PRECEDENTS:
Memory Structure in Design Case Libraries

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The paper presents an approach to a memory structure of design ideas in a library of design precedents. A model of case memory for design is developed. The model is composed of distinct chunks of knowledge called design stories*. A formalism for the design story is proposed which represents the linkage between design issue, concept and form in stories. Stories are structured in memory according to a semantic network. The lexicon of the semantic network acts as a memory index. The memory structure and indexing system are demonstrated to enhance search and to support cross-contextual browsing and exploration in the precedent library. The approach is demonstrated in a pilot design aid system in the task domain of early conceptual design in architecture.*

Keywords: knowledge-based systems, case-based reasoning, case-based design aids systems, precedents, electronic libraries, memory organization, indexing, storage, retrieval, Hypermedia systems, content analysis.

1 Introduction: Memory Organization *of* vs. *for* Design

1.1 The Electronic Library

The primary objective of computer-based libraries of architectural information has been to store large archives in order to make the search and retrieval of cumbersome information a more efficient task than with conventional media. Examples of such large libraries are the Dutch BOUW-CD of the Nederlands Bouw-Documentatie (NBD), TELERATAS of the Finnish VTT, the RIBA-CAD Product Drawings, the Detail Library of the British RIBA, and the American CCB System of the National Institute of Building Sciences (Kennett, 1991).

In contrast, the intelligent library may be 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 information in design, there is potential for browsing and cross-indexing when the information sought is incomplete, and so forth. Advances toward "intelligent libraries" have been made recently in various pilot systems (Vanier, 1990). Libraries of designs used archivally as information resources have also begun to demonstrate their utility in computer library systems (Purcell and Applebaum, 1990).

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Moreover, knowledge can be provided to the designer through a library in a form which can contribute to design reasoning. In such libraries, the ability to encode, search and extract design knowledge relevant to the problem at hand is highly significant. In *design aid libraries* support of current design through provision of structured knowledge from past experience can provide ideas relevant to the current design task. Designs may be recalled from the *organized memory* of a library of designs in order to support the human designer with their unique ideas and their explicit design concepts. In this context, the term *design precedent* is employed to designate a recognized, specific design in which the unique conceptual points and ideas are denoted.

The exposition of knowledge by a system is dependent upon the structure of chunks of information. Knowledge may be considered here as the explication of *relevant insights* and *appropriate linkages* of information. In this work, we propose a memory organization *for* design as opposed to a memory organization *of* designs. For example, the relationship between issues in design, their affinity for certain design concepts, and their resolution in known designs. It is in the provision of such knowledge in library systems that we denote the distinction between conventional archival information systems and the knowledge resource functions of design libraries.

1.2 The Relevance of Case-Based Reasoning to Electronic Libraries of Designs

Proposing relevant design concepts from a memory of designs is a current research subject in "Case-Based Reasoning in Design" (Oxman, 1992). "Case-Based Reasoning" (Riesbeck and Schank, 1989; Kolodner, 1991) is a paradigm based on a cognitive model of memory. Current work in case-based design aid systems (Domeshek and Kolodner, 1992; Goel et al., 1991) is directed toward the development of CBR-based tools for assistance in the retrieval and presentation of useful information from organized memories of past experience. In such approaches the human designer and the CBR system collaborate in a partnership relationship. Compared to other systems which employ cases for giving advice; warning of a pitfall (Domeshek and Kolodner, 1992), or to suggest evaluative criteria (Goel et al., 1991) we consider that the role a case memory for design aid is to provide meaningful conceptual solutions for design. Therefore, an approach to case memory for design aid is that it should represent the knowledge of design cases which makes them worthwhile to remember.

1.3 Objectives

A central objective of our work has been the representation of design precedent knowledge. We have extended the concept of the "story" (Schank et al., 1990), as *Design Stories.* This concept provides a potential means to decompose precedent knowledge into separate independent chunks. Each story relates to a distinct design idea within a design precedent.

An additional objective has been the modelling of the memory structure of a design case library. This deals with the representation and indexing of the story chunks of the precedent. In a precedent-based library, the organization of precedents and chunks of knowledge in memory should support the associative and explorative nature of design.

A third objective has been to employ the structure of memory and the indexing system in order to support search and browsing in the library. In the course of exploration of design ideas within precedents, designers appear to be able to browse freely and associatively in order to make relevant connections between concepts in multiple precedents. Furthermore, browsing enables the discovery of new, often unanticipated, concepts in precedents.

