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CAAD INSTRUCTION: THE NEW TEACHING OF AN ARCHITECT

The Library of Babel:
The Representation of Technological Knowledge in Electronic Libraries

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1. The Electronic Library

"...this vast library is useless: rigorously speaking, a single volume would be sufficient, a volume of ordinary format, printed in nine or ten-point type, containing an infinite number of infinitely thin leaves. "

With the development of storage media such as the CD ROM, the availability and usage of very large data bases of information has dramatically opened new vistas for the creation of electronic libraries. From dictionaries and encyclopedias to historical treatises, the electronic packaging of large and cumbersome information sources has begun to demonstrate its utility and efficiency. Today the bridge to an unknown territory of *electronic knowledge resources* lies here at the boundary between the passive (though electronically accelerated) access to information through electronic books and the user interactive access to knowledge. This paper is about that boundary.

At an elemental level, the *electronic library* may be considered as performing an *archival function.* With respect to building technology knowledge, the subject of our research, the archival function provides storage and access to graphical and textural materials such as information) on building details and specifications. Beyond this basic definition of the library function, we encounter a series of challenging computational issues. These issues can potentially expand the definition of both the contents and performance of an electronic library within the range of possibilities of information technology. *Indexing* and *search* are a set of issues related both to the content and memory organization of a library. If, for example, the information provided is simply manufacturer's catalogues, indexing and search is a matter of the use of an indexing convention, such as CI/SfB. If however, the content provides a degree of knowledge regarding details and detailing, in addition to a catalogue of details, then the question of search may become more complex. The organizational structure of a library and its operational characteristics can enable *browsing* in order to search for an appropriate detail. The representation of the detail itself may provide an on-line environment in which design knowledge can support the adaptation of the detail to fit new requirements, or the use of the detail in order to avoid detailing pitfalls. Conceptually, several of the existing libraries reviewed below are essentially electronic books. We have researched the possibilities in the electronic library to enhance performance through the knowledge potential of information technology. Issues such as the role of knowledge representation within libraries and the potential of design aid systems for providing knowledge in libraries are developed in this paper.

The subject area of our research is building technology knowledge. This is a field for which electronic documentation has particular relevance. Firstly, building technology represents a field which has expanded rapidly in the modern period with respect to both content and quantity of information. Secondly, access to the huge quantities of technical information available to the architect today and necessary to practice has become cumbersome. This is aggravating the architect's loss of understanding and ability to control the technical aspects of professional activity. As a result of these conditions, information technology has begun to provide solutions in the form of computerized catalogues and libraries (Ray-Jones, 1990). These developments have raised theoretical issues such as relevant operating characteristics and user interface of such systems, and appropriate formats for the representation of technological information. Beyond these questions of format and operation, the possibility of encoding design knowledge as part of the representation in order to support design in building technology is a promising possibility for the future of the field.

The paper reports on research into the *representation of building technology knowledge in an electronic library,* and the operating characteristics and user interface for such systems. Its frame of reference is the potential use of the computer as a *knowledge resource* rather than as an electronic book, as is the case in most. current applications of electronic libraries of technological information. Therefore the problem of representing "building making knowledge" rather than simply technological information is an emphasis of the research. Reference to the potential for 'intelligent libraries', as welt as the relevance of design support technologies within libraries, is developed. The educational implications of such knowledge resources are also considered.

2. Building Technology Knowledge: A Library of Manuals and Brochures

" Someone proposed a regressive method: To locate book A, consult first a book B which indicates A's position; to locate book B, consult first a book C, and so on to infinity..."

What is knowledge of building technology, and how is it conveyed? Conventional textual information sources on building 1.echnology constitute a diverse body of approaches to knowledge. In this section we analyze these approaches in order to establish a vocabulary of concepts. The following analysis relates primarily to building details as a form of building technology knowledge. In the review, a distinction is drawn between information sources and knowledge bases.

The most common form of information source is that of the *catalogue of building elements.* At an atomistic level of basic units, building elements occur in manufacturers catalogues, and constitute the contents of commercial compendia of manufacturer’s information. With respect to catalogue organization, these elements are indexed and searched according to a list of conventions for numbering such as CI/SfB (Ray-Jones, 1976). A similar approach to *indexing by element* can be found in non-commercial catalogues of details. Compendia of standard, or recommended, building details usually *annotate* the graphic representation of the detail with textual information. This provides basic knowledge supporting use of the detail. The annotation may he in the form of general recommendations and checklists (Stitt, 1990), or descriptions of potential pitfalls, or failures.

The graphic representation of elements may be in a detailed form, or in an abstracted, outline form. We employ Stitt's term, *generic detail,* to denote the specific detail in an outline form. A generic detail is an abstract description of a class of detail which captures in its representation the essential qualities of the class. Annotations for generic details may refer to the way in which the class of detail can be developed, or varied. We refer to such annotations to generic descriptions as, *refinement rules* (Oxman and Oxman, 1992).

