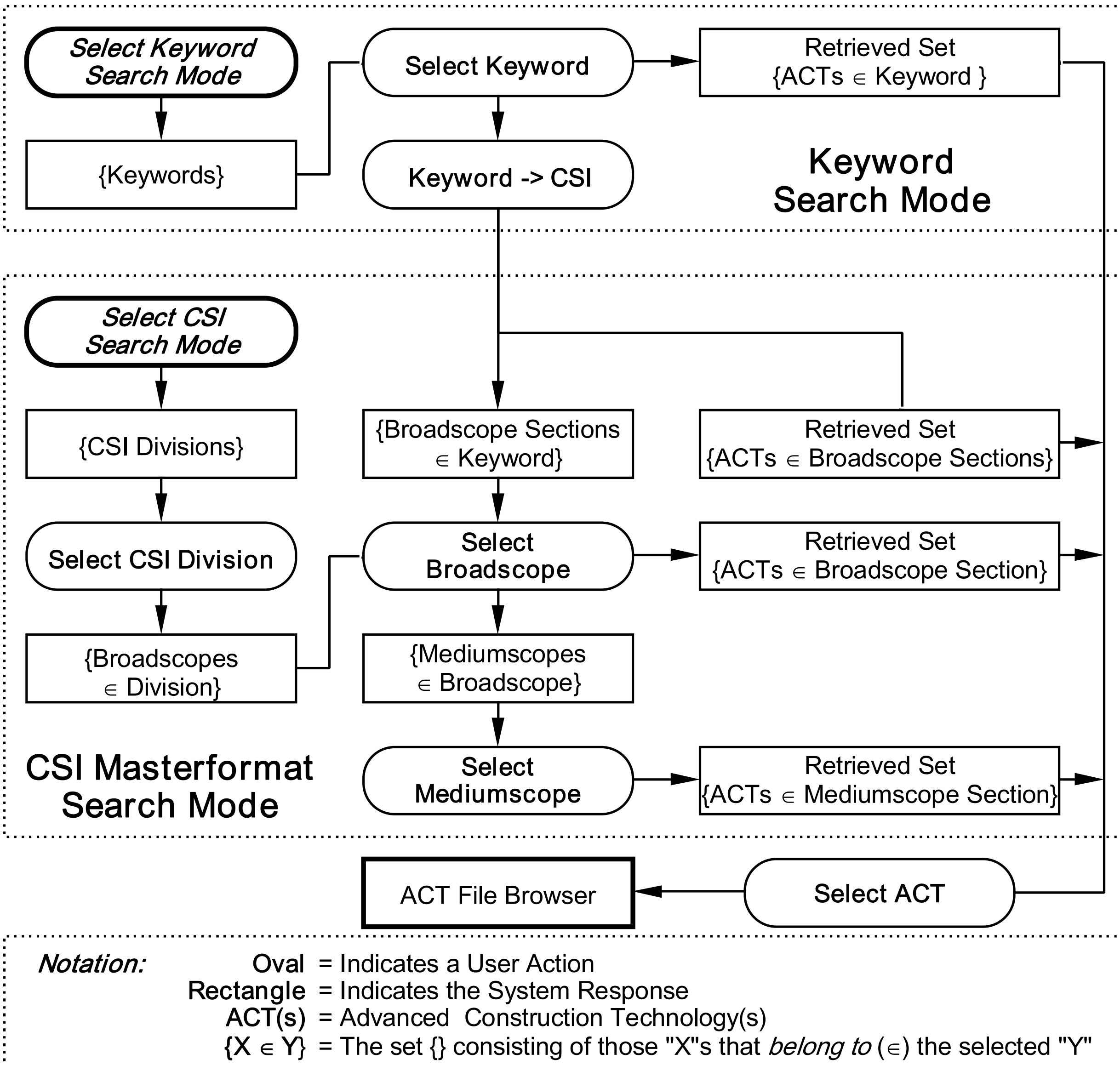

Figure 2 – Schematic of ACTS Search and Retrieval Operations in User Mode

USER MODE

The "User" mode window is the main window for searching the ACTS database. It is a dual mode window whose contents change depending on the active search method. It allows searching the ACTS database either by keyword or by using the CSI Masterformat classification system. The selection of search method is controlled via the window's menu.