In the following sections we address the theoretical and implementation issues of knowledge chunking, representational schema, indexing system and organization of memory in design precedent libraries. In the final section we demonstrate an approach to the implementation of a design precedent library in the domain of architectural design.

2 The Design Story: Knowledge Chunks in Design Precedents

In employing knowledge from prior designs in order to aid in current design problems, relevant design ideas may be accessed from past designs. Since a *design precedent* is a recognized past design (Clark and Pause, 1985), the term provides a convenient reference for this characteristic of the unique knowledge embedded in a known design. The process of the selection of these relevant ideas from prior designs in current design situations has been termed, *precedent-based design* (Oxman,1991; Oxman and Oxman,1992).

One of the distinctive problems in representing designs is the richness and complexity of descriptive content. Each design contains many related pieces of information which are often difficult to describe and decompose. In order to represent the distinctive content of the precedent, we have proposed a concept termed, *Design Story*, based upon the concept of the "story" currently employed in the CBR community (Schank et al., 1990). While up until now the story has been used as a complete case, the design story is here employed as a device to decompose existing descriptions of complex design precedents into independent chunks of knowledge. The design story is proposed as an individual descriptive chunk which is part of the conceptual uniqueness of a design precedent. For each design precedent, many design stories can be represented.

A design story is a descriptive text which embodies a design idea. The idea contains design knowledge in the implicit linkages in the text. A concept for acquiring knowledge from textual annotations has been developed by Schank. By analyzing descriptive and critical writings we can collect textual annotations of ideas which characterize the uniqueness of the design. Each describes its noteworthy conceptual points, design rationale, etc. In this research we have developed a formalism which makes this linkage explicit. These chunks of knowledge are the content of the precedent representation.

For example, consider the following story related to the Staatsgalerie in Stuttgart, Germany, a well-known building design:

> The problems posed by programme: site and city. The site sloped down to a motor way that cut the old cultural area of the city in two (urban continuity). The new gallery had to complement the demands for .... a democratic path-through the scheme. Stirling found ... the circular drum, a public space at the heart, that could also act as a pivot resolving the varied circulation patterns (Curtis, 1984).

The story illustrates references to significant concepts in the design of an urban museum. The story annotates one or more design issues, a particular solution concept, and a related form description. In the example the design issue is "urban continuity." The design concept which was employed to address the design issue is the principle of "path-through". In this case the concept, "path-through," describes the ability to pass through the building without entering it. The ramp within the drum, or central circular courtyard, is the form element which materializes the solution principle of "path-through."

The relationship of a design issue, the concept of a solution principle responding to the issue and the form element is proposed for the encoding of a chunk of knowledge in a design precedent. In the following section we elaborate on issue, concept and form as components of a knowledge schema for design precedents.

3 Issue-Concept-Form: A Tripartite Schema of Memory Organization for Design

Knowledge schema such as function-behavior-structure have been employed in architectural design (Rosenman et al., 1991). The suitability of the formalism to the architectural design domain may not be generally applicable. If we differentiate between design tasks in specific domains, the formalism of function-behavior-structure appears to be more suitable for the representation of performance of elements or dynamic behavior of components in structural or mechanical design than to certain design tasks in architecture. In architectural design tasks such as spatial organization in early conceptual design, another formalism may be required. In this task environment, it is the relationship between a design issue and a concept of configuration which designates a design idea.

In our approach, we have defined a knowledge chunk which consists of three parts: the issue, the design concept, and the form solution. In the task domain of early conceptual design in architecture, it is their particular linkage which constitutes a design idea as a meaningful chunk of knowledge. Each of the three components is described and discussed below.

3.1 Design Issues

Design issues are questions related to the design task which are deliberated by the designer. Such points may be formulated by the programmatic statement, the intrinsic problems of the domain, or by the designer himself. The characterization of design as the deliberation of issues was promulgated by Rittel (1972; McCall et al., 1990). It offers a convenient term to identify particular points in design problems. Each story generally contains one issue. For example, in the story presented earlier, the issue of "urban continuity" through the project site was a programmatic objective of the design, provision for which had to be achieved in the final design. As we shall illustrate below, in any precedent there are generally many issues.