Catalogues of building elements which are selected from practice are *exemplars.* These are common in the literature and have the advantage of being well-annotated as well as well-documented. Examples of a general catalogue approach to building detail exemplars are Devereau (1964) and Pegrum (1984). When the building details, building, or architect are well-known, the detail may constitute a *design precedent* (Oxman, 1992). Ford (1990) is a collection of details which may be considered historic precedents.

All of the forms of representation which we have considered until now have been elemental components, organized into universal catalogues. Another common form of information source is a building sub-systems catalogue, such as windows or stairs (Meyer-Bohe, 1973). These catalogues usually provide exemplars, as welt as some knowledge regarding the *design principles of* elements within the sub-system. Thus, the sub-system catalogue may be considered to contain a level of knowledge in addition to the information provided by the examples. Knowledge, in this case, are the general design principles and the *design pitfalls* connected with a holistic building sub-system.

In building, such elements occur as parts of compound systems, such as wall systems, in which conditions of interface with other materials and details are significant, in design. Therefore, a higher level of systematic knowledge may be found in treatises which cover whole building systems such as facades (Meyer-Bohe, 1975) or roofs. From the designer's point of view, knowledge at this *integrative level is* significant in design. A design aid system for building technology knowledge would have to address, the problem of integration of separate components and the representation of the *relevant links of* information. A high level of knowledge exists in building technology when the *underlying principles* of a component, or a system, are well-represented. There are several existing examples which treat either whole environmental systems, such as the performance of the building envelope, (Eldar, 1974), or an essential building condition. An example of a work which provides a high-level of knowledge regarding a universal aspect of building technology is the study of joints in building (Martin, 1977).

We have observed that the following kinds of representations contain various degrees of knowledge associated with the representation. *Examples, or exemplars,* and *precedents* are types of specific instances of designs. *Generic details* and *design principles* are two levels of general, or typological, knowledge. Each of these two classes of graphical representation, the specific or the generic, can he annotated by knowledge which supports its usage in design. This is achieved through *adaptation* of the specific representation to the current design situation or *refinement* of the generic representation according to certain design recommendations (Oxman and Oxman, 1992). These basic representations may be *elemental* or *compound,* and have associated *annotations* and types of *linkages.* For on-line usage of technological information, the accompanying knowledge must support the usage of the graphic representation of the detail. A design aid system may require a specific linking relationship of these representations in order to provide knowledge on how to use the details in the library.

Let us know consider how certain of these concepts are relevant to the current generation of electronic libraries of building technology.

3. The Electronic Archive and Beyond: Some Current Approaches to the Representation and Utilization of Knowledge in Electronic Libraries

"I know, of an *uncouth region whose librarians repudiate the vain and superstitious custom of finding a meaning in books ......"*

3.1 Electronic Libraries of Building Technology Knowledge

In recent years virtually every industrialized country has developed, or begun to develop, computer-based archives of building technology information sources. This work has included both governmental agencies and private commercial agents who sell the service. Thus the field, though relatively young, is developing at a rapid rate. Before considering directions of development in electronic archives of building details, I review certain general developments in the field.

Among international efforts to organize building information, the CIB has been a long-standing supporter of computer integration in the dissemination of building technology knowledge. ICONDA is an international database of articles and technical publications available on CD-ROM and through various host services such as Orbit Search, USA. The Construction Criteria Base (CCB) of the National Institute of Building Sciences (NIBS, USA) contains over 750,000 pages of technical information on CD-ROM. Contents include technical and design manuals, guide specifications, the AIA MASTERSPEC, referenced standards, manufacturers information, including graphical and textural information, CADD libraries and executable programs. Its size is currently approximately 2 g-bytes.

Standardization of libraries of technical literature and details has been most actively pursued in recent years under the guidance of CIB work groups W57 and W74 and national building agencies. This work has advanced in areas of the standardization of conventions. The Danish institute SBI has been working for many years on the standardization of formats of technical literature. Graphic standards and symbol conventions for computerized information bases have been developed by national members of the ISO such as Canada (Strelka and Vanier, 1986), and layering standards are currently under development in various countries. Examples of archival libraries of manufacturers technical literature are the Dutch BOUW-CD of the Nederlandse BouwDocumentatie (NBD) and the RIBA-CAD Product Drawings and detail Library of the British RIBA.

RIBA-CAD is currently a highly well-developed example of an archival system. The CD-ROM contain AutoCAD) DWG and DXF formatted drawing files, text files and slide libraries. This AutoCAD based system is supplemented by a very large library of technical and manufacturer's information called the Construction Information Service (CIS) on 15 CD's. There is a new complementary system for specifications called, Specification Manager. During this year work is being undertaken to provide functional linkages between the CAD-based system, the large CD-ROM library and the Specification Manager.

