Think-maps: teaching design thinking in design education

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A pedagogical framework for design learning and design teaching termed Think-Maps is introduced, presented and demonstrated. In this framework, domain knowledge becomes explicit as a significant component to be taught and transferred in design education. The Think-Maps framework proposes that by constructing a conceptual map that reflects one's thinking in a domain, we make explicit the knowledge learned. The learner constructs structured representations of concepts and their relationships to other concepts and fills these structures with the content of the specific design domain or design task. This resulting structured representation of knowledge can later be accessed and expanded in additional processes of design thinking. Web-Pad — a computational tool that implements these ideas is presented and illustrated. Web-Pad is used for organizing and representing conceptual maps of a specific domain. The Think-Maps framework and the Web-Pad tool are demonstrated in an educational environment.

Keywords: design cognition, computational models, design education, design teaching, design knowledge

In recent years there has been a growing interest in the study of the cognitive aspects of design as a basis for design education. Schon's early work[1] was seminal in that it emphasized the significance of design thinking and the role of cognitive studies and empirical research in studying design pedagogy. In research on design teaching, the role of cognitive studies was found to be significant, since they encourage an explicit approach to the development of design pedagogy[1,2].

Research in this area generally falls into two broad directions: empirical and experimental. In the former, empirical methods such as protocol analysis of particular design processes are frequently employed. This research is often associated with the explication of *thinking processes* in activities

1 **Schon, D A** *The Design Studio: an Exploration of its Traditions and Potential* RIBA Publications, London (1985)
2 **Eastman, C M** 'Special issue on Design Education' *Design Studies* Vol 20 No 2 (1999) 99–103
3 **Newstetter, W C, Eastman, C M and McCracken, W M** (eds) *Design Knowing and Learning: Cognition in Design Education*, Elsevier Science, (2001) pp 1–10

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0142-694X $ - see front matter *Design Studies* **25** (2004) 63–91
doi:10.1016/S0142-694X(03)00033-4

such as problem formulation, solution generation, and integration of design strategies on the part of the learner, or the teacher[4]. The work is characterized by the observation of intuitive and individual methods of teaching. The emphasis is on the critical observation of current teaching methods rather than on the postulation of new theory-driven teaching models as a basis for research. With respect to extrapolating research findings into new educational models, empirical research alone appears to be of limited utility.

It is in this context of the critical research study of new educational models that experimental research offers certain advantages as a supplement to empirical tools. Rather than emphasizing observation of existing teaching approaches, experimental research is frequently associated with the study of experimental teaching methods. That is, experimental methods tend to encourage experimentation with learning theories as a basis for cognitive modeling. In research in design education, experimental approaches involve theoretical foundations for modeling based upon cognitive theories of thinking, creativity and learning in design. The work generally exploits cognitive models and theories as a basis for constructing the computational models. While interesting in itself as a research approach to cognitive modeling, we believe that such experimental approaches may also have potential as an educational medium.

While empirical studies often emphasize the cognitive style of communication between the instructor and the student, our approach concentrates on modeling knowledge of the domain itself. Domain knowledge becomes explicit as the significant component to be taught and transferred in education. Through modeling, conceptual knowledge is acquired as well as cognitive processes in design. The student functions as a design researcher while learning *about design*, in addition to *how to design*. Ultimately, we believe that both are related.

In a recent workshop on design learning and knowing we have introduced our experimental framework. We presented an approach for the use of cognitive and computational models in design teaching as well as demonstrating their attributes in design learning[5,6]. In this paper we advance the theoretical basis of this educational approach and explicate the cognitive basis of conceptual structures as a form of design knowledge. We then present the Think-Maps model that we have developed and demonstrate its usage in an educational environment.

4 **Cross, N** 'Design cognition: results from protocol and other empirical studies of design activity' in **W C Newstetter, C Eastman and W M McCracken** (eds) *Design Knowing and Learning: Cognition in Design Education*, Elsevier Science, (2001) pp 79–124

5 **Oxman, R E** 'Educating the designerly thinker in W M McCracken C M Eastman and W Newsletter (eds) Cognition in design education' *Design Studies* Vol 20 No 2 (1999) 105–122

6 **Oxman, R E** 'The mind in design — a conceptual framework for cognition in design education' in **C Eastman, W M McCraken and W Newsletter** (eds) *Knowing and Learning to Design: Cognition in Design Education*, Elsevier, Oxford (2001)

1 Knowledge acquisition in design education

One of the inherent problems in design education is the difficulty to define requisite knowledge, that is, the residue of knowledge that should result from the design teaching process itself. Characteristically, design teaching is built about problem types and design theoretical issues. What kind of knowledge should be taught and acquired in order to achieve a conceptual understanding of design and of the nature of design processes in specific activities of designing? Is it possible to achieve a cognitive contribution to design education?

A naive approach to the knowledge issue might claim that the more knowledge the student gains the more design skill he will acquire. In fact, we often observe the contrary. Competence in design praxis appears not to be measured by the quantity of knowledge gained, but by knowing where to find it, which specific kind of knowledge to apply in a particular situation, and how to use it when needed. It is the development of thinking skills that is critical in design education. Lacking a theoretical basis for design knowledge, studies exploiting lectures and textual or visual material do not assure the acquisition of design thinking skills. The actual practice of design in the problem-related studio situation of most design schools rarely, if ever, *treats the cognitive processes of design thinking as a form of explicit teaching content*. How then can we formulate the aims of design education relative to knowledge content, and how can we then incorporate such explicit definitions within successful pedagogical approaches?

Quantity of knowledge and information is not the most useful construct. Educational research suggests that the organizational structure of knowledge is at least as important as the amount of knowledge in understanding any particular knowledge domain[7]. If knowledge is stored and encoded in a way that makes it readily accessible and usable it is more likely to be used. In his well-known paper, 'Designerly Ways of Knowing' Cross points out that design has its own things to know, ways of knowing them, and ways of finding out about them[8]. This suggests that there is more in knowing how to design than just knowing more about designs. Meta-knowledge in this sense is the knowledge of how to organize what one knows. According to this view learning that contributes meta-knowledge regarding the organization of knowledge may be a significant class of knowledge that helps us to organize and exploit the quantity of factual knowledge we absorb in education.

1.1 Teaching with non-explicit knowledge: problems in the design instruction paradigm

Does this line of logic help us to define certain of the pedagogical problems of the tutoring paradigm common in design education? Design has fre-

7 **Baron, J B and Steinberg, R J** (eds) *Teaching Thinking skills: Theories and Practice*, Freeman, New York (1987)
8 **Cross, N** 'Designerly ways of knowing' *Design Studies* Vol 3 No 4 (1982) 221–227

quently been characterized as commonly dealing with unstructured problems, while design domains though rich in domain knowledge are also characterized by unstructured knowledge[9–11]. In design education the studio setting is the main pedagogical framework for teaching. Here, the tutor provides instruction to the learner in an interactive situation in which knowledge is frequently implicit. The pioneering work from a cognitive point of view that investigated how knowledge is acquired in the design studio is the work of Schon[1,12]. The deficiencies of the studio as a medium for conveying knowledge in a manner that addresses the endemic unstructured quality of both domain problems and domain knowledge comes through clearly in much research on the studio. According to Akin the design instruction paradigm suffers from the following weaknesses: motivational difficulties, insufficient instructions of the design process and inefficiencies in learning[13]. Another intrinsic problem of the studio instruction paradigm is that it is carried out individually and strongly dependent on the personality, experience and cognitive style of both teacher and learner. In other words the method of teaching the student how to acquire, organize and apply design knowledge depends very much on the tutor's cognitive content and teaching style. The way in which design is currently taught according to Eastman[2] remains completely in the grasp of the tutorial relationship. The tutor's understanding of what has to be learned and what knowledge must be transferred is based on his personal experience and knowledge. The knowledge to be transferred may be implicit, and consequently, unarticulated in an explicit form. Each student acquires knowledge according to his own interpretation of the process through which he or she has passed. In the face of the dominance of this paradigm, there is a lack of an alternative conceptual basis for design teaching, or a supplemental/alternative method for conveying knowledge in design education.