3.2 Design Concepts

The *design concept* is the formulation of an idea in relation to an issue. It is a form of ideation related to the design task. For example, the development of ideas related to a particular issue such as the provision of urban continuity in a building design may take the form of a solution principle, such as "path through," i.e., providing a path through the building mass. The concept describes the principle of the physical separation of enclosed building space from public circulation, rather than the specific design. This relationship is a concept which can be realized in various ways in building design. Another example of a design concept in the same building design is "focal space," that is, the employment of a spatial focus, such as a central court. Collectively, the domain concept vocabulary can encode the key concepts of a particular design domain. The implications of this important idea are discussed below.

3.3 Form

The *form* is the specific design artifact which materializes the solution principle. For example, in the Stuttgart museum the design concept, "path-through," is realized by the public ramp passing through the drum, or open central courtyard. It is important to note that this is one element of the total building design which directly relates to the design issue. The three components of the design precedent are illustrated diagramatically in Figure 1. The large black circles are design issues. These are linked to the small squares which are design concepts. These are, in turn, linked to form representations in the precedent. Figure 2 illustrates the example discussed above.

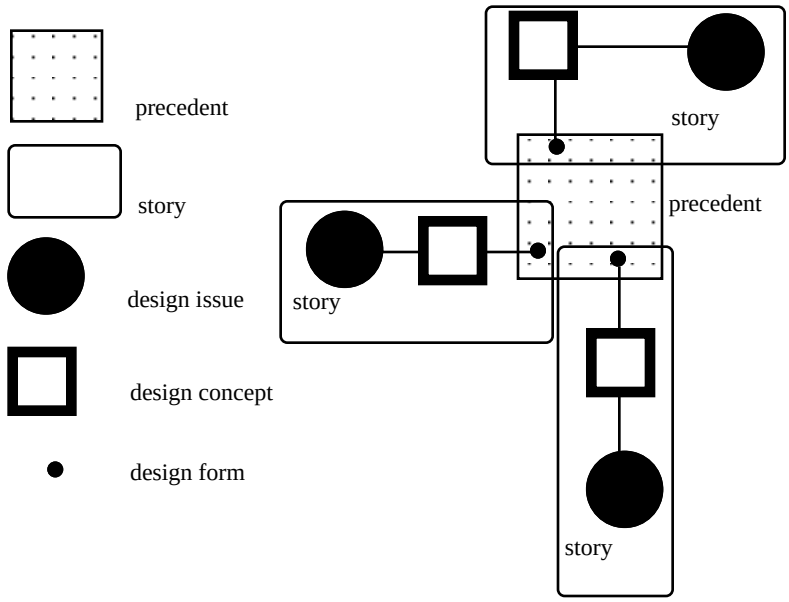

Figure 1. The three components of story chunks in precedents.

3.4 Cross-Contextual Stories

Design issues in stories may be cross-contextual. For example, in the case of early design in architecture, the same issue may be relevant in the design of various building types. Similarly, with design concepts, body of concepts related to configurative design can be potentially applicable to several building types.

Design issues and concepts may be common to stories of other design precedents in which the same idea occurs. For example, the issue "urban continuity" occurs in two different precedents: in the Staatsgalerie by James Stirling, and in the well-known Visual Arts Center at Harvard by Le Corbusier. Furthermore, these similar design concepts are realized in the two buildings by different form elements. In the Stirling example, by a ramp within the central court, and by a central ramp in the building of Le-Corbusier.

Design concepts appear to be general within the domain task and independent of specific building types. This characteristic of the design concept contributes to cross-con-

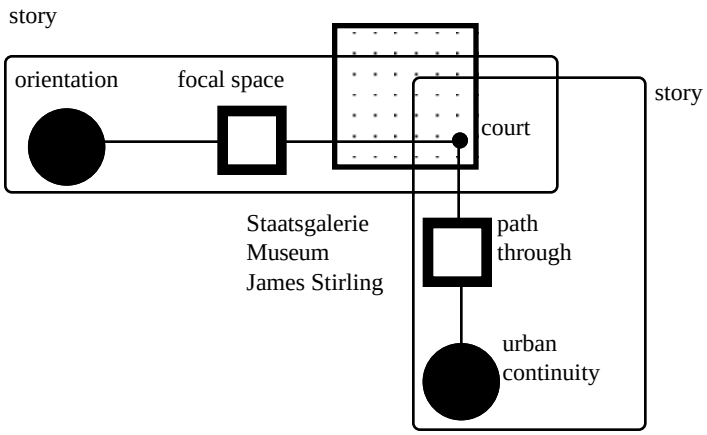

Figure 2. The three components in two stories of an architectural precedent.

textual linkages in a structured memory. This is an important attribute of the cross-contextual potential of the proposed memory schema in library systems.