3.2 Beyond the Electronic Archive

In each of the systems described so far the purpose has been to store large archives of technical information in a form which makes the search and retrieval of information a more efficient task that with conventional media. Despite the fact that the field has developed rapidly because of the advances in storage technology, it now is at a cross-roads al which the *conceptual potential of the medium as a knowledge resource* will begin to have an impact on the future of electronic libraries. Advancement toward "intelligent libraries" have been developed recently in various pilot systems. The intelligent library may he considered one in which there is a high-level of knowledge behind the representation, there is intelligent support for search, the representation supports the use of the technical information in design, there is potential for browsing and cross-indexing when the information sought is not clear, and so forth. I will consider a small number of examples which begin to realize the potential for intelligent libraries. These pilot systems address issues of the potential for multi-media presentation of information, knowledge representation, user interface, intelligent search, browsing and cross-indexing, the representation of expert knowledge, and the provision of knowledge in the form of design aid systems within the library.

a. The Library as Integrated Information Resource Providing Design Aid

Vanier has developed a pilot system, "Architectural Details for a Cold Climate" (ADCC) (Vanier, 1990). This is a well-known application of hypermedia in the field of building details. To my knowledge, this is one of the first applications of hypermedia technology to building technology information. It provides a series of well-annotated exemplars for building envelope design in cold climates. The original text on which the system is based (Brand, 1987) was selected as representing technical information needs:

" 'high resolution' graphics, strong relationships between graphics and text, a comprehensive database structure, references to associated technical information, and modification or expansion on a continuing basis" (Vanier, 1990). The system is an electronic version of the book which, is itself, a well-structured information source.

Vanier has analyzed in some detail the relevance of hypertext systems for technical information transfer in computers. The pilot system explores certain of the intrinsic characteristic of the medium, and evaluates the appropriateness for technological information transfer to support design decision making. The utility of facilities such as layers, standard templates, transparent buttons, and automatic zoom, are analyzed.

Zoom and annotation fields are provided as is cross-reference to other detailed technical information sources to be contained within the system. There are several interesting provisions within the system which should be noted. There is on-line access to a CADD system for working with the detail. The revised, or adapted, detail can then be incorporated within the library. This provides an important provision within such libraries, that of personalization. Periodic *information maintenance* through up-dating by agencies and manufacturers must also be taken into consideration. This may necessitate separating the personalized library from the remainder of the library which can be up-dated. In addition, the library provides a building technology lexicon, which offers on-line assistance with terminology. As we shall see, the lexicon must also perform an *indexing function*, which becomes a most significant theoretical and operative aspect of efficient *search* and *browsing* in large libraries. The need for the lexicon function, or a thesaurus, is identified as an important component of a detail library.

There are certain aspects of the pilot system which raise interesting questions regarding the potential for intelligent libraries. Hypertext is widely recognized as a medium supporting *associative networks* of knowledge. Browsing through a structured or open net of information can be supported by the medium. How can the knowledge structure of the domain, and the needs of technological design decisions he served by hypertext, beyond the archival function? Can the *multi-media potential* of the medium be utilized to support design or in learning support systems ? The ADCC System employs explicit, rather than *generic representations* of details. Should some provision be made within such a system for explaining *principles* which can support the use of the detail ? The textual annotation of the system provides excellent information on *pitfalls of* design, the *sources of failures.* Can *rules of adaptation* be incorporated with a generic representation so that design support is accessible from the system ?

Vanier's work is pioneering. It has identified certain of the potential of the field for technology information transfer, as well as charting some of the potential for *integrated computer-aided design environments.* Certain of the questions raised are addressed in the following approaches.

b. Domain Knowledge in Integrated Design Support Environments

I have selected the work of McCall, et alia, as a representative example of work on integrative design support environments employing libraries of past designs in the Phidias System (McCall, Ostwald, Shipman, and Wallace, 1990). The system employs certain concepts of AI in seeking to "improve design by improving the designer's reasoning rather than automating it."

Design in the case of this system is considered as the deliberation of issues, or design questions, a process which the knowledge of the system can support. The work addresses design knowledge as domain-specific and attempts to formalize knowledge in the area of recognized problem-solving realms. In the case of this system the design knowledge generally relates to typological knowledge associated with building types, such as housing. The system also illustrates knowledge of planning in kitchen design. Knowledge of general design "rules" in kitchen planning, support particular design decisions made in the CAD work- area of the system.

The CAD work-area, in the *construction mode* of the system operation, provides for work with both elemental components as well as whole solutions in the form of prior design cases stored in the library. As design acts are made in the construction field, they trigger the appearance of information which assists in refining the problem specification (the designer can chose, or reject , certain elements of a kitchen design) and solution (the system provides rules on good practice in kitchen design related to the specific elements activated). This *issue base is* a collection of information about a *specific design domain*, such as detailing, or stair design. It is a hyper-document which is integrated with, and activated by, the icons of the CAD system. Thus providing for an integrative knowledge support environment.

