A CONCEPTUAL NETWORK FOR WEB REPRESENTATION OF DESIGN KNOWLEDGE

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abstract:

The nature of the Internet as a medium for the representation, storage and accessing of design knowledge is explored and various research issues were introduced. The appropriateness of certain characteristics of the medium as a potential environment for a new interactive way of doing design by exploring design ideas are investigated. Considerations of the Web as a collaboratively constructed and maintained design resource are explored. Cognitive models are proposed in order to support cognitive behaviors in search, browsing and concept expansion. Our particular approach utilizes the ICF (issue-concept-form) as a conceptual network for design knowledge bases. Finally, a report is given on a pilot program demonstrating how the exploitation of the ICF model structured around design chunks can support the construction and maintenance of shared design resources.

1. Introduction

The increasing use of the internet and availability of design subjects has opened up opportunities for the representation of design knowledge. New distributed and interactive tools, virtual reality on the net, multimedia, networked digital video, and Java applications are providing new and exciting media for the construction of virtual design spaces (Schmitt, 1996). Despite these developments, the nature of the net as a medium for the representation, storage and accessing of design knowledge does not yet provide direct support for the enhanced content of ideas and concepts which are part of design thinking. The cognitively rich behavior of design can be supported, but how? If we are interested in the development of cognitively powerful knowledge representations, we require accepted models behind the organization and presentation of design knowledge.

In this paper, we report on research in which the Internet is considered an environment for the representation, storage and retrieval of design knowledge. The research demonstrates that the embedding of design conceptual content in Web-based representations provides a powerful advantage for expanding the cognitive richness of design content. It further contributes to expediting the processes of search and retrieval in design knowledge bases.

Our approach considers strengthening conceptual content through structuring the representation of information as a key to the advancement of Web-communication and utility. Information structure, the way information is displayed and organized, has implications for functionality in navigation, browsing and search. We demonstrate that appropriate structuring can also emulate and support cognitive behaviors. Stucturing also provides the added advantage of enhancing the possibility of collaborative development of shared sources of knowledge. In order to move in this direction, we require

conventionalized structures and models behind the organization and presentation of design information.

Three components: design descriptions, underlying information models and the intrinsic potential of Web technology provide the theoretical and methodological foundations for Web-based Design Information Systems. Web technology can contributes to new forms of interactivity, communication, presentation and collaboration by the integration of a variety of tools. However, without the introduction of knowledge models capable of cognitive level performance, we cannot advance beyond the presentation level of design information. Thus, our long-term objectives are: to strengthen the cognitive content (particularly conceptual richness) of design representations; to exploit Web utilities optimally in design information resources; to conventionalize models of design knowledge in order to support the shared construction and usage of open Web sites; to enhance forms of search.

How can design be represented in a way that encodes the conceptual content of design knowledge ? We demonstrate that structured conceptual representations provide, beyond the improvement of functionality, potential for supporting conceptual linkages. This behavior appears to emulate the important cognitive phenomenon of concept expansion, a form of the evolution of design concepts which is characteristic of creative thought in design.

In the system we demonstrate how enhanced conceptual representations of design concepts can support search through a body of design ideas in an associative manner. It is the complexity of this Web of associations which emulates concept formation in creative design in the human designer. In our approach, current emphasis has been placed upon the exploration of cognitive models as a methodological basis for the representation of both typological and design precedent knowledge. We present certain of the theoretical and research issues in a cognitive approach to Web-based design information bases, report on classes of design conceptual structures which have been implemented in the system, and consider the implications of our current approach as a basis for shared, open sites.

The paper reports on an educational experiment, and the resulting information base which has been developed by a group of architectural students. The formalization of this conceptual knowledge (Regionalism in Architecture) on the Internet has proved to be extremely challenging as an educational medium. This attempt at the formalization of conceptual knowledge in an information base has helped to identify issues for further research and development. Among these, we place emphasis upon shared, or conventionalized, knowledge structures. These are considered a precondition for collaboratively constructed Web-based design resources.

The work demonstrates the potential of future collaborative development of shared design sites. We consider selected theoretical and research issues related to this powerful concept. As a design community it would be of great potential benefit, if we could focus collaborative efforts on the structures, norms and procedures required for the development of shared environments. We believe that only through large-scale collaborative efforts will it be possible to formalize domain