4 Knowledge Acquisition: From Design Stories to the Issue-Concept-Form Schema

4.1 Knowledge Acquisition in Design Stories

One approach to the acquisition and formalization of knowledge is to investigate how descriptions are employed to present precedent knowledge in traditional media. While the holistic design is presented by graphical illustrations, conceptual points are generally presented in textual descriptions in a notational and explanatory form. These annotated sections of text contain chunks of conceptual knowledge which characterize the uniqueness and relevance of a design. These textual annotations are not exhaustive records of a past design, but illustrate generalizations which underlie a conceptual point, or a significant idea, manifested in a particular design precedent.

A method for acquiring knowledge from textual annotations has been developed by Schank in the area of social advice (Schank et al., 1990). In our work, we have employed the approach by analyzing key words in descriptive and critical writings relative to the design task. We investigated textual annotations of design precedents in current museum designs. Relative to the organizational task of conceptual design in urban art museums, each story was selected for its description of noteworthy conceptual points, design rationale, etc. Through these annotations the linkage between form, concept and issue is formalized in each of the design ideas which they describe.

A preliminary concept and issue vocabulary was developed which is currently being expanded.

4.2 Content-based Domain Vocabularies for Issue-Concept-Form

Design stories may provide issue and concept vocabularies as a basis for the formalization of design knowledge in a particular domain. Conceptual descriptions are domain-dependent and generally derived from the concept vocabulary of the design task.

Through analysis of the textual content of writings on museum designs, stories begin to form a lexical vocabulary of forms, concepts and issues related to the design problem task. For example, the vocabulary employed in the stories relates to the spatial-organizational task in museum design. These may be common to stories of other design precedents in which the same issues and concepts occur.

Collectively, design stories may provide issue and concept vocabularies as a basis for the formalization of conceptual knowledge of the design task. A future research objective is to define and collect the concept vocabulary of the spatial-organizational design task in architecture.

4.3 A Formalism for the Representation of Knowledge Chunks in Design Stories

A formalism which makes explicit the linkage between issue-concept-form in design stories was investigated. It can be employed in the knowledge acquisition process. A preliminary version of a formalism similar to the Universal Content Frame proposed by Schank et al. (1990) has been developed. It contains a frame, slots and fillers, with slots predefined and fillers to be filled. Fillers employ the domain vocabulary which underlies each story. The formalism encodes the particular linkage of components which are the essence of the message of the story. The message is a particular exemplary point contained within the story and worthy of storage in memory. Each design precedent may contain many such stories.

In the formalism illustrated below, slots are organized according to the three categories: issues, concepts, and form. In the problem domain in which we are working, a further distinction is required between design problem and problem context. For example, significant issues may derive from objectives of the context as well as from objectives of the problem itself. In our proposed formalism, Problem Type describes the building type, while Context Type describes the problem environment.

An additional slot provides for the designation of the class of design story. One significant type of story is a design conflict. In the design literature, there are frequent references to design conflicts, such as conflicts between problem type and the design environment. Design conflict stories are particularly memorable chunks of knowledge in design precedents, since they describe conflicts between objectives and constraints which require trade-offs, or innovations.

Concepts identified as goals in a solution type and identified as constraints in the problem environment frequently occur in architectural design. For example, the urban site of the Stuttgart museum has as a programmatic objective of context "through circulation". This is in conflict with the design problem objective of closed circulation or "no pass through" which indicates the requirement for control of entry and exit in the museum. The basic story formalism is shown below. The issue-problem and issue-context pair is the problem specification. The concept-problem and concept-context pair is the solution principle, while the form-problem and form-context pair are the details of the form solution. Finally, Story Type is an additional slot for classifying the type of story.

	problem type *building type*	***context type*** *site type*	***story type*** *story type*
issue	*issue*	*issue*	
concept *form*	*solution principle* *form element*	*solution principle* *form element*	

The applications of the formalism to represent the specific textual story mentioned above is illustrated below.

	problem type *museum*	***context type*** *urban site*	***story type*** *conflict type*
issue	*control*	*urban continuity*	
concept ***form***	*path through* *ramp*	*path through* *ramp*	

5 Memory Organization and Indexing

5.1 Memory Organization

Our approach to memory structure for design cases is based upon a model in which the basic modules of knowledge are stories, rather than instances of cases. These primary memory elements are clustered into design precedents. Design stories also have a substructure which is the content-based domain vocabulary of issues and concepts.