It is expected that such *hyper-CAD linkages will* become common in the next generation of commercial CAD systems such as the proposed incorporation of the Xanadu hypertext system with AutoCAD. This technology will support the emergence of *domain-based linkages* with CAD systems to *libraries of cases* such as ADCC and *domain knowledge representations* such as Phidias. Phidias represents one example of the design support environment approach through integrating a CAD domain specific construction kit with domain knowledge representations.

c. Representing Design Knowledge of Past Experiences within the Library

The issue of knowledge representation within systems which can function as an aid in design is one of the central research questions in electronic library design. How can this knowledge be acquired, represented and made available for search, or design aid. Another approach to a design-aid system is one in which the library functions to make available to the designer the meaningful knowledge which is part of the library of designs in the system. How can he find the appropriate knowledge when he needs it to aid in design? What approaches and technologies are available to incorporate in electronic libraries in order to enhance design case representation, as well as search and browsing in large libraries?

Case-based Reasoning is an AI research field which is based upon a cognitive, memory-based model of experiential knowledge. I will briefly discuss recent, work in Case-Based Design (CBD) which addresses these issues (Domeshek and Kolodner, 1992) for the design of libraries of architectural precedents as design-aid systems (Oxman,1992).

Among the objectives of CBD is to assist human designers by making useful information and knowledge available to them when needed. The particular emphasis of work in CBR is to extract that knowledge from prior experiences, or cases. Various researchers are currently working on the development. of Design-Aid Systems based upon a library of past designs. The designer can search or browse through the library in order to find cases and knowledge relevant to the current design situation. Three types of contributions which can be made by design aid systems are described as suggesting solutions, describing pitfalls inherent in past designs, and proposing relevant evaluative criteria.

The system, ARCHIE 2 (Domeshek and Kolodner, 1992) is currently implemented as a pilot system in a hyper-text version. It contains examples and knowledge related to court-house design. There are three levels of representation in the system: a browsing level containing the graphic presentation of plans with mouseable annotations; a zoom-to detail level with graphic representations of areas of plans amplified by deeper explanations, called "stories"; higher level explanations of design principles behind the stories, called "guidelines".

There are several relevant aspects of this example for the performance and design of libraries of technological information. Cases in the library are design precedents in the sense that they have *lessons* to teach. These lessons are diverse and may relate to parts of the design. That is, the knowledge associated with a design is represented in units of explanation which annotate the meaningful aspects of a part of a design. These are called *stories,* of which there are various types which have been defined by the researchers. *Guidelines* are abstractions behind the design lessons of stories. Given that guidelines are high-level design knowledge, they can also function as a source of other related stories. Thus the designer is free to *browse according to design concepts* rather than according to specific design examples. So both knowledge representation and browsing technique are different from the examples which we have seen so far. Finally, CBD places emphasis upon the subject of *indexing* as a medium for the selection of relevant examples. Indexing may be treated as a basis for using high-level concepts as a key, rather than the classes of specific examples as in libraries. This might be associated with Vanier's lexicon, or McCall's, design issue vocabulary.

In the following sections, the implications of these works for the structuring of technological information into knowledge are summarized (section 4), and the possible operational characteristics of a library of building technology information are considered (section 5).

4. Design Knowledge in Building Technology

"I have wandered in search of a book, perhaps the catalogue of catalogues..."

Beyond the catalogue function of the electronic library, which provides information, knowledge in building technology is an amplification of information through the explication *of relevant insights* and *appropriate linkages* of information. The keying of insights and linkages to some model of design process constitutes, *design knowledge.* In fact, design knowledge in building technology is diverse. It may be considered to include certain of the basic design sub-tasks of architectural design including:

procedural knowledge: a process, or algorithm, for design may exist, e.g. the calculation and design of stairs as a normative procedure based upon floor to floor height, length of stair run, and normative practice regarding tread to riser relationships;

causal knowledge: a detailed procedure for calculation may exist, e.g., the calculation and design of partitions for thermal or acoustic properties;

behavior knowledge: understanding of the performance achieved by particular materials or by a particular configuration of elements in building. This constitutes much of building-making knowledge, and most of building detailing. Detailing is usually a goal-directed search for a certain behavior. This may include aesthetic characteristics. Search is generally within cases, such as manufacturers literature, or detail handbooks. Design of details usually requires the modification of an existing design or the generation of a new design based upon certain generic principles which the designer has learned.

It is possible to accommodate all of these types of knowledge within the library. In the present work we concentrate on this latter form of knowledge in building detailing. On the basis of the review of traditional knowledge sources (section 2), and current research work in design support and design aid in libraries (section 3), we can now attempt to identify the classes of building technology knowledge which *should be* incorporated within the design supportive electronic library of building details.

exemplars: the detail is the basic unit of information. It is normally, as in wall sections, represented in two states: elemental, in which the specific detail, such as a window opening, is presented with only its immediate interface conditions Or it may be compound, in which the detail is presented within the integrated systems context of other related details, such as the window detail within a wall section. We have seen that this basic unit of the exemplar may be presented at three levels of: the *detail,* a *close-up* of a part, or a presentation of the detail in the larger *building context,* each of which is a separate chunk of information of the example.

generic representations: this is an abstracted representation which captures the essential configurative qualities of detail. It is a simplified presentation of the detail which is intended to enhance its re-use.

precedents: these are high-level examples, such as the Miesian curtain wall or corner details, which are particularly important historically and well-known.

types: this is a generic representation of a precedent and may articulate a principle, or set of principles, within the class of details. This is a presentation of a class of detail al a high-level of abstraction which is intended to enhance design within the class.