This condition, being traditionally embedded in the design studio orientation of design education, is now being questioned with respect to its ability to prepare students cognitively to be able to do design. The obvious question that comes to mind is can we develop pedagogical approaches that directly address the teaching of design thinking. If so, what might be their objectives, pedagogical form, and knowledge content?

1.2 Teaching with explicit knowledge

Following these arguments regarding the problems of implicit knowledge in education, how can we address the problem of the *formulation and transfer of explicit knowledge in teaching*? How can we *relate such formulations to cognitive processes of design thinking*? In our past work we have developed an approach to the representation of design precedents through a

9 **Akin, O** *Psychology of Architectural Design* Pion, London (1986)
10 **Lawson, B** *How Designers Think* Butterworth Architecture, London (1990)
11 **Lawson, B** *Design in Mind* Butterworth Architecture, London (1994)
12 **Schon, D A and Wiggins, G** 'Kinds of seeing and their functions in designing' *Design Studies* Vol 13 (1992) 135–156
13 **Akin, O** 'Case-based instruction strategies in architecture' *Design Studies* Vol 23 (2002) 407–431

mapping of the important structure of concepts in the precedent[14]. Through representing this conceptual structure as a network, similar to representation in semantic nets[15], we have been able to model such cognitive phenomena as analogical reasoning as a form of conceptual net structuring. This form of modeling cognitive processes through the dynamics of network structures has proved to be not only a robust modeling medium, but also an excellent tool for experimental design research. The mapping of the design concepts embedded in precedents has proved to be a powerful descriptive medium when applied to cognitive modeling. Given that concept mapping is a form of explicit knowledge, and that the process is teachable, might it be the key to one approach to conveying design thinking to students?

According to Eastman, one of the aims of design education is to build a *conceptual understanding of the knowledge domain*[2,3]. In order to achieve this we must be able to explicate the knowledge of the domain in a form that can be conveyed in a pedagogically successful way. We have developed one such approach to this general problem.

1.3 Think-Maps: a cognitive and computational framework for design teaching

In a previous paper we argued that the cognitive content of design thinking should be considered a main pedagogical objective in design education. In order to implement one approach to this general objective, we have suggested an educational framework in which knowledge acquisition is based upon the organization and development of conceptual structures[5,6]. The current version of this methodological framework is termed 'Think-Maps'. It means, that in order to model design thinking processes, the conceptual mapping of design ideas can be constructed into larger structures. This framework provides the means, for both teacher and learner, to explicate their knowledge. Think-Maps is a teachable method that provides the means to organize the knowledge acquired by the learner and makes it explicit. Furthermore, we believe that the resulting mapping reflects the learner's domain knowledge in a specific area.

In order to exploit the modeling as a pedagogical framework we have developed a computational system, 'Web-Pad'. The objective of this paper is to describe the theoretical foundations of Think-Maps, discuss their implementation in the Web-Pad system, and to describe and assess our pedagogical experiments with this environment.

14 **Oxman, R E** 'Precedents in design: a computational model for the organization of precedent knowledge' *Design Studies* Vol 15 No 2 (1994) 141–157

15 **Sowa, J F** *Conceptual Structures: Information Processing in Mind and Machine* Addison Wesley, Reading, MA (1983)

1.3.1 Cognition as a learning theory: constructing Think-Maps

How is knowledge gained through this process and how does it contribute to learning? Think-Maps are anchored in two main learning theories. The first is Constructivism and the second is concept mapping. Constructivist theories of learning[16] propose that the learner is not conceived of as a passive recipient of knowledge, but is an active participant in the process of learning through construction. Instead of constructing designs we teach how to *construct knowledge* related to designs, or designing. *Knowledge construction* helps to explicate how knowledge is formulated. We have termed this learning paradigm as a *knowledge construction paradigm*[5,6].

Concept mapping is a well-recognized learning method[17]. Conceptual mapping in Think-Maps contributes to a constructivist-learning model by providing a tool for organizing and representing knowledge. The fundamental idea is that learning takes place by assimilating new concepts and propositions into conceptual frameworks held by the learner. Following the theory of the conceptual map, the Think-Maps approach proposes that by constructing a map that reflect one's thinking in a domain, we make the knowledge learned explicit.

1.3.2 A rationale for modeling Think-Maps in a computational environment

Among first generation computational models of domain knowledge in architectural design in educational contexts were models based on syntactic investigations. These types of studies became the subjects of design teaching including such material as the syntax of architectural composition[18] the syntax of hierarchical knowledge structures[19] and refinement and adaptation as cognitive strategies related to syntactical operations[20].

In principle, the constructivist approach with its 'learning by doing' emphasis is employed as a foundation of both syntactic models and constructive cognitive models. In both cases computation can provide an effective learning environment in which to exploit constructivist learning. However, as we have stated instead of teaching how to construct a model of a design object we teach how to organize domain knowledge and construct a model of knowledge structures. That is, the cognitive content and structuring of design knowledge are, in themselves, the subjects of the educational program. The attempt is to *convey knowledge directly*, to emphasize the *direct study of design reasoning*, and to introduce the *significance of concepts and conceptual knowledge* in design.

16 **Kolb, D A** *Experiential Learning: Experience as the Source of Learning and Development* Prentice-Hall, New Jersey (1984)

17 **Novak, J D** 'Clarify with concept maps' *The Science Teacher* Vol 58 No 7 (1991) 45–49

18 **Flemming, U** 'Syntactic structures in architecture' in **M McCullough, W J Mitchell and P Purcell** (eds) *The Electronic Design Studio*, MIT Press, Cambridge, MA (1990) pp 31–48

19 **Mitchell, W J** *The Logic of Architecture* MIT Press, Cambridge, MA (1990)

20 **Oxman, R E and Oxman, R M** 'Refinement and adaptation in design cognition' *Design Studies* Vol 13 No 2 (1992) 117–134

1.4 The objectives and the organization of the paper

The objective of this paper is to present the Think-Maps teaching framework. The Think-Maps framework depends on the learner's ability to construct conceptual structures and fill them with content of a specific domain. This content can be later accessed by the learner and can inform the design process. The theory of Think-Maps will be presented and the use of the WEB-PAD system for constructing them will be described.

A short theoretical introduction dealing with the nature of concepts and conceptual structures in design will be presented in the following section. The theoretical basis of Think-Maps — our pedagogical framework, will be presented in section 3. In section 4 the computational tool we have developed termed Web-Pad, will be presented and illustrated. Section 5 will explain how Web-Pad is employed within the Think-Maps framework in a learning experiment, and section 6 will conclude with summary and discussion.

2 Concepts and conceptual structures as design knowledge

2.1 Concepts

Concepts are part of our everyday life; they present our understanding of the world, and govern our thoughts and our communication with the world. The way we think, the way we experience, and what we do is much a matter of our conceptual understanding of the world around us. Concepts are, therefore, intellectual constructs and a form of ideational structure. According to diverse theories, they can be innate, formed from experience, or formed from other concepts.

In thought, concepts are used in many ways. For example, they can be used as metaphors or analogies in order to understand, or experience, one thing in terms of another. Lakoff and Johnson argue that thought processes are largely metaphorical, and therefore, the human conceptual system is basically metaphorically structured and, defined[21]. Analogies also play an important role in human thinking and are often used as a way to describe conceptual content[22]. Analogy is a conceptual construction that points out some systematic similarity between two kinds of sources. Analogical reasoning becomes useful when there is previous experience with various domains, but little actual experience, or general knowledge, of a particular domain under consideration. The structuring of concepts into relational structures such as analogies is a form of the expression of knowledge.

21 Lakoff, G and Johnson, M *Metaphors We Live By* University of Chicago Press, Chicago (1980)
22 Thagard, P *Mind: Introduction to Cognitive Science* MIT Press, Cambridge, MA (1996)

2.2 Modeling conceptual knowledge structures

The way conceptual knowledge is organized is as important as the amount of knowledge one has. This view emphasizes the notion of structure. Our conceptual structures, or the structure by which we organize our knowledge of the world, is not something of which we are naturally aware. Language is a case of the natural structural organization characteristic of human thinking. It is an important source of evidence in the investigation of conceptual structure. For example, we can explicate conceptual structuring in how people externalize their thought processes in communication with other people. One of the main resources for the acquisition of knowledge is through written language and textual description, forms in which knowledge is conceptualized and organized.