Figure 2 shows a schematic representation of the ACTS “User” mode search and retrieval capabilities. Ovals indicate the user’s actions while rectangles show the system’s response. Actions include selecting a menu item, pressing a button or selecting an item from a dynamic listbox. The system’s response includes redesigning the user interface to switch search modes, retrieving related Masterformat sections or technologies and showing them in listboxes or browsers.

The “User Mode - Keyword Index” search mode, shown in Figure 3, is the default. It uses two side-by-side listboxes, the “Keyword” listbox on the left and the “Technologies” listbox on the right. Both listboxes can scroll to accommodate any size lists. The “Keyword” listbox shows a list of the keywords that have been associated with the technologies stored in the ACTS database. Keywords are automatically sorted alphabetically and can be selected by clicking the mouse. Since this list is quite long, keywords can also be selected by using the “Keywords” button to search for a specific text string. The selected keyword is highlighted in inverse video and the names of the associated technologies in the ACTS database are retrieved and shown in the “Technologies” listbox in alphabetical order. Selecting any of the retrieved technologies brings up its documentation in a new browsing window. The name of the associated documentation file is shown in the window’s title bar. Any number of browsing windows can be opened to allow comparison of the descriptions of many related technologies. Figure 3 shows one open and two minimized browsing windows. Browsing windows can be maximized, minimized, resized, and moved using standard MS Windows procedures.