These graphic presentations may be amplified and explained by four classes of information:

index: an hierarchical lexical code. This can be based upon a conventional *index* for building components, or based upon a vocabulary of domain concepts in detailing, or both. The lexicon is, first of all, an index of building components categories related to the field of building details and based upon a convention such as CI/SfB. It can have a *sub-index* (design domain task lexicon) based upon a lexicon of terms in the (design task, e.g. building details. The vocabulary of *design domain concepts* may enable selecting suitable examples of solving a problem such as water-tightness across lexical domains. This enables browsing, cross-indexing and problem-solving through analogy which is not easily possible with only a building components lexicon. Therefor, indexing affects the knowledge content of the library system.

stories: explanations of specific successes, pitfalls and failures in examples which are representative of a building technology. An example is explications of causes of problems, or success in a particular detail for an exterior panel joint.

issue base: issues are statements of basic knowledge in detailing, as well as general goal statements. Consistent with the work of McCall, issues provide a basic mapping of the design problem domain related to a particular design decision and also the basic good practice knowledge associated with the design decision, e.g. with what techniques water-tightness may be achieved in exterior panel joints, and what are the major objectives of design. **Guidelines** and **principles:** are the high-level lessons which a case teaches, and can be expressed as a guideline, or a principle of design. This is a higher level generalization than an issue statement. It teaches a particular kind of knowledge about, the principles behind making panels water-tight.

procedures: procedural statements of design process in a particular detailing domain. These may be recommendations for the *adaptation* of details to fit changed objectives or problem situations. They may also be statements of step-wise *refinement* of generic details (Oxman and Oxman, 1992).

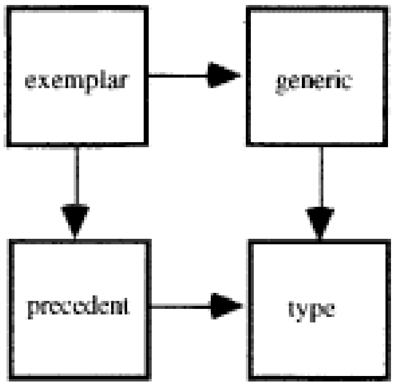


Figure 1. The Graphic Representation of Building Details and their Relationships

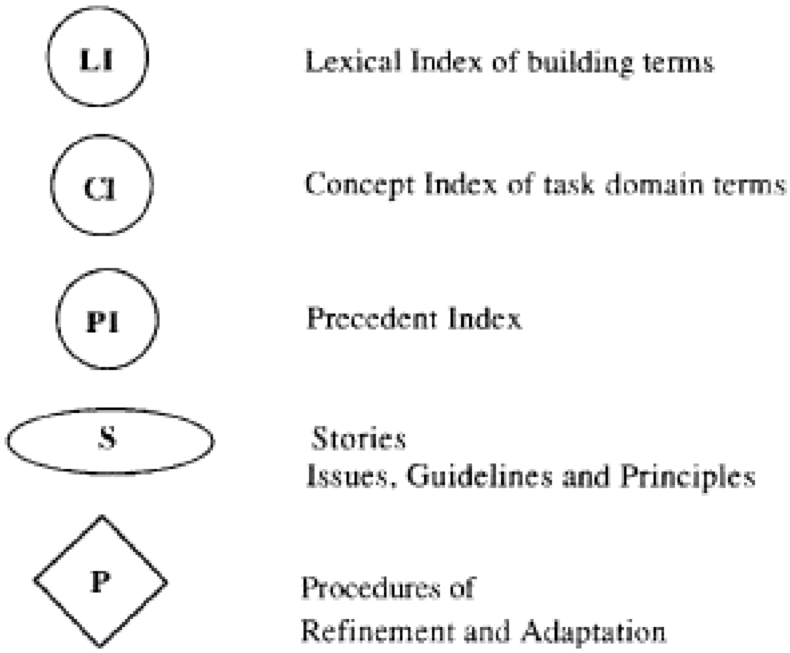


Figure 2. The Textual Annotations which Amplify the Graphic Representations

In a library, these four classes of information may be employed to annotate knowledge in the graphic representations. How they are put together, or linked, creates the knowledge structure of the system. *Linkage,* for example, in a hyper-media, or hyperCAD, system may be structured or flexible. Since both text and graphic may he System nodes, the structure of access and linkage is particularly important. It can be said to constitute the knowledge of the system. Important theoretical questions regarding network structure, operating characteristics and user interface in hyper-media systems have been reviewed in recent literature (Mitchell and McCullough, 1991; McAleese, 1989). They suggest various methods for the organization of knowledge as well as for techniques of linkage which will enhance exploring diverse chains of association. The design problem tasks are the basis for the structuring of knowledge. Conceptual organization of knowledge should be relative to these problem tasks. The representations and annotations are illustrated below. Their organization into design knowledge within an electronic library and relative to design tasks is discussed and illustrated in the following section.