Among the fundamental questions of Cognitive Psychology are how concepts are represented and how they are acquired in learning. These two basic questions are related and are. Cognitive scientists are interested to understand and model processes by which knowledge is acquired and concepts are learned from experience or formed from other concepts. Modeling such phenomena depends upon knowledge representation. Issues in representing knowledge ultimately refer to knowledge structures[23]. Johnson-Laird provides such a view in his overview of concept definition and various representational schemas in cognitive and computational studies of knowledge representations[24]. In any representational formalism, the structuring of conceptual organization can contribute to the explanation and modeling of thinking and reasoning processes. Knowledge representations are described as various structures such as the *schema* that can represent concepts in various ways. Well-known examples in addition to schemas are the *frame*[25] the *script*[26] and *cases*[27] these are among major representational formalisms, all of which are formalisms based upon conceptual structuring.

2.3 Modeling conceptual knowledge in design

Conceptual knowledge, the ideational basis of design, constitutes one of the most significant forms of knowledge in design. Concepts are fundamental to design thinking, since they operate on an ideational level. They are the fundamental material of design thinking. Various researchers have explored the conceptual nature of knowledge and the different ways designers explicate conceptual knowledge[10,11,28,29].

Conceptual knowledge is often structured in the form of domain conventions such as typologies, rules, precedents, or other such domain representation conventions. These cognitive structures have been investigated in design thinking by both empirical and experimental researchers. Conventionalized knowledge structures such as *types* have furnished an important

23 **Galambos, J A, Abelson, R P and Black, J B** *Knowledge Structures* Laurence Erlbaum, Hillsdale, NY (1986)
24 **Johnson-Laird, P** *The Computer and the Mind: An Introduction to Cognitive Science* Harvard University Press, Cambridge, MA (1988)
25 **Minsky, M** 'A framework for representing knowlege' in **P H Winston** (ed.) *The Psychology of Computer Vision*, McGraw-Hill, New York (1975) pp 211–277
26 **Schank, R and Abelson, R P** *Scripts, Plans Goals and Understanding* Wiley, New York (1977)
27 **Kolodner, J L** *Case-Based Reasoning* Morgan Kaufmann, San Mateo, CA (1993)
28 **Alexander, C** *The Timeless Way of Building* Oxford University Press, New York (1964)
29 **Rowe, P G** *Design Thinking* MIT Press, Cambridge, MA (1987)

source of knowledge representation for cognitive studies of design. Certain of these representations have also been of utility in computational modeling. In experimental design research computational modeling has been exploited in studying such knowledge structures as rule schemata and typologies[19] and design precedents[14].

2.4 Conceptual knowledge of design precedents

The design precedent has a significant place in design research. According to Akin, referring to the domain of architecture, conceptual abstractions derived from the precedent are those which bridge between the conceptual and the physical and thus provide the basis for exploiting the conceptual knowledge of precedents[13]. Researchers in architectural education have pointed out the significance of precedents as one of the most common types of knowledge employed in design education[13,30,31]. In our approach, the *acquisition and the construction of the body of concepts* from precedents is considered as means to demonstrate and facilitate meaningful learning.

The conceptual content of precedents and its application in design education has also been an important subject of recent research studies. Akin describes an empirical study in which data has been collected from designers regarding their use of design precedents[13]. The results of this study have been employed in the development of a Case-Based tool called EDAT[13] to assist studio instruction. In EDAT, storage and retrieval were based on a relational database organization. Data include entries such as building type, building name, topics and sub-topics. Heylighen and Neuckernman[32] have developed a design assistant tool called DYNAMO. The tool employs a CBR model in an educational setting in order to offer a communication platform for sharing and exchanging information between students and professionals regarding design ideas and insights.

While many of these tools are concerned with providing information for those who use design precedents, our approach emphasizes the construction of precedent knowledge as a learning experience. Given a design precedent, the student learns to identify relevant concepts. The knowledge gained contributes to the construction of an extended body of theoretical and instrumental knowledge. The existence of an *explicit shared representational schema* that can be used to represent the conceptual content in design precedents helps to organize knowledge and to provide structure; it is, therefore, a fundamental component.

30 Delage, C and Marda, N 'Concept formation in a studio project' in **M Pearce and M Toy** (eds) *Educating Architects*, Academy Editions, New York (1995) pp 65–67
31 Marda, N 'Visual design thinking' *STOA, Architectural Review of EAAE* Vol 2 (1997) 42–53
32 Heylighen, A and Neuckernman, H 'DYNAMO: A dynamic architectural memory on-line' *Educational Technology & Society* Vol 3 No 2 (2000) 86–95

2.5 Summary

Computational modeling appears to be a promising direction for capturing both knowledge and knowledge structures through the use of *appropriate representations of concepts, conceptual structures, and conceptual knowledge*. In the next section, a representational framework for conceptual mapping in design is proposed as a medium for representing concepts and conceptual structures in design. We further develop this representation with a view to its exploitation in computational modeling. Finally, the modeling attempts to achieve explication of design knowledge structures and related cognitive strategies. Learning of design thinking derives from the constructive modeling procedures that were undertaken by a group of students.

3 Think-Maps: the construction of concept maps in design education

Think-Maps is a cognitive teaching framework that is based upon the student's ability to organize and formulate knowledge structures in design. Think-Maps employs computational modeling as a medium to represent, design and construct models of conceptual structures in design thinking. The Think-Maps framework depends on the learner's ability to construct structured representations of concepts and their relationships to other concepts and to fill these structures with the content of the specific design domain. This resulting structured representation of knowledge must be such that it can later be accessed and expanded in additional processes of design thinking. The construction and indexing of the mapping, and the extension of the mapping in further situations of design reasoning are contributions to the acquisition of knowledge by the learner.

The employment of computational modeling in design education as an effective teaching method can be considered only under an explicit pedagogical framework and guidelines. We have developed such a framework for cognitive modeling of Think-Maps. This includes developing *a representational formalism for concept mapping in design*, as well as integrating it in a computer program for the construction of Think-Maps. In the following sections we introduce the theoretical basis for the representational formalism including an introduction to concept maps, a review of the learning theory utilized in Think-Maps, and, finally, we discuss the representational formalism. In section 4, we introduce the computational system for constructing Think-Maps.

3.1 Concept mapping

A *concept map* is a representation of knowledge structures. Concept mapping can be used for organizing and representing knowledge. A concept mapping can be interpreted as representing important aspects of organization of concepts of one's mind[33]. As a symbolic language of representation, it includes concepts, and relationships between concepts indicated by a connecting line between two concepts. Sometimes these are called semantic units, or units of meaning. Links between different domains of knowledge may also help to illustrate how ideas or domains are related to one another.

A *concept map* is a representation of knowledge structures through a graph-like structure of nodes and links. The nodes represent the conceptual elements, while the links represent the relationship between two nodes. The links may, or may not, be labeled in order to describe the type of relationship. The form of the map becomes significant relative to the form of the knowledge being represented. For example, in class-type knowledge, the map is generally hierarchical with the more general concepts leading to less general concepts. However, concept maps may also be used to represent more complex patterns of relationships of ideas, and the morphology of the structure will differ accordingly. For example, in design we may use concept maps to define an analogical relation (relation of similarity) between two concepts, for example, the concepts, 'centrality' and 'focal space'. A *map* is achieved when a meaningful structure has been created; this may be as simple as the relationship of the two concepts above. However, the map may become an extensive and complex network as the knowledge represented becomes more complex. Detailed descriptions of conceptual structures may be found in Sowa[15] and Gardenfors[34].

An important distinction is frequently made between *in-domain linkages* in the map and *cross-domain linkages*. In-domain linkages are generally in the logic of the network structure. For example, in representing a building type, the map relates the salient concepts. An out of domain linkage occurs when a concept has dual properties, one in the domain, and one in another domain. For example, the concept, interior courtyard may have one meaning in patio houses and another in the design of shopping centers. The property of cross-domain linkages becomes very important, as we shall see, in representing design thinking.

As a *descriptive approach to learning* this idea derives from Ausubel's learning theory[17]. According to this theory, incoming information is organized and processed by interaction with long term, existing knowledge. Learning may be conceived as a process of extending our knowledge according to the existing propositional networks, or conceptual map, that exist in our minds. The fundamental idea is that learning takes place by assimilating new concepts and propositions into existing conceptual frameworks held by the learner.