Thus, the model of design memory presents a new approach to case memory organization. In distinction to current case-based approaches, memory is here organized by knowledge chunks rather than by cases. It is organized according to a structuring of stories. The archival category of the case is not employed in the internal organization of memory. Clusters of stories are grouped into design precedent cases. However, the functionality of the case memory derives from its being organized about stories, that is, about domain design ideas, rather than about cases. This particular organizational approach to case memory has important implications for the operative capacity of the memory.

We propose the following organization of memory. Issues and concepts are organized into a semantic net based upon the domain content vocabulary. This is the main structuring element of the memory. This net is a mapping of key issues and concepts within a design problem domain. From any node of issue, concept or form in the net, stories can be retrieved which can, in turn, call up precedents. Links in the memory network can connect, for example, from concept to concept in different stories and precedents. Figure 3 illustrates the memory network.

5.2 Indexing

Indexing is a complementary issue to memory content and organization. Indexing, or the labeling of cases, contributes to a particular functioning of retrieval of relevant knowledge from case memory. Indexing is, therefore, the functional key to the exploitation of memory structure. Many current approaches to case indexing lack sufficient expressive power to describe the significant relationships in design cases between the problem type, problem context and the complexity of real world design situations and solutions.

We have stated that decomposing designs into stories as separate chunks offers a method to deal with the complexity and richness of design description. In the memory, we have treated each story as an elemental case. Indexing becomes an issue of *story indexing* rather than case indexing. We have developed an explicit internal structure of story representation which provides for a mapping between the issues, concepts, and the form description. These assumptions provide a basis for indexing.

We index stories as the main memory elements and employ the fillers of the representation, the domain vocabulary of concepts and issues, as the lexicon of the indexing

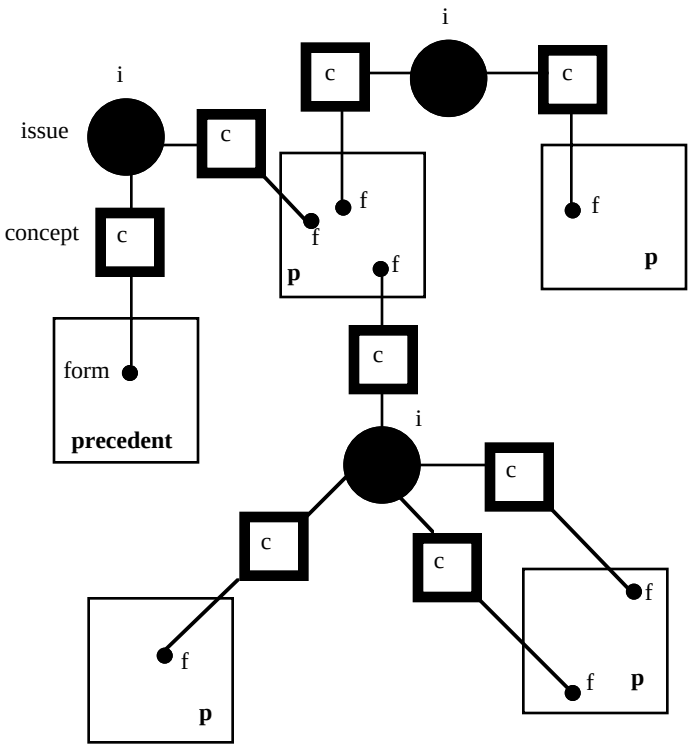

Figure 3. The structure of the memory network.

system. It is with this lexical system that linkages are established through matching. Two kinds of lexical vocabularies have been distinguished already in the story formalism above: situation descriptors (problem and context *issues*) and solution descriptors (problem and context *concepts* and *form*). We shall now demonstrate how these lexical categories function within the memory structure to support search and browsing.

5.3 Cross-Contextual Indexing in Search and Browsing

It is important to note the distinction in the use of the terms, search and browsing, as employed here. The following definitions have been proposed for search, browsing, and exploration (McAleese, 1989). In search, an explicit goal is known beforehand. In browsing, information is sought without the establishment of an *a priori* goal. Browsing is explorative within certain overall boundaries. Exploration is a form of search for new information where the information sought is unknown beforehand, but anticipated. Two kinds of indices have been identified: *search indices* and *browsing indices*. The search index is the filler in the story formalism. These indices can match all stories which have concepts and form relevant to stated issues. The indexing system for browsing is responsible for setting the linkages between design concepts after retrieval of a relevant concept presented in a story.