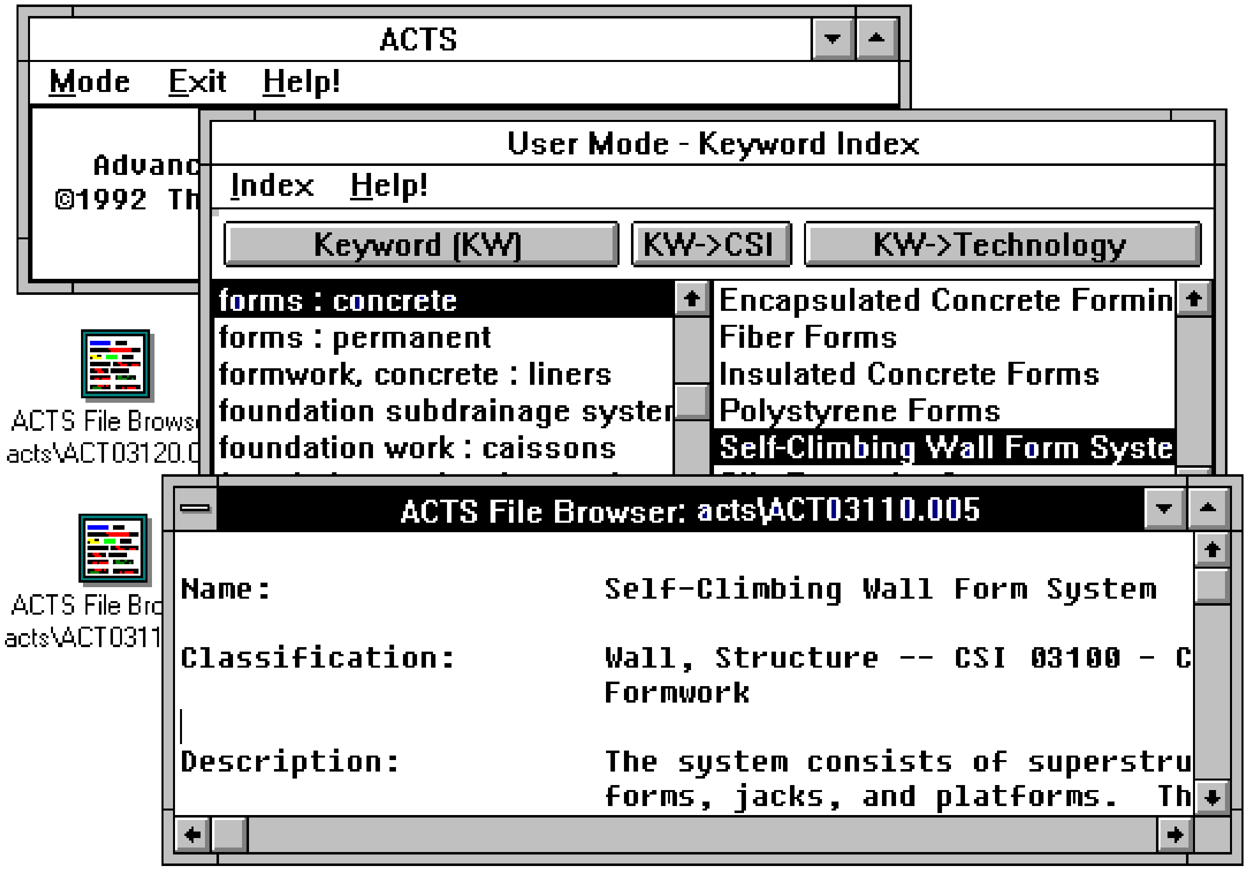

Figure 3 – ACTS “User Mode - Keyword Index”

Information retrieval using the “User Mode - CSI Index” window is based on four listboxes that implement the CSI Masterformat hierarchical classification system as shown in Figure 4. When the “User Mode - CSI Index” is first activated all listboxes are empty except for “CSI General Divisions” which contains a scrolling list of the 16 General Divisions. Selecting a particular Division brings up the related Broadscope Sections in the second listbox. The “CSI Mediumscope” and “Technologies” listboxes are still empty because no Broadscope Section is selected yet.

When a particular Broadscope Section is selected, ACTS shows the related Mediumscope Sections in the third listbox and retrieves the associated technologies in the fourth. These are all