5. Knowledge Structures in the Electronic Library

"When, it was proclaimed that the Library contained all books, the first impression was one of extravagant happiness. "

What is the *design supportive library* and what are the appropriate operating characteristics for an electronic library which can support, design? We can consider the ways in which search is supported in a library of building details, and the ways in which knowledge is made accessible to the designer during the processes of search. Among the live search strategies suggested by McAleese (1989), three appear to be relevant to libraries of details.

Search is the generic term for goal-directed information or knowledge seeking. You know what you are looking for. **Browsing** is following a path through a net of information within the library until a goal is arrived at, or in order to gain an overview. In providing the possibilities of following a path through a system the linkage techniques are significant both in content and structure (Mitchell and McCullough, 1991). **Exploration** is a broad navigational sweep to find the extent of the relevant information within the system. It is a special capability which must be provided by the system.

In order to provide design knowledge we have made provision within the system for various kinds of search and browsing. As we will illustrate below, these can be combined in various ways.

a. Search 1: Lexical Search and Detail Adaptation Support

The library is searched through the lexical index for relevant details. These details appear with their stories. One is selected and zoomed so that the relevant portion of the detail appears with design issues and guidelines. As the detail is modified, adaptation procedures are cued for design recommendations.

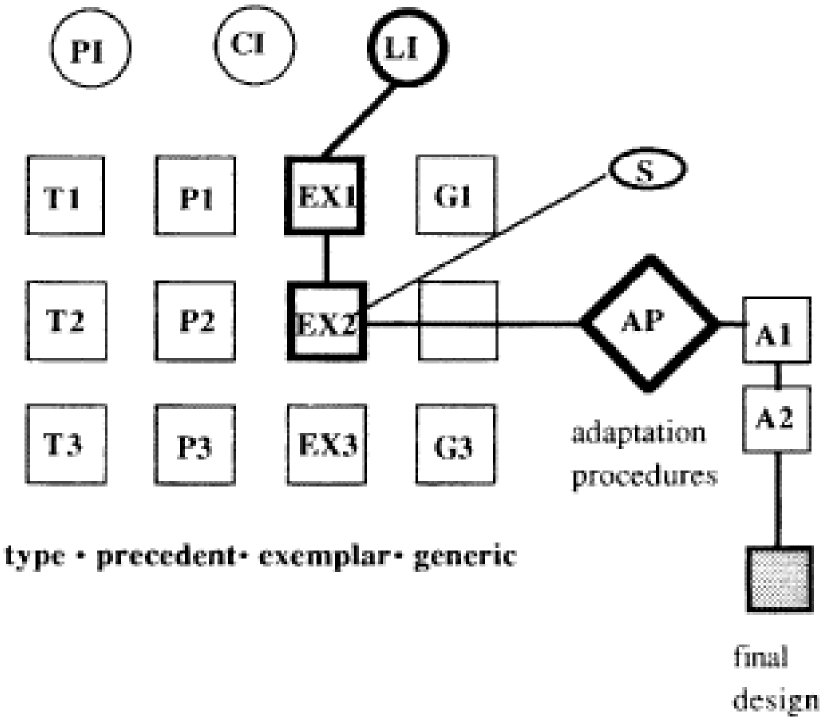


Figure 3. Lexical Search and Detail Adaptation Support

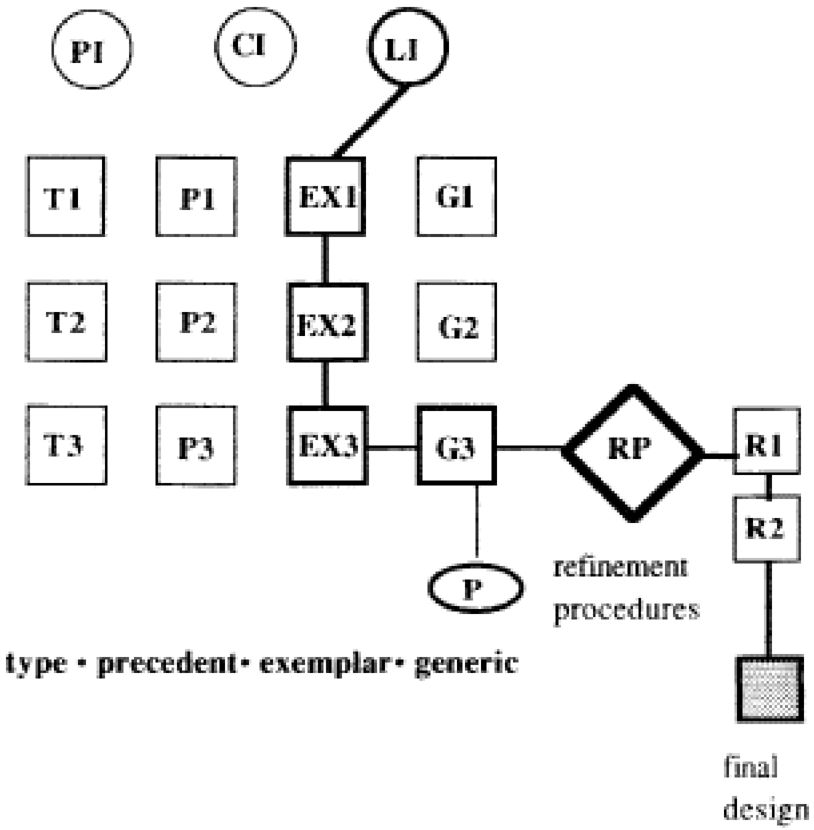


Figure 4. Generic Design of Exemplars of Details

b. Search 2: Generic Design of Exemplars of Details

Lexical search selects a set of relevant building details. One is elected and the generic representation of the detail is called up. The generic representation is annotated by an issues base, and an explanation of design principles. In working within the generic representation of the detail, design is supported by design aid in the form of step-wise design procedures.