Concept mapping is the process of construction of concept maps. Mapping

33 Ruiz-Primo, A M and Shavelson, R J 'Problems and issues in the use of concept maps in science assessment' *Journal of Research in Science Teaching* Vol 33 No 6 (1996) 569–600

34 Gardenfors, P *Conceptual Spaces — The Geometry of Thought* MIT Press, Cambridge MA (2000) has been used in various ways in educational processes and in learning evaluation[33]. In educational situations a concept map can act as a special form of diagram for exploring knowledge and for sharing and gathering information. It was originally proposed as a tool to develop an understanding of a particular body of knowledge by mapping in order to make the knowledge explicit. In this paradigm students learn by formulating as a concept map their understanding of knowledge gained. Later, by focusing upon in-domain links and cross-links, they learn about conceptual relationships and larger conceptual structures. Comparison of maps between students is also of educational value[33]. Concept mapping is regarded as a means that can contribute to high levels of cognitive performance in education.

Think-Maps is a form of conceptual mapping for design. We first discuss the advantages of using mapping as a pedagogical approach, advantages derived from Constructivist learning theories.

3.2 Constructivism as a theory of learning applied in Think-Maps

Constructivism is the dominant pedagogical approach in our educational framework. Learning according to the constructivist approach implies that new cognitive structures are acquired. Constructivist theories of learning[16] propose that the learner is not conceived of as a passive recipient of knowledge, but is an active participant in the process of learning. The philosophy behind constructivism is that the learner constructs his own knowledge based on his experience and relationship with concepts. Each learner has a unique representation of knowledge formed by constructing his or her own solution and interpretations to problems and ideas. This approach is usually interpreted as 'learning by doing'. In Think-Maps there is a unique interpretation to constructivism. Instead of constructing an experiment or an object the learner constructs the conceptual structures of domain knowledge.

Conceptual mapping creates a network of associated concepts. *knowing to construct and to read the network of associated concepts* adds to learning gained through traditional expository material. This promotes individualized learning and the support of diverse learning styles in which each student can navigate and explore multiple and individualized paths in the network of concepts. Furthermore the map of domain knowledge may be utilized to support design thinking during the conception of a design. In such situations, the student designer extends the network with his own concepts.

3.3 A formalism for constructing Think-Maps

Think-Maps exploits a representational formalism called ICF originally developed for the representation of conceptual knowledge of designs. ICF is an organizational schema of knowledge[14]. It was first developed as a computational model rooted in the theory and method of Case-Based Reasoning. It has been used to support the selection, representation and coding of relevant ideas from prior designs. It employs a 'story' formalism that represents chunks, or independent segments of conceptual knowledge, that is intrinsic to design descriptions. In the Think-Maps framework, ICF acts as a *structuring ontology for the construction of conceptual networks of design concepts*.

3.3.1 Brief review of the ICF model

The ICF model is based upon a decomposition of holistic precedent knowledge into separate chunks. A design chunk, termed a 'story', is an original annotation of an entity of conceptual content that characterizes a specific design. A typical ICF (Issue–Concept–Form) chunk provides explicit linkages between issues of the design problem, a particular solution concept, and a related form description of the design, or a part of it.

A design issue is domain-specific semantic information related to the goals and issues of the problem class. Issues can be formulated by the programmatic statement, intrinsic problems of the domain, or by the designer himself. A design concept is a domain-specific formulation of a solution principle, rather than the explicit physical description. A design form is the specific design artifact that materializes the solution principle. For example — orientation is an architectural issue, centrality is an architectural concept to achieve orientation and a central hall may represent the actual physical realisation of this set of issues and concepts. A single issue may be addressed by different concepts, just as a single concept may address different issues.

Among the objectives of the ICF model is to identify and represent individual components of design knowledge in a design in order that larger bodies of knowledge can be created from individual cases through a process of network construction. By providing a network structure of issues and concepts, it can function as a lexical basis for storage, search and navigation of knowledge. A further attribute of the semantic network structure is the ability to identify linkages between design ideas that were not originally apparent, but can be established by navigating the connections between related design ideas. For example, Fig. 1 illustrates an ICF conceptual structure of linked issues, concepts and forms that represent ideas of the Mediatheque designed by Norman Foster. Each linked ICF presents a

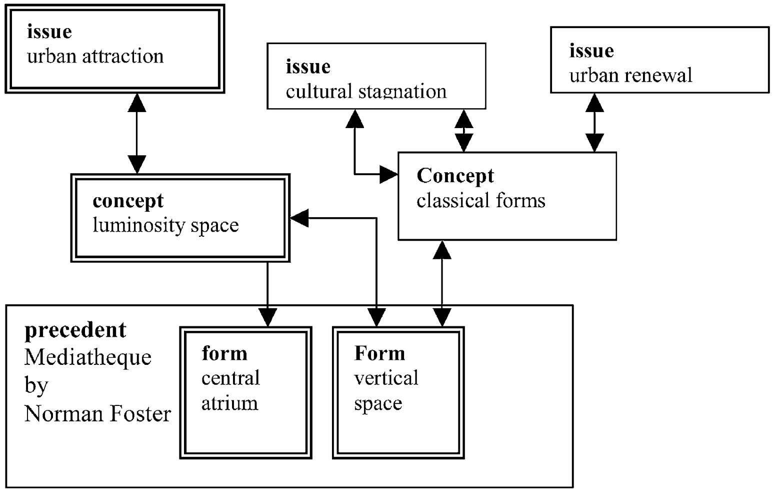

Figure 1 An ICF structure of the Mediatheque designed by Norman Foster.

unique design idea. For example, the following linked ICF (illustrated by a double line) can be read as follows: in order to create an urban attraction (an issue) a luminosity space (a concept) was achieved by introducing a vertical space of a six story vertical space (a form) as a central atrium (a form).

3.3.2 *Operative characteristics of the structure and attributes of the model*

The relationship between issues, concepts and forms in the ICF model are represented as a tri-partite schema. This schema has implications for memory organization, indexing, and search that provide operative characteristics that are inherent to the network.

The first of these attributes is cross-contextual indexing. The organization by knowledge chunks, rather than by holistic cases, enhances the capability of cross-contextual connections within the conceptual net. Links can connect different concepts from different designs.

A central point in using this ontology as a structural formalism is that it preserves a high level of representational flexibility while providing the essential structure to support search. By providing a network structure of terms for issues and concepts, the structure functions as a lexical basis for storage, search and navigation. Potential for browsing is significantly enhanced by the possibility for independent search of each of the three components of the ontology.

A further attribute of the semantic network structure of the ICF is the ability to identify linkages between design ideas that were not originally apparent, but can be established by navigating the connections between design ideas. Given that each node in the network is both textual and visual, *concept mapping of design concepts and related forms* begins to suggest unique possibilities for the understanding and structuring of conceptual knowledge.

4 *Web-Pad: a computational tool for constructing Think-Map*

Web-Pad is a system that was implemented for the construction of a *conceptual mapping* of key concepts of design precedents. The ICF underlies the representation of chunks of knowledge of designs and provides the representational formalism as well as the basis for automating the linkages and indexing in the Web-Pad system. In the following sections we describe the Web-Pad system and its operational modes.

4.1 *The Web-Pad system*

The methods employed in the implementation of Web-Pad are based on the AI methodology of Case-Based Reasoning (CBR) and Web technology[36,37]. Within Web-Pad the ICF formalism, provides a tripartite organizational structure. This structure supports a non-hierarchical construction of concept maps. This structured representation of textual concepts and visual forms is a specific form of representation developed especially for the *unique characteristics of design cases*. The creation of *conceptual indices*, a classic problem of CBR, is accomplished directly by the system. The indices provide a powerful basis for search within a shared global knowledge base. Web-Pad supports associative linkages and assists in self-navigation in the knowledge environment.

Textual and image sources of precedent descriptions are treated as a source for knowledge acquisition and conceptual mapping. In Web-Pad, conceptual design knowledge is treated as the confluence of visual representations and semantic content. A concept in Web-Pad can, therefore, be expressed as a text associated with a 3D model of a real object, animation sequence or vice versa.