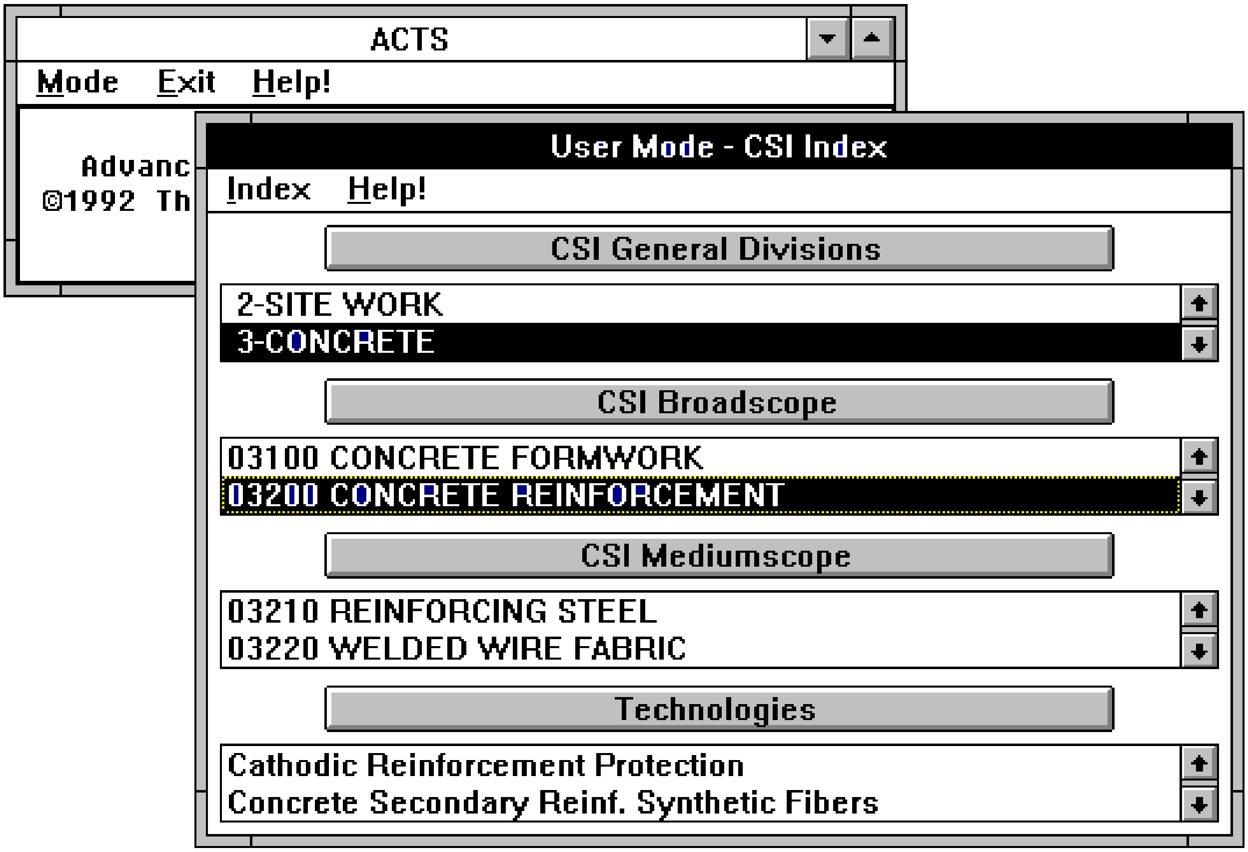

Figure 4 – ACTS "User Mode – CSI Index"

technologies that belong to the selected Broadscope Section or to any one of its Mediumscope Sections. If none exist, the "Technologies" listbox remains empty. When a particular Mediumscope Section is selected, the list of technologies is narrowed down further and includes only those that are explicitly associated with the selected Mediumscope Section. This list is of course a subset of the list shown when the parent Broadscope Section was selected. The "Technologies" listbox for the "CSI Index" search mode is identical to that for the "Keyword" search mode described earlier. It contains a scrollable list of technologies that correspond to the selected Broadscope or Mediumscope Section. Technology names are automatically sorted alphabetically. Selecting one of these technologies shows its description in a new browsing window.

The “KW->CSI” button in the “User Mode - Keyword Index” window provides a hybrid search method that uses both keywords and the CSI Masterformat classification system. Selecting a keyword and clicking this button switches the “User Mode” window to the “CSI Index” search mode but only the Broadscope Sections associated with the selected keyword appear in the “CSI Broadscope” listbox. The “Technologies” listbox shows all the technologies that belong to all listed Broadscope Sections, even if they belong to different General Divisions. This search mechanism is based on the relationship between each keyword in the ACTS database with one or more Broadscope Sections and is most useful when the user does not know the appropriate CSI Broadscope Section in which to search for technologies. In this case, a reasonable selection of a keyword is sufficient to identify the correct Broadscope Section(s).