While search brings us directly to relevant stories, browsing activates the network in an associative fashion. In browsing, linkages between similar concepts are activated in

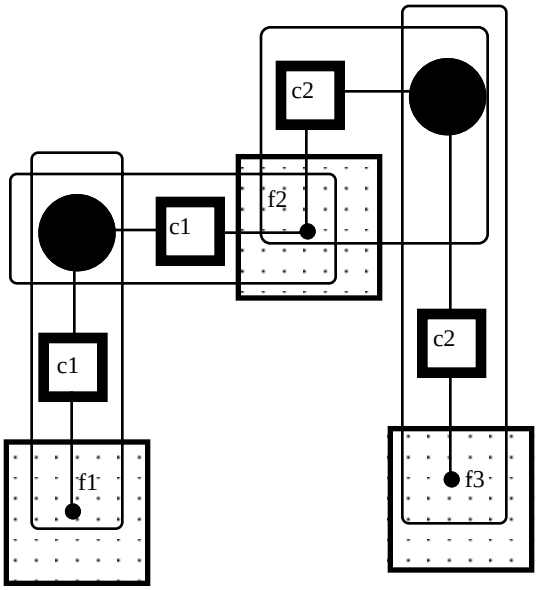

Figure 4. Cross-contextual browsing.

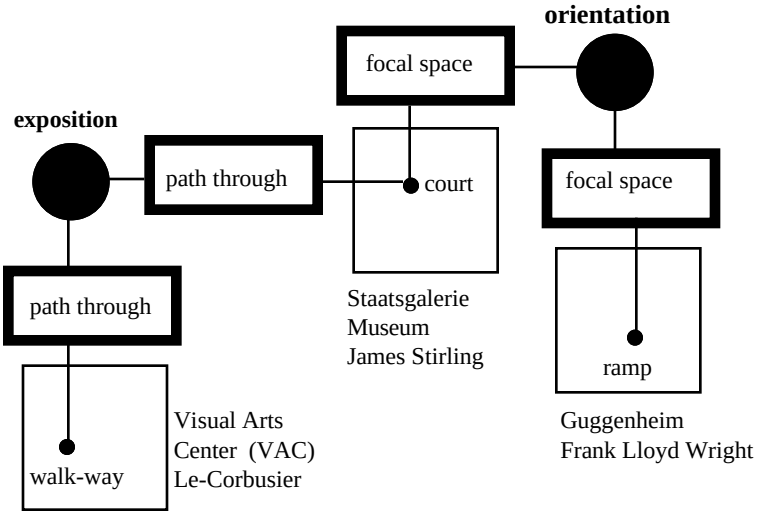

Figure 5. Cross-contextual linkages.

order to find alternative approaches to form which materialize the same design concept in diverse stories and precedents. The form elements of a solution are also a lexical index which may be employed to browse for new precedents employing the same form device.

Matching by concept, or form, indices retrieve stories and precedents which may make unanticipated linkages. This is illustrated in Figure 4.

Cross-contextual linkages operate through the form-concept-issue vocabularies. Since this indexing may cue a relevant concept in a different building type, the linkage is cross-contextual. Terms in the vocabularies may be common to many stories. This enables linkages and the operation of cross-contextual search and associative browsing. For example, in the illustration below, design concepts in the Staatsgalerie in Stuttgart, Germany provide for cross-contextual indexing to related concepts in other architectural precedents. The "exposition" concept links to a similar conceptual point in the Visual Arts Center by Le Corbusier, which is a teaching facility. Exposition in this precedent is provided by an elevated walkway through which the interior functioning of the building is "exhibited" in the walkway. Similarly, the concept of "orientation" indexes a story about the ramp and central court of another precedent, the famous Guggenheim Museum in New York, as is illustrated in Figure 5.

Figure 6 illustrates how the knowledge of the system can be expanded. In the example, the concept of "decorative emphasis" exemplified in the entrance of the Staatsgalerie cues a decorative entrance example in a different building type, a famous Viennese shop design. This adds another branch to the memory network as illustrated in Figure 5.

6 PRECEDENTS: A Prototype Precedent-based Library

6.1 Introduction

PRECEDENTS is a library of significant precedents which provide relevant ideas for current design. The library is intended to support initial stages of architectural design through structured knowledge from past experience. It is a pilot precedent-based design aid system which supports search and browsing through cross-contextual indexing by design issues and design concepts. The domain is the spatial-organizational task of early architectural design through which a design concept is established. This is a concept-rich task referred to in the design literature as concept formation in the *design partis*. It provides a particularly relevant case study for the potential of the story approach to design precedent libraries.