Web technology provides for a collaborative construction of knowledge. It encourages knowledge dissemination and supports an extensible, dynamic and collaborative case base for design. It provides a medium for information exchange of both textual and visual material employing hyperlinked multi-media, and interactive representations and supports the *extension of the design case base* for both individuals and collaborators in distributed sites.

36 Oxman, R E and Shabo, A The web as a visual design medium International Conference on Information Visualization, Proceedings IEEE, London (1999)

37 Shabo, A *Web-Pad User's Guide CDM Lab DFG Research Report* Faculty of Architecture and T.P, Technion, Haifa, Israel (1999)

4.2 Design and implementation

The developmental components of the Web-Pad tool consist of the following modules integrated in the Web-Pad systems architecture: the interface for case representation formalism; the facility for construction and extension of the concept base; the indexing mechanism for the storage and retrieval of design concepts; and the implementation of different search mechanisms for retrieving relevant designs through conceptual linkages and semantic relationships.

4.2.1 Case representation and case indexing

In Web-Pad each precedent undergoes the decomposition of holistic knowledge into separate chunks. While the precedent may be represented graphically in a holistic fashion, textually, it is represented by individual concepts. A typical chunk, then, provides explicit linkages between issues, concepts, and a related form in any micro-description. While providing a facility for studying all of the chunks in any design precedent, the system is also capable of searching by clusters of related concepts.

ICF provides for modeling conceptual content and linked visual representations. This *dual functionality* with interactions between the two levels, textual and visual, is a unique characteristic of Web-Pad. Within this multi-level structure of the Web-Pad case-base, the upper level consists of a case-base of design precedents that are represented textually as a network of concepts. The lower level consists of a visual case-base in which each visual element can be represented by a graphic image. The visual content of each design case is indexed according to the concepts at the textual level. Issues can be illustrated by various concepts, which are theoretical solutions to the problem manifested in the issue. These, in turn, are linked to the visual images.

4.2.2 Navigation

The semantic network structure functions as a lexical basis for mapping construction, search, and navigation. The implementation enhances the capability of navigation through cross-contextual indexing by exploring the conceptual net of indices. Conceptual links in the semantic network can connect different chunks from different precedents. A further attribute of the semantic network structure is the ability to identify potential linkages between design ideas and concepts that were not originally apparent, but can be established by navigating the connections in an associative manner between design ideas. Thus the facility of navigating the system through its conceptual linkages provides a structured representation of conceptual design thinking.

4.2.3 Search mechanisms

In Web-Pad, associative learning is supported by provision of two types of search mechanism. The search mechanisms act as a knowledge organizer that enables identifying the occurrences of terms despite their syntactic differences. This supports free navigation through the content material and enables cross-referencing through the conceptual network. We have implemented a CBR search engine in Web-Pad for retrieving a precedent or a similar case. There are various search and retrieval mechanisms in Web-Pad.

4.2.3.1 Data-based search

The 'data-based search' provides the user with 'database' style retrieval through the use of the 'Data Retrieval' interface. In the data retrieval mode the retrieval merely brings up precedents that contain links to the items indicated by the user.

4.2.3.2 CBR search

A CBR search mechanism allows the user to enter a partial description of a desired case and to retrieve a complete description of similar precedents from the case-base. In the CBR retrieval mode, the user may get precedents that have certain degrees of similarity to the precedent sought. The degree of similarity is expressed as a decimal number between 0 and 1 where 0 means the lowest degree of similarity and 1 means the highest degree. As a result of CBR retrieval, all examined precedents that have a similarity score above a certain threshold, are presented in a descending order, so that the most similar precedent is at the top of the result list.

4.3 WEBPAD technology

The Web-Pad system is written in Java. The software architecture of the Internet site is based on three modules: Case-based design repositories on a data server, a server program, and a Java designer's utility running on the client side. The designer's utility is implemented either as a Java Applet or as a stand-alone client that communicates with the server. The Java Applet interacts with the user and accepts his requests. It passes user's requests to the server program. The server program queries the case-bases on the data server and returns results to the applet. The applet presents the results to the user.

5 Teaching Think-Maps: constructing the learning experiments

In the following section the Think-Maps teaching approach is presented, illustrated and demonstrated. Think-Maps has been used in a teaching and learning experiment that is based upon the student's exploration and formulation of knowledge structures in design, and his ability to construct a conceptual mapping in a specific domain.

In this research we have explicitly encouraged the creation of precedent knowledge as part of the learning experiment. This was designed to support the development of relationships and structures of knowledge on the part of individual learners. We are also interested in helping students to associate non-visual conceptual information with spatial information. Another pedagogical concern has been to study when and how students learn to chain, or link, different concepts in tackling knowledge construction problems. Such linkage suggests the acquisition of capability for planning at a meta-cognitive level.

In the Think-Maps learning approach, the acquisition of the body of concepts from precedents and their constructive mapping is considered as means to facilitate meaningful learning. In the material below, case studies of conceptual knowledge acquisition are illustrated from the domain of museum design. In the present learning experiment, the body of concepts has been acquired from specialist texts in this domain. The sources illustrated below are from one of such recent well-known texts in this field[35].

This experiment also demonstrates a novel application of conceptual mapping. The experiment was carried out among a team of design students in a collaborative setting. Each student acted independently as a single contributor to a collaborative and dynamic process of knowledge-base construction. Collaboration was accomplished from distributed locations. Here we emphasized the role of the social and collaborative construction of knowledge. This is a particularly significant problem, if knowledge is to be created by a design community located on remote sites. The fundamental pedagogical idea behind this is that learning takes place by the assimilation of new concepts into existing concept maps.

5.1 *Employing Web-Pad in Think-Map*

Learning tasks in Think-Map combine cognitive skill and knowledge. The learner develops the ability to analyze textual material and to extract from it significant inferences that can be useful. He has to choose associated issues, concepts and forms that are relevant and should be stored for exploitation in a future design. Furthermore, the construction process fosters the ability to develop conceptual content in designs. The employment of the Web-Pad tool in the Think-Maps experiments is significant, since it provides a representational schema to be shared by all participants and systems mechanisms for collaborative construction, search, and retrieval of knowl-

35 Lampugnani, V M and Sachs, A (eds) *Museums for a New Millennium: Concepts Projects Buildings*, Prestel, Munchen, New York, USA (2000) edge structures. In the following sections learning tasks of the Think-Maps approach are described and illustrated.

5.1.1 Knowledge acquisition through textual analysis

One of the main resources for the acquisition of knowledge is through written language and textual description. Think-Maps emphasizes the pedagogical role of knowing how to analyze and structure new information in order to be able to build a relational structure of relevant knowledge and to use the knowledge in other contexts. Organization of knowledge is important to the extent that it challenges and permits the student to analyze more effectively and to conceptually structure his own knowledge.

Students were instructed to analyze significant written references related to precedents. They were required to draw a set of inferences and organize them in such a way that the resulting knowledge base might be structured to represent a significant relationship of ideas in museum design. Figs. 2–4 illustrate the analysis task employing the ICF methodology. It illustrates the encoding of conceptual design knowledge presented in original textual descriptions and critical interpretations of the Mediatheque in Nimes, France designed by Sir Norman Foster. The main issues, concepts and forms are marked by colors.

Conceptually, Foster Associates, the architects, have been faced with a series of projects in historical contexts and in the extension of historic buildings. They have developed a unique theoretical approach for the

MAIN ISSUES
Carre d'Art museum , Nimes France
Norman Foster

When approaching the design of the Carre d'Art , we think the architect identified four main issues he believed were crucial to the planning of the building itself and to the overall development of the site as a part of the heart of the old city of Nimes.
Foster and the initiator of the project, mayor Jean Bousquet , were unanimous in the opinion that what was needed on the site was an **"anti museum"**, rather than the conventional gallery type museum .They both instinctively believed that creating an arts and media center where the citizens of Nimes could take an active part of ,would be a greater generator of attraction.
The mayor realized his town was suffering from **economic and cultural stagnation** and by doing some **urban renewal** in the heart of the city, he thought he could stop the young from running off to bigger cities, while also boosting the pride and the cultural life of his dormant little town.
After Foster was done with the WHY he went on to dealing with the HOW. He thought that the best way to approach the planning of the museum was first to look at it's surroundings . Thus , through **contextualism** he sought to plan not only a single building , but also the meaningful spaces around it , so as to create an urban whole rather than a separate , detached entity.