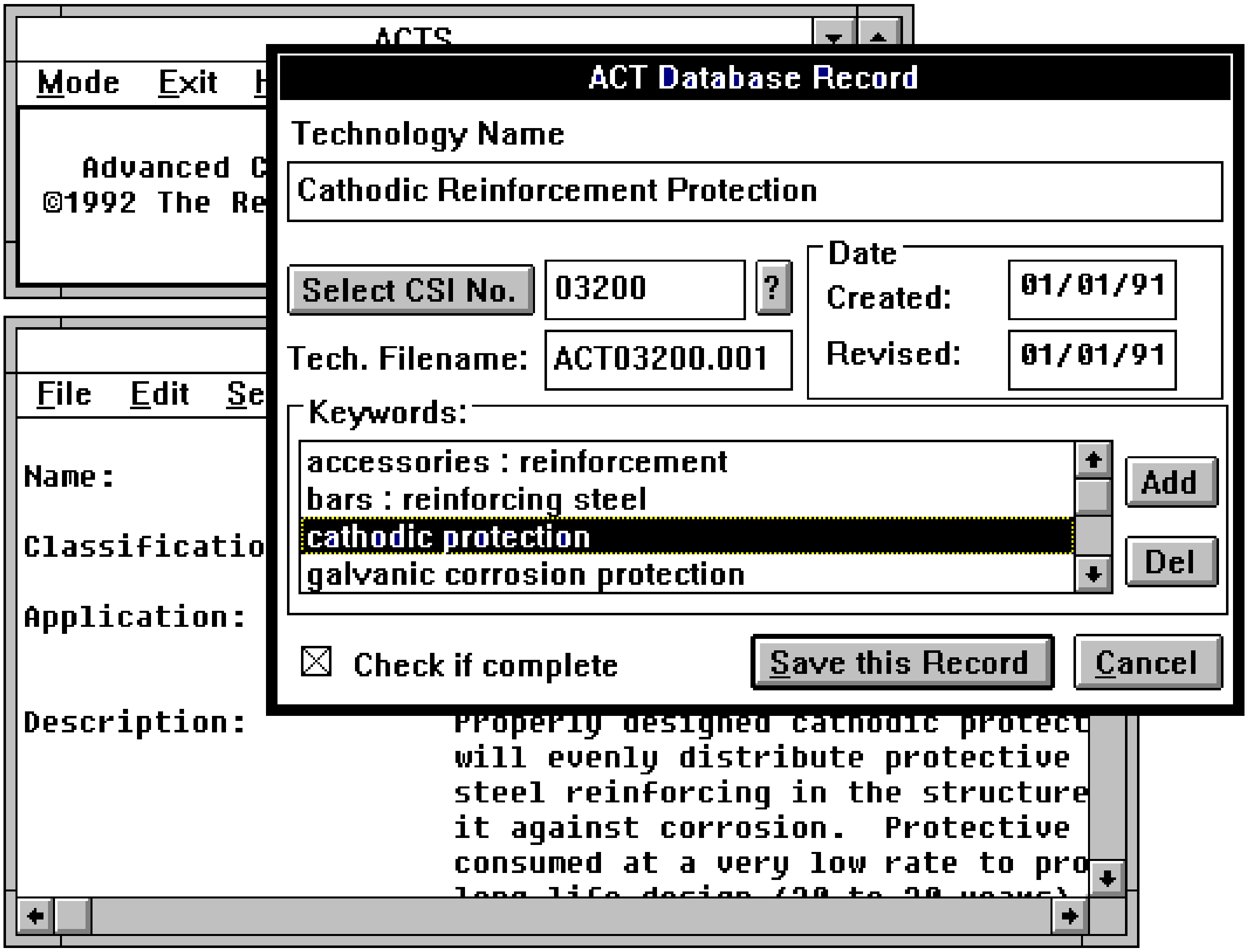

Figure 5 – ACTS "Administrator Mode"

ADMINISTRATOR MODE

The main window of the "Administrator" operating mode includes one listbox that contains all technologies currently stored in the ACTS database. Its menu allows saving the database, creating a new technology record, editing or deleting an existing record, sorting the technology listbox by CSI Number, Technology Name, File Name, Date created, Date revised, and by Completion status, and searching the list for a particular text string.

Creating or editing a new technology record is accomplished via the "ACT Database Record" dialog and the associated text editor, shown in Figure 5. Most of the elements in this dialog are self explanatory.

It should be pointed out that the appropriate CSI classification code and keywords cannot be typed directly into the database. Instead they are selected from hierarchical listboxes through an elaborate system of windows. This was of vital importance in the design of ACTS in order to minimize errors, misspellings, use of synonyms, etc., that can compromise the system's integrity and retrieval effectiveness. For example, the assignment or change of a technology's CSI number is accomplished by clicking the "Select CSI No." button. A hierarchical dialog box appears, similar to the "User Mode – CSI Index" window shown in Figure 4, that allows the assignment of a Broadscope or Mediumscope Section Number via a set of listboxes. The small "?" button to the right of this field shows the complete names of the General Division, Broadscope and Mediumscope Sections that correspond to the chosen CSI number.