c. Search 3: Design Precedents Search and Precedent-Based

Historic precedents of building details may be cued in the library. These are linked to related examples and may he indexed through them, or independently. The linkages between precedents and other examples are strong, There can the dual-directional links between examples and precedents, thus permitting review a group of precedent and examples together. Precedents can also be accessed directly through a precedent index and then browsed. The precedent detail can be used like an exemplar. It has an associated generic representation, the type. The precedent representation can be redesigned through adaptation. The type representation can be designed through refinement.

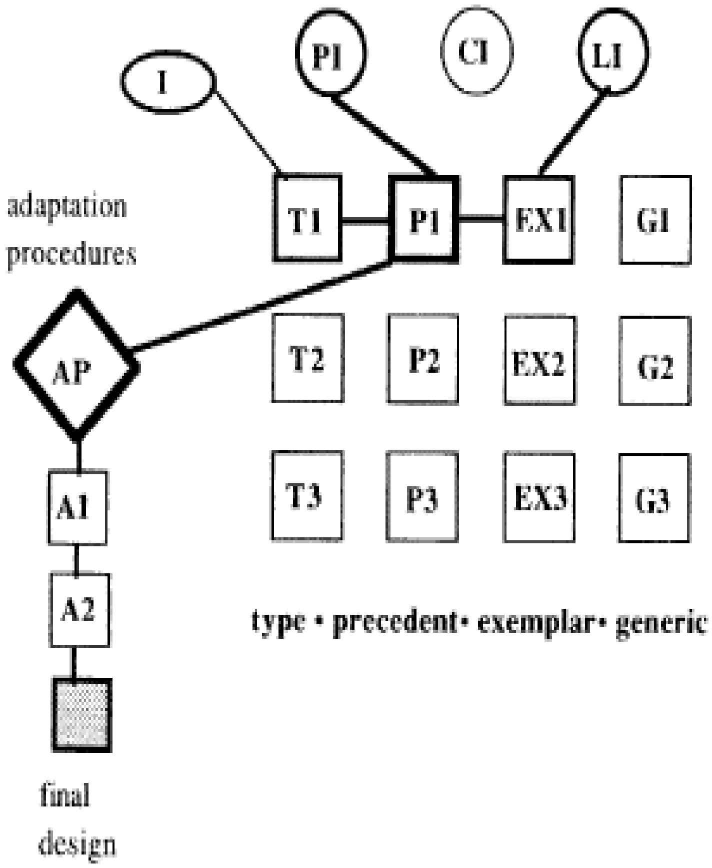
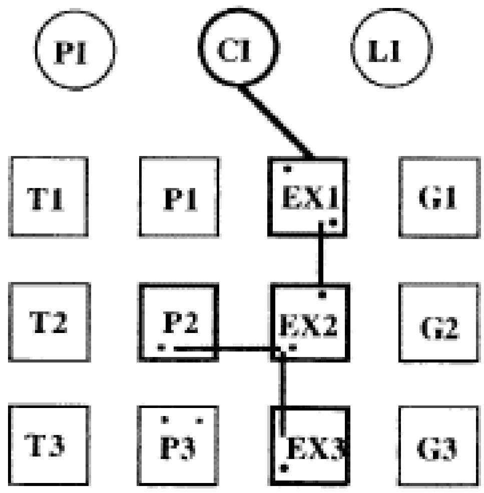


Figure 5 . Adaptation of a Design Precedent

d. Browsing 1: Browsing through an Associational Network

Browsing appears to be very highly textual, as compared to graphical, in nature (McAleese, 1991). The links are achieved through the index, lexicon, and conceptual vocabulary categories. We have seen that search uses the major lexical indexes. Browsing is possible through a *lexical domain sub-heading index* which supports cross-reference of different details. For example, under the archival heading of "railing details,wood", may occur sub-headings such as "tongue and groove joints", "butt joints", etc. which can be used as cross-references to other examples in different archival categories of wood details. Another basis for browsing and cross-contextual search is through a *domain concept vocabulary. A* domain vocabulary of design concepts and attributes can contribute a rich structure to the system. For example, such basic detailing concepts as "smoothness of surface", "embellished meeting of materials", "disguised meeting of materials" may be conceptual cues in an associated network of concepts through which approaches to various wood details may be browsed. This is cross-contextual search, that is, a quality sought in a wood railing detail may be also found in a wood paneling detail, etc. The browsing may cue precedents which are also conceptually cued.