Figure 2 Content analysis of design issues using the ICF methodology.

MAIN CONCEPTS

Carre d'Art museum, Nimes France

Norman Foster

After looking at the bigger picture, there was a need to focus in on the CONCEPTS that would eventually evolve into the physical planning of the site.

Since Bousquet and Foster had already opted for an "anti museum" , Foster thought that to achieve that he would have to design **a flexible structure** that would be able to accommodate different activities and changing needs .This , coupled with the need to work in the urban context , brought about the visual concept of the **"anti monument"** .

While working in the context of the old city heart, Foster sought to reinforce the urban **classical order** of the city. He also wanted to pay **homage** to Nimes through the establishment of a dialogue between old and new. NEW in this context surely does not mean alien, but rather a new that is planned through an exploration of **classical forms**, while taking into consideration the **surrounding buildings and spaces**.

Dealing with the building itself, Foster wanted to create a building that would be an **attraction** both physically and as an urban institute , using the natural resources both around the building (using the reflection of the surrounding buildings) and within it (creating a **luminosity** through the vertical space of the building).

Figure 3 Content analysis of design concepts using the ICF methodology.

MAIN FORMS

Carre d'Art museum, Nimes France

Norman Foster

The Issues identified and the planning concepts evolved, now it was time to translate all this into PHYSICAL form.

As we discussed earlier, the museum was planned as an "anti museum" and an "anti monument" through a flexible structure. It was designed to hold a varied **mix of uses** under the title of an ARTS AND MEDIA CENTER.

Since the building was situated in an existing classical urban context, there was a need to incorporate in it's design those classical qualities and forms. A visitor would meet those forms right upon entering the building, passing under the **entrance canopy** resting on steel columns, a conscious gesture to the impressive facades of it's famous neighbor the maison Caree. By putting much of the **accommodations bellow ground** the building's height was kept in check with it's surrounding buildings, especially that of the MC.

Once. our visitor has entered the building, he will at once be in sight of the six story **atrium**. The latter creates a "vertical route" linking the spheres from the upper floor right down to the basement library levels, while using the **natural light** sifting down from the skylights to enhance that effect. The atrium effect is further enhanced by the classical **plan form**. Foster was also using **elements of transparency and reflection** both within the building around the atrium, and on the outside in order to attract people into the building as well as for reflecting the beautiful surrounding buildings. Moving from 2d to 3d Foster went on to design an integrated **massive and light building systems**. By that he was able to incorporate light elements of modern materials such as glass and steel with the heavier elements such as reinforced concrete columns. This in turn evolved into the **classical elevations** of the building.

In short , the sum total of the different elements and forms of the building make for a marvelously contextual building while at the same time it is an utterly modern building both technologically and functionally.

Figure 4 Content analysis of design forms using the ICF methodology.

coexistence of modernism and the historic context. Their use of ideas and conceptual knowledge in this case — the juxtaposition of contemporary and classical architecture and the various ways it have been achieved in their approach were made transparent by this textual analysis.

5.1.2 *Constructing conceptual maps*

The available critical writings were extensive. The analysis of the content of concepts, issues and forms elicited from the texts in the form of a network map that has been constructed for this building was the next stage.

The goal of this task is to develop a conceptual map from the knowledge that was extracted from the texts. This analysis/construction task makes it possible to capture the conceptual knowledge of a design and to decompose it into independent chunks of knowledge. This is accomplished through content analysis of design issues, concepts, forms, and cognitive abstractions such as metaphors and analogies.

5.1.3 *Implementing conceptual maps*

Each conceptual map that represents domain specific issues, concepts, and specific forms, some described as metaphors and analogies, that had been developed by each individual student was stored and implemented in Web-Pad. Figs. 6–8 present interface screens of Web-Pad that document an implementation process of the Mediatheque by Norman Foster, illustrated in Fig. 5. Fig. 6 presents an interface screen for linking concepts to the issue ‘contextualism’. Fig. 7 illustrates an interface screen for linking issues and forms to the concept ‘exploration of classical forms’. Fig. 8 illustrates

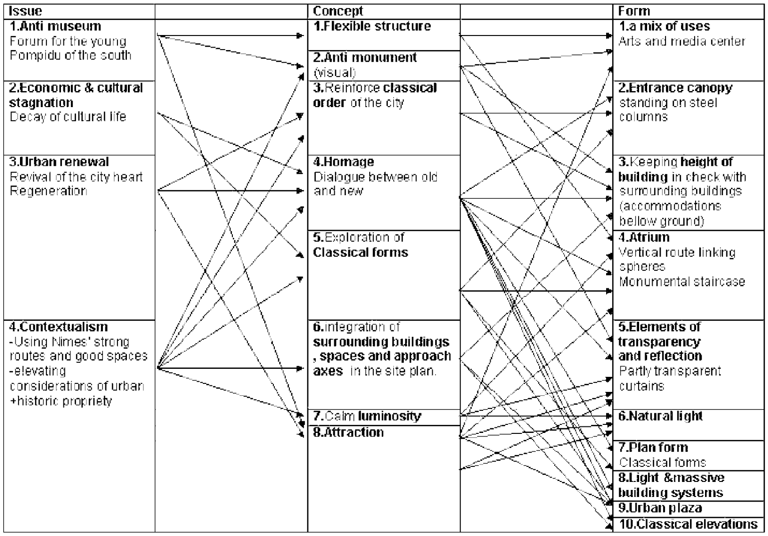

Figure 5 Constructing an ICF conceptual structure. Of the Mediatheque by Norman Foster extracted from the textual material.

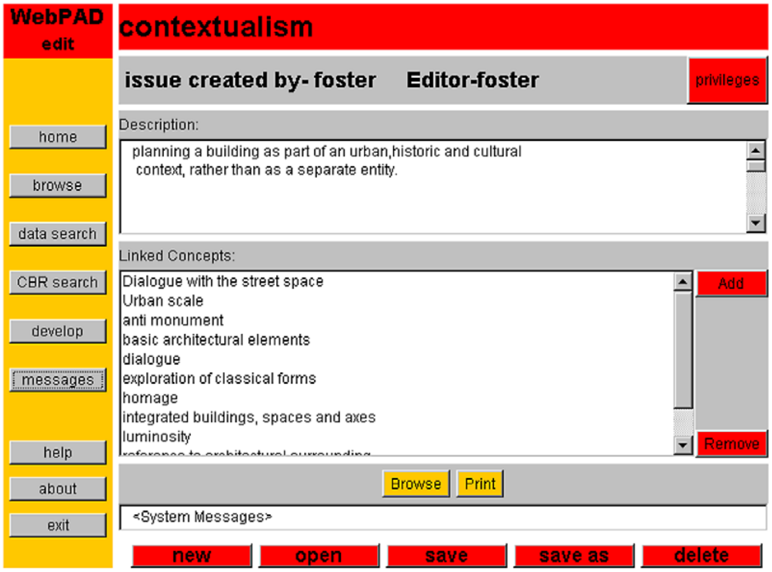

Figure 6 Web-Pad interface for linking concepts to the issue 'contextualism'.

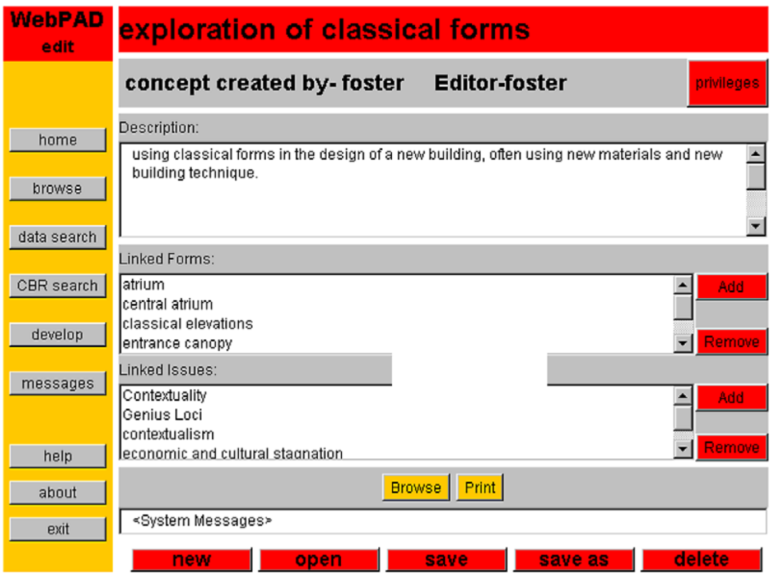

Figure 7 Web-Pad interface for linking forms and issues to the concept 'exploration of classical forms'.

an interface screen for linking concepts and images to the form 'central atrium'.