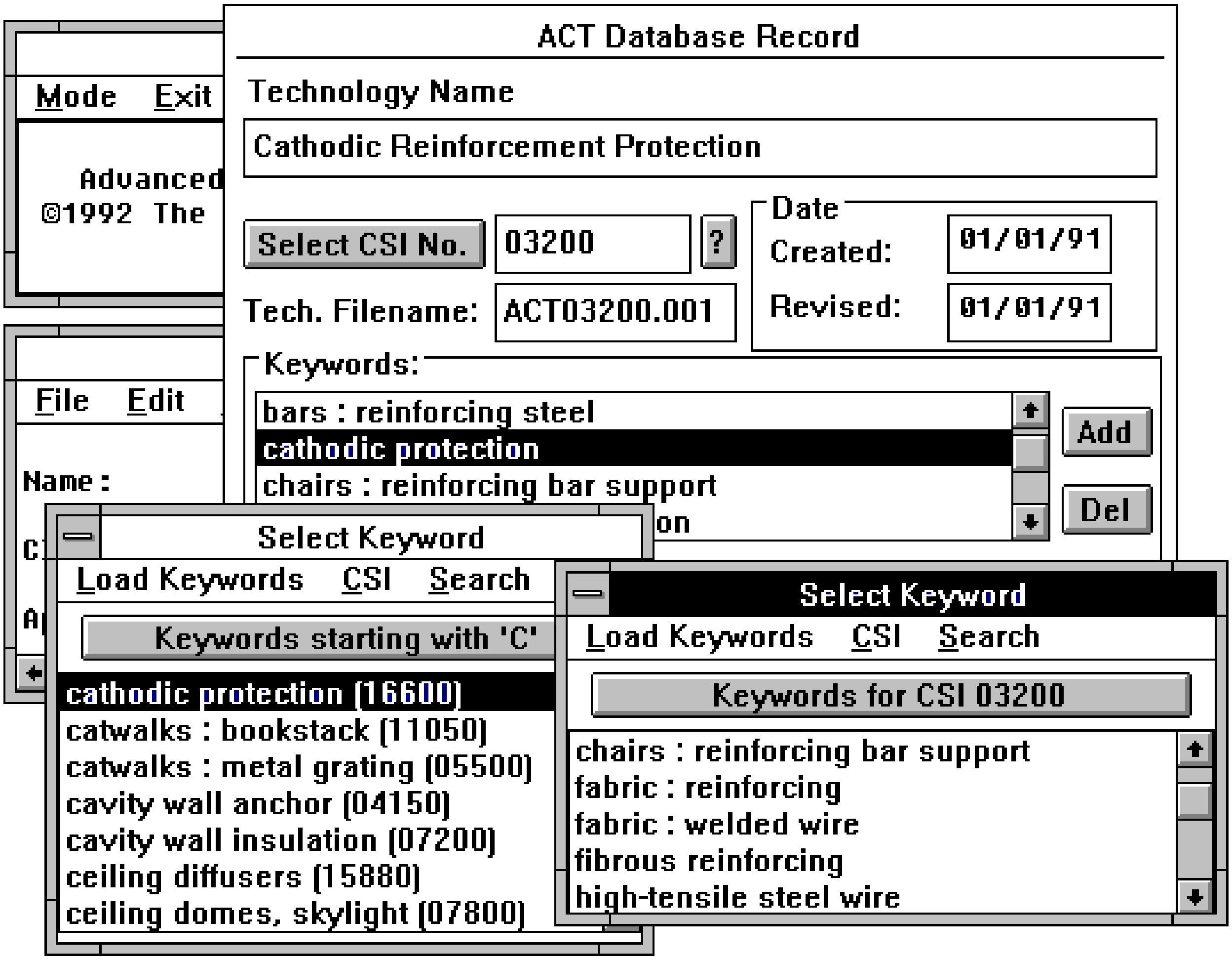

Figure 6 – Definition of Keywords in Administrator Mode

The "Keywords" listbox shows an alphabetical list of all keywords associated with the current technology. New keywords can be added by clicking the "Add" button. This brings up a window entitled "Select Keyword" that contains a listbox with all the keywords associated with the technology's Broadscope Section as shown in Figure 6. Selecting any one of these keywords adds it to the "Keywords" set in the "ACT Database Record". This was another area of concern during the design of ACTS. A listing of 9,247 keywords can be overwhelming even for a system administrator. Thus, the default listbox had to contain only the most likely keywords, which obviously are those that relate directly to the selected Broadscope Section. Any number of keywords can be added to the "Keywords" listbox. Additional "Select Keyword" windows can also be opened that show either the keywords for any selected Broadscope Section or the keywords that begin with a particular letter of the alphabet from A to Z.