The sub-domain is the design of urban art museums. A content analysis was performed in selected works in the architectural literature in order to identify significant issues and concepts. The design precedent library contains museum design precedents, and certain related building types which help to illustrate the operation of cross-contextual search in a future larger precedent-base of designs. These were selected as representative of current significant designs, and for the range of issues and concepts which they represented.

The pilot system PRECEDENTS is currently developed in a prototype Hypermedia system for experimentation and demonstration. Hypermedia is widely recognized as a medium supporting associative networks of knowledge (Mitchell and McCullough, 1991). Browsing through a structured or open net of information can be supported by the medium. Architrion II was employed for modelling and visualization of the form description. The resulting graphics format was imported and edited in Hypercard.

6.2 System Organization and Operation

The system contains three kinds of cards. The issue card, the story card, and the precedent card. To initiate a session in the system, the user presents a description of the

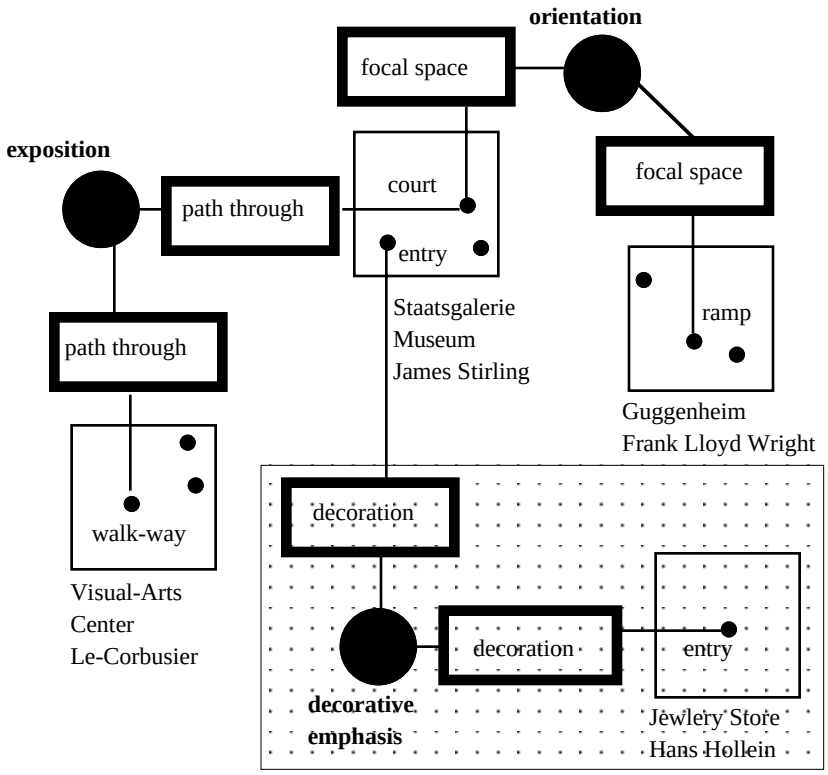

Figure 6. Network expansion.

design problem and situation by filling out an *issue card*. The card contains scrolling fields in which the user highlights the appropriate terms for indexing.

Generally, the user will fill in the issue category for problem and context, and search for concepts and forms. The system searches for relevant stories. These are presented to the user as *story cards* (Figure 7).

The user can select the interesting concepts among the stories which were presented to him for further browsing. If the user wishes to investigate how related concepts were realized in other building type, he may browse through the library by employing the "concept" linking button.

The story cards contain a textural description of the selected story and a graphical description of a specific related form element. Also included are link buttons to the *precedent card* (Figure 8) and other design story cards.

Precedent cards contain the holistic description of the precedent and a set of buttons. The buttons provide for the linkage between a precedent card and story cards. The user can investigate how a particular concept was realized in a specific precedent. He may explore other concepts in that particular precedent by employing the buttons of the precedent-card.

The user is free to browse within the network of issues, concepts and related forms. Browsing in PRECEDENTS was demonstrated in previous sections through an example of the Staatsgalerie in Stuttgart, Germany.