type • precedent • exemplar • generic

Figure 6. Browsing through an Associational Network

e. Browsing 2: Browsing by Class of Graphic Representation

Browsing is also possible in a more directive manner by browsing within a class of graphic representations, and then branching out to other representations and returning. This process may cut through a selected part of a graphic library such as that for historic precedents or detail types.

Browsing by *types of details* searches through high-level classes, that is, at the level of design principles; for example the design principles of wood detailing. It is probably an unusual type of search for an experienced designer who would not look for the principles, but rather the relevant examples. However, from the point. of view of education, the library can function as a learning support environment when it provides this kind of knowledge which is very significant to the learning of design through a rational understanding of design principles.

6. JOINTS: Learning from a Library of Joint Details and Historical Precedents

"I know of the feverish library whose chance volumes are constantly in danger of changing into others and affirm, negate and confuse everything like a delirious divinity. "

JOINTS is a pilot Design Aid System which is intended to teach the principles of wood detailing by teaching about joints in wood. The major content and concepts are taken from Martin's excellent work, *Joints in Buildings* (Martin,1977).

The pilot system concentrates on wood joints, and particularly on the "lap joint". The lap joint is significant in modern architectural history. It was commonly used in the buildings and furniture of Rietveld (Baroni,1978). As an "open joint", it provides an analogical link to other aspects of configurative form in building design, such as the motifs, of the elements in the facade of Rietveld's Schroeder House of 1924. The detail also provides possibilities of linkages to other historical precedents, e.g. wood detailing in the early work of Frank Lloyd Wright, and the lap-joint principle in Mies van der Rohe's, Brick Country House project of 1923. Adaptation of the lap joint principle in a symmetrical form to create the famous Miesian corner is one of the interesting examples of transformation of concepts in building detailing. Thus the lap-joint has been employed as a case study in order to illustrate the rich vocabulary of concepts, and principles as well as the complexity of design thinking which exists in the field of architectural detailing.

The system provides an approach to wood joint detailing which emphasizes the instruction of detailing principles. The forms and types of lap joints are illustrated, as is the relationship to other joint principles. Browsing through historical precedents is the medium through which the student learns not only about detailing, but about other design subjects: adaptation of a concept in different materials; the evolution of design ideas; generic type and variety. This is taught through the browsing in a small library of historical precedents, all of which exhibit some connection with the lap-joint , or some design concept associated with the lap joint. Thus the student gains insight into one of the important subjects of the architectural curriculum, building construction and detailing, through the study of historical precedents in Modern Architecture. The computer provides, a medium for the integration of knowledge in history, design and construction. It also functions as a laboratory within which the student can construct, explore. and design. Thus providing a new medium for the teaching of building technology knowledge, one of the important and often neglected subjects of the architectural curriculum.

The system attempts to explore and illustrate the potential for a library of precedents to act as a design support system by creating knowledge and supporting browsing. Many of the techniques of linkage described in the previous section are exhibited in the pilot system. In addition, the potential contribution of animation techniques within a hypermedia system are explored as a medium for constructing a design-aid system, which in functioning to explain construction, or construction principles, also acts as a learning support system for building technology knowledge.

The current pilot system is implemented in Supercard. Animation sequences are employed to demonstrate the construction principles of the joints in furniture. The three-dimensional models and the animation sequences provide a unique dynamic representation which illustrates construction. In fact, the making of these models is in itself a significant learning medium in detailing. The electronic construction provides a simulation of actual construction.

7. Empathy: Supporting Reflection in Action in Building Technology Design

" The impious maintain that nonsense is normal in the library....

In contrast to current electronic libraries which are conceptually treated like a book, we have attempted to explore a certain range of possibilities for the electronic library to become a knowledge resource, rather than simply an information source. We have investigated various experimental approaches to design aid systems which are based upon libraries. Among the important contributions of these recent works has been the emphasis upon the representation and linkage of information into structures which can be considered structures of knowledge.

We have considered certain possibilities for the organization and structuring of knowledge in building technology and for the search and browsing of an electronic library. Knowledge depends upon the *empathy of the system* that is, its ability to support the human designer during the process of design.

Libraries of building technology knowledge offer great potential as parts of design support systems. The future significance of this technology depends upon our ability to transcend the limits of archival systems. Research should he focused about the integration of design support mechanisms within libraries. The frontier of the field lies somewhere beyond the electronic book. The integration of new technologies of design support systems and intelligent CAD with the storage capacity of large libraries appears to be a promising way across that boundary.

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