5.1.4 *Extension of conceptual maps through collaborative processes*

The ICF conceptual schema was designed to support the development of relationships and structures of knowledge *on the part of individual learners*

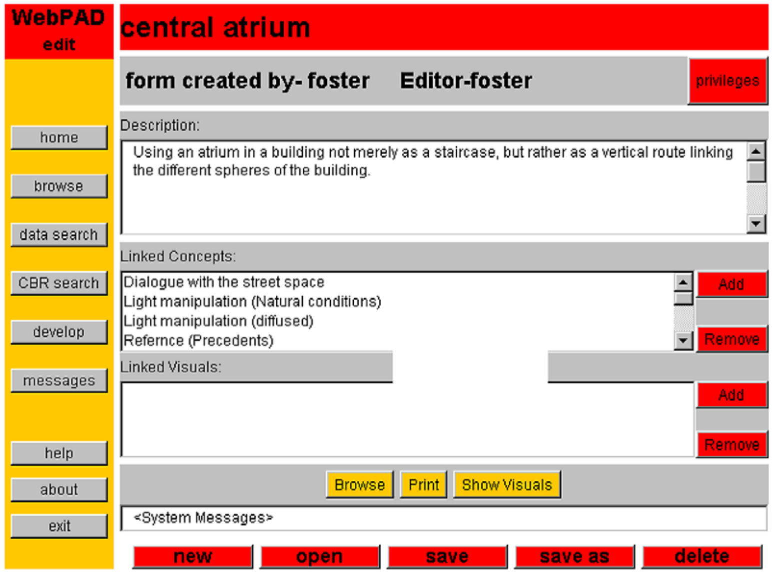

Figure 8 Web-Pad interface for linking concepts and images to the form 'central atrium'.

working as a part of a team. By assimilating new concepts into existing conceptual maps the learner shares and extends his knowledge with others. Students in distributed environments shared their ideas and comments in real-time discussions. The processes of knowledge implementation can be seen as the growing understanding of structures of knowledge with social interaction serving as a pedagogical as well as a strategic (more minds) advantage. Fig. 9 presents an implementation process of another ICF structure of a project designed by Ricardo Legorreta.

5.2 *Web-Pad operational modes*

Various implementation modes are offered by Web-Pad. The system provides the capabilities: Develop, Browse and Navigate, Data Search and CBR Search.

5.2.1 *Develop*

As well as a basis for indexing, retrieval, and search, the ICF formalism becomes a standard shared schema for the input of new cases. It supports a single user or a team of users in adding new precedents: issues, concepts and visuals of forms to the case-base. Develop mode, as illustrated in Figs. 6–8, is the basic input and construction mode that is employed for new construction, or for the updating and extending of existing ICF structures. The system automatically up-dates itself during each develop session.

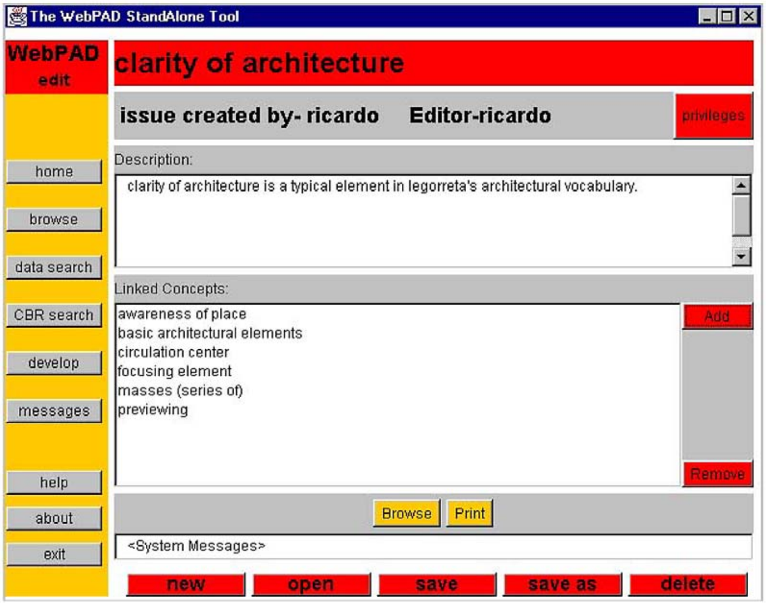

Figure 9 Web-Pad interface for linking concepts to an ICF structure of a museum designed by Ricardo Legorreta.

5.2.2 Browse

This mode supports hypertext style browsing of the case-base in navigating through precedents by issues, concepts, forms and there associated visuals. Browsing is a form of search that activates a link-by-link path in the network. It is activated through the browse button in the interface screen with interaction by mouse on textual or graphic content.

The browse menu illustrated in Fig. 10 presents a list of precedents and the precedent outline of issues/concepts/forms structures. By selecting an issue–concept–form in the outline a new screen appears with a description, links to issues and links to forms. The mouse click activates search for related issues–concepts–forms in the mapping.

5.2.3 Semantic Search

Semantic Search is an elaborated form of the *Browse* mode. It is a search by concepts that brings up all of the related precedents. The visualization is achieved by showing a precedent outline. Clicking on the button brings up a floating window with a detailed outline of the edited precedent with all links to concepts and issues. This outline serves as a navigation tool as well: Clicking on any entry in the outline brings up the selected item. An example of semantic search is illustrated in Fig. 11.

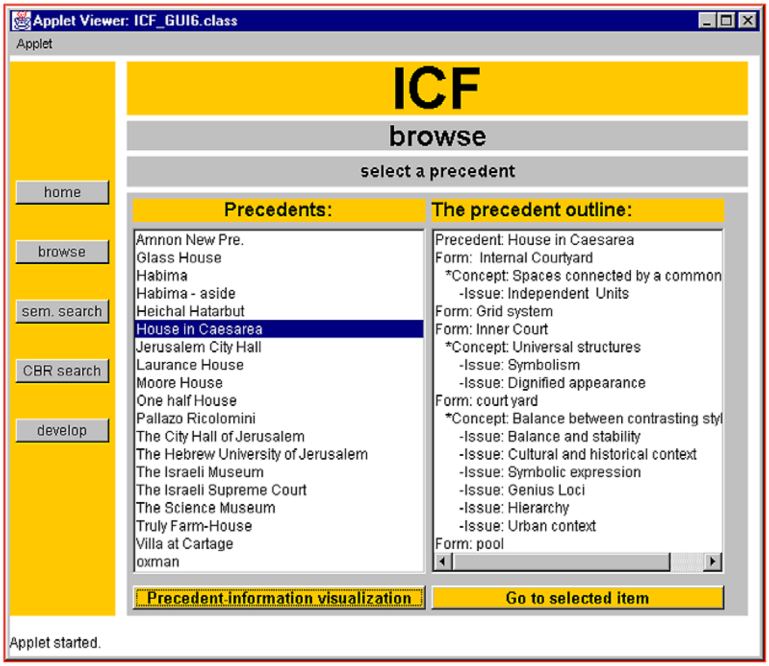

Figure 10 Browsing in Web-Pad.