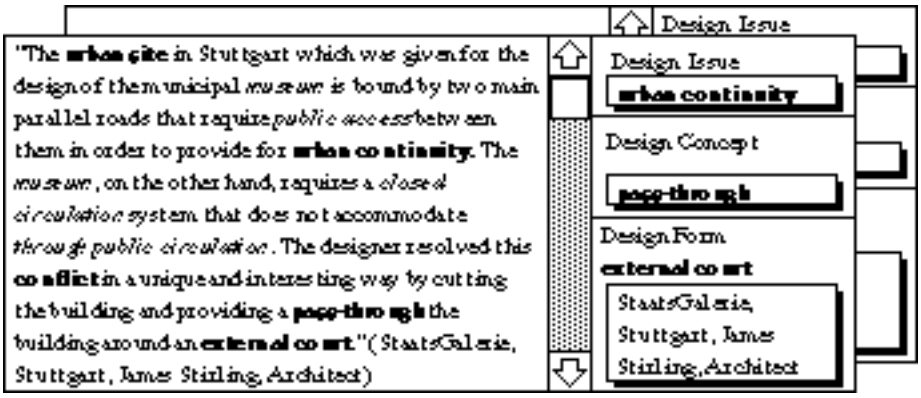

Figure 7. Story cards.

7 Summary Conclusions and Future Work

Design precedent libraries have been demonstrated as design aid systems to support the initial stages of architectural design through structured knowledge from past experience.

The design story was employed as a device to decompose existing descriptions of complex design precedents into independent chunks of knowledge. It was proposed as an individual descriptive chunk which is part of the conceptual uniqueness of a design precedent.

The design story was developed as an effective *formalism* for encoding relevant design ideas. It enables the representation of complex and rich knowledge by breaking designs into tractable chunks of information. *The tri-partite schema* of issue-concept-form appears to be an effective formalism for design knowledge in early conceptual design. It is suitable in early architectural design and may be relevant to other domains.

A *memory structured* around design stories rather than design cases has been proposed as a means to support browsing and explorative modes of search. Stories are structured in memory according to a semantic network. The lexicon of issue-concept-form in the semantic network acts as a memory index.

The development of *domain concept vocabularies* in design stories provided issue and concept vocabularies as a basis for the formalization of design knowledge in a particular domain. A promising approach to the acquisition of design vocabularies which was presented in our research is based upon knowledge acquisition through the content analysis of *written descriptions* of designs in the literature. Research in domain content analysis in various domains is required in order to develop the vocabularies.

The application of Hypermedia to the development of precedent-based libraries explored the potential of this technology in supporting browsing and exploration in libraries. In contrast to a system with highly structured networks of objects and linkages, we experimented with indexing in order to support associational search and browsing. The pilot

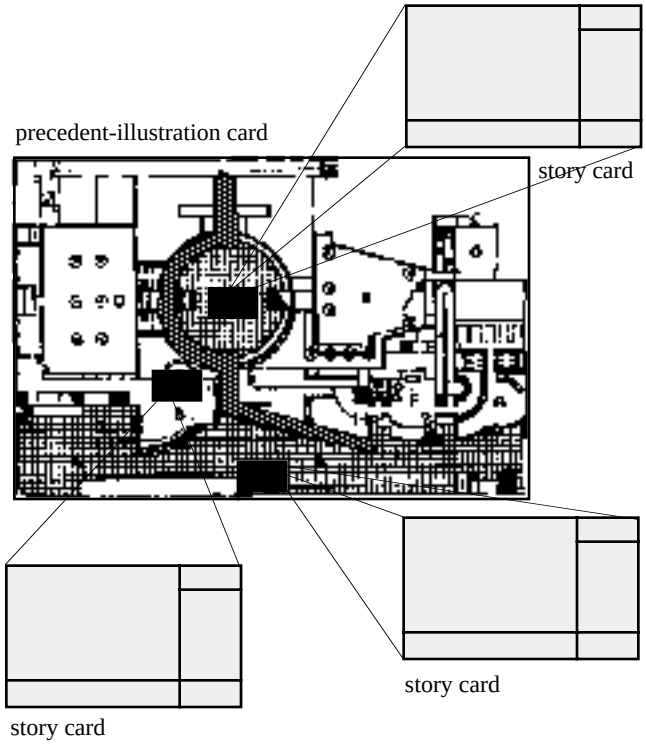

Figure 8. Precedent card.

system has provided a means to explore certain of the theoretical assumptions. A large scale system is required in order to validate these assumptions.

In encoding the relevant conceptual knowledge of prior designs and making the system responsive to the character of design thinking, our approach to design support through libraries of design ideas appears to be of promise as one possible paradigm of design aid.

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