The description of the selected technology can be entered or modified in the “Editor” window which implements a full fledged text editor for entering technology documentation. The functionality of this editor is similar to the “Notepad” application distributed with MS Windows.

CONCLUSION

The introduction and prompt use of innovative technologies that improve quality, raise productivity, promote efficiency, and reduce costs is a very effective solution to the increasing problems faced by the U.S. construction industry both in the domestic as well as in the international arena. Construction has long been criticized for its slow performance in transferring and adapting new technologies even when these were shown to provide better results and lower costs. A major reason for this is the lack of an industry-wide effort to systematically survey, evaluate, organize, and disseminate technology information to owners, designers, and contractors.

The Advanced Construction Technology System represents a considerable effort to speed up the process of technology transfer in the construction industry. Given the amount of interest generated in the industry by its predecessor, the ABT Matrix, and the development of ACTS, we believe that there is an urgent need for this type of system. The initial release of ACTS represents a robust and useful system that provides a solid foundation for future growth. In fact, a major objective of the ACTS project is to establish the system as ongoing service to the construction industry. Several organizations have already been canvassed as to their interest in undertaking this effort. It is envisioned that at the conclusion of the project the ACTS system and its database will be transferred to this maintenance organization which will then be responsible for upgrading the software and populating the database with new information about emerging technologies. These upgrades will be distributed periodically to subscribing members in the industry, probably in CD-ROM format.

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APPENDIX II. ACTS TECHNOLOGY DOCUMENTATION FORMAT

First Entered:	Date of first entry.
Last Revision:	Date of latest revision.
Name:	A generic and descriptive name for the technology.
Classification:	The ACTS classification lists the appropriate CSI Masterformat Broadscope or Mediumscope Section Number and Title.
Application:	Short description of the specific applications for the technology.
Description:	A short description of the technology that explains what it is, what it does, what it is used for, how it is applied, and the materials involved. Includes major components of a piece of equipment.
Costs:	Construction, operation, and maintenance costs. Best if given as unit material and installation costs, including ranges and sources of information.
Benefits:	The particular benefits of this technology.
Limitations:	Any limitations and weaknesses of the technology or other pertinent information that should be weighed against the benefits described above. Also included are special problems and conditions under which it misbehaves, fails, or does not fulfill its function, etc.
Construction:	Who can undertake or incorporate the technology in construction; includes any requirements for licensing agreements.

Design:	Design requirements, ease of design, availability of codes and specifications, who does the design for systems that include this technology, need and ease of access to sources of (standard) design details.
Specifications:	Specifications sources for the technology, including installation specifications.
Connections:	Brief description of connections to other systems; what it will support and how attachments are made.
Joints:	How joints are made; special methods, procedures and materials involved.
Compatibility:	Compatibility with other systems or materials: materials/components with which it does or does not work.
Experience:	Summary of past experiences, types of construction where used and performance therein. Includes testimonials of previous users of the technology, if available.
Lifetime info.:	Lifetime information, life expectancy, factors affecting life, major component life, etc. If possible, this information will list both material and installation warranties. Also included will be warranty type, i.e., limited, conditional, etc.
Aging:	Aging information including how well it ages, causes of aging, how to prevent aging, changes in properties and behavior, etc.
Oper. Environ.:	The operating environment and possible restrictions within which a technology may operate.

Repair & Maint.:	Possibility and ease of repair, repair methods, and probability of success. The maintenance requirements of the technology as dictated by usage or passage of time. The availability or lead time for major replacement components.
Properties:	Short description of important properties applicable to the technology: thermal, structural, waterproofing, color, texture, etc. The specific properties listed vary depending on the nature of the technology. Applicable ASTM tests are used to describe technology properties.
Dimensions:	Dimension classification varies depending on the nature, shape, and application of the technology. May include length, width, depth, thickness, cross section area, sheet area, weight, etc.
Acceptance Test:	Standard acceptance tests for quality assurance and quality control. Acceptance of various codes.
Sources:	Sources from which the technology can be procured, procurement time and availability.
Further Info:	List of available information sources, including the total number of known manufacturers.