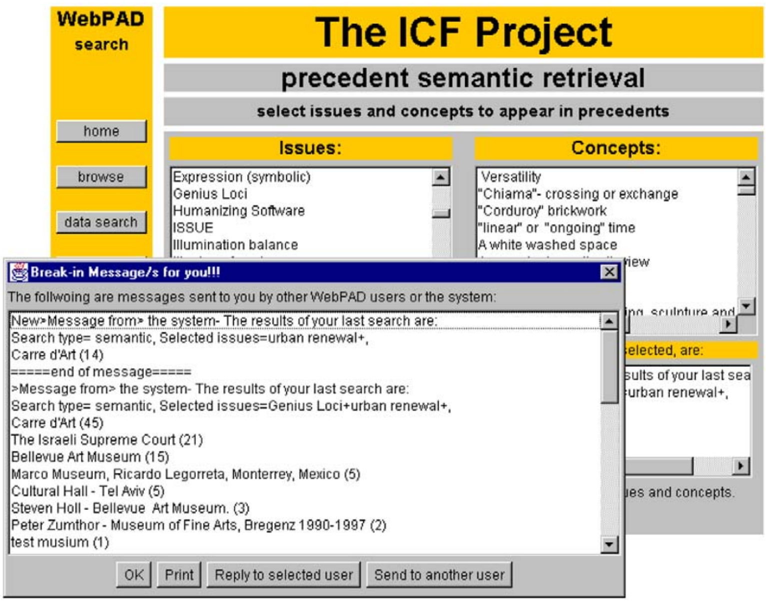

Figure 11 Semantic search in Web-Pad.

5.2.4 Search: cross-context precedent retrieval

Beyond its specific relevance in the case-base of museums, Ligoretta's museum also exemplifies a case study in regional architecture. Thus it provides a good example of how certain design resources can provide in-put to two different references of conceptual knowledge. In this case, they provide knowledge of a museum design and of regional architectural design. As these multiple case-bases come into development, they become richer as design resources, since by connecting them, search can become cross contextual. That is, certain concepts in the museum can call up precedents that are not museums, but still provide relevant ideas for design in a particular context. This cross-contextual reasoning is one of the hallmarks of creativity in design. The ability to support such search in a case-base is a high level of richness. We have developed two kinds of search: a semantic search and a similarity search.

5.3 Semantic search mechanism

The semantic search is a database driven search mode allows the user to search for precedents that have links to specific issues and concepts. It searches for precedents by using the ICF semantic network. It selects only precedents that consist of forms that have links to the selected issues and concepts. Fig. 11 illustrates the search. The search result is a sorted list of precedents with the number of occurrences of the selected concepts and issues indicated beside each precedent.

5.4 Similarity search mechanism

The similarity search allows the user to search for precedents similar to a selected precedent. This search is based on a CBR search and retrieval methodology. As opposed to the data search, returns precedents that might have no links to concepts and issues in the new precedent. Similarity to a new precedent requires the use of the 'develop' option to enter the new precedent to the case-base. The user selects a precedent and as a result an ordered list of precedents is presented. The similarity score is indicated beside each precedent. An example is illustrated in Fig. 12.

5.4.1 Collaboration modes

This is an approach in which social interaction among the participants enhances learning. Web-Pad explicitly encouraged the individual acquisition of knowledge as part of a collaborative learning process. With the elaboration and expansion of the knowledge base of design precedents, we have expanded the next exercise in collaborative construction sessions with our research partners.

Web-Pad provides an environment in which new knowledge can be in-put

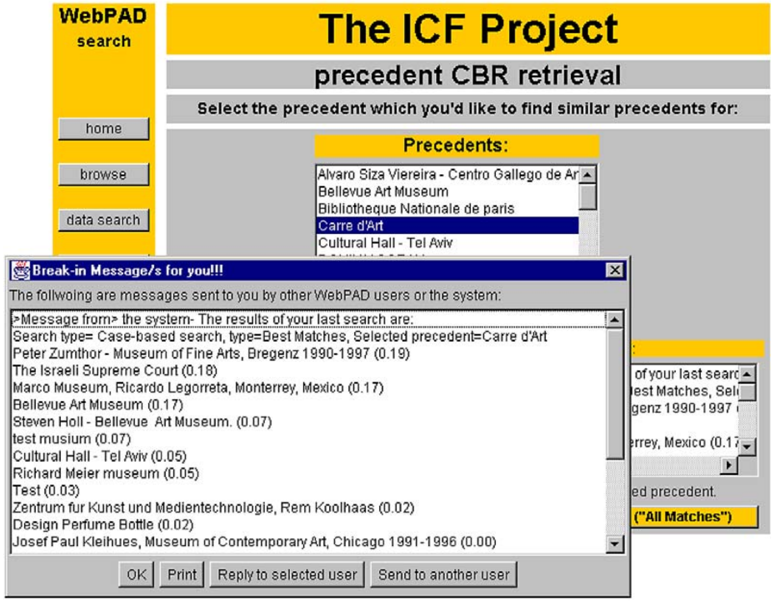

Figure 12 Search in WebPad: precedent retrieval.

by independent agents using the system. It provides certain utilities that support the *independent and collective construction and modification of the knowledge base*. Figs. 11 and 12 illustrate at the bottom of the screen facilities to support communication among collaborators in a construction session. This property addresses one of the inherent possibilities of knowledge construction in electronic communities.

6 *Summary and conclusions*

Think-Maps was introduced as an alternative and complementary approach to design teaching and learning in design education. In this approach domain knowledge in relation to design thinking becomes explicit as the significant component to be taught and transferred in education.

Think-Maps was introduced as a cognitive-based pedagogical framework in which the construction of conceptual structures is exploited through computational modeling. Instead of teaching how to construct a model of a design object we teach how to organize domain knowledge and construct a model of knowledge structures. That is, the cognitive content and structuring of design knowledge are, in themselves, the subjects of the educational program.

This framework provides the means, for both teacher and learner, to explicate their knowledge. Think-Maps is a teachable method that emphasizes the following points: it provide a means for the organization of the knowledge acquired by the learner and makes it explicit; the resulting mapping reflects the learner's domain knowledge in a specific area. Think-maps encourages collaborative learning. The fundamental pedagogical idea behind this is that learning takes place by the assimilation of new concepts into existing concept maps, and relative to the knowledge of the learning group.

Think-maps differs from other conceptual mapping approaches. While most existing approaches are mainly paper-related, Think-maps employs a unique computational tool that assists and modeling as well as providing other pedagogical advantages. Web-Pad is the computational tool that we have developed and employed within the Think-maps framework. Web-Pad utilizes a representational formalism and a shared schema that renders design concepts explicit and helps to organize knowledge and to structure it according to each student task. In addition to a shared representation, Web-Pad provides a medium for the storage and accessing of design knowledge.

The use of this computational tool demonstrates the following general advantages: It provides an environment in which new knowledge can be in-put by independent agents using the system; it provides certain utilities that support the *independent and collective construction and modification of the knowledge-base*; the content of a computational system can be later accessed by the learner and can inform the design process. Furthermore, the computational tool creates re-usable knowledge that can be extended and updated. The tool also supports a collaborative learning environment for the construction of knowledge. The *learning community* that is located on remote sites can create knowledge. Web-Pad is designed to provide a unique environment for the coding of design knowledge in a social and collaborative context that supports a social construction of knowledge. It explicitly encouraged the individual acquisition of knowledge as part of a collaborative learning process.

Within the scope of this experimental program a detailed learning evaluation process was not undertaken. In future application, this module will be undertaken. However, it is our impression that the exposure to design thinking as a specific kind of transferable knowledge made a powerful impression upon the groups of design students who have undertaken this first series of learning experiments.

In this paper we have presented the theoretical basis and the design and implementation of the computational tools as a general contribution to the idea of *cognitive-based teaching approaches in design education*. Whether or not the Think-maps approach may be considered of general relevance it pioneers the kind of pedagogical experimentation that is highly desirable in order to overcome deficiencies of conventional approaches to design education. There appear to be emerging today new paradigms in design education. Among them, cognitive-based design education approaches in which design thinking becomes an explicit subject of knowledge appears to us to be of immense promise.

Acknowledgements

This work was supported by a DFG grant from the German government. Professor Bernd Striech and his research team, particularly Architect Oliver Fritz, are acknowledged for their contributions to our research and pedagogical experiments. Their partnership in the overall framework of the 'Media-Based Creativity' research program has been most stimulating. Dr Amnon Shabo was the computer programmer of Web-Pad. His background and knowledge contributed much to this project. As always my students are greatly acknowledged for their participation in this pedagogical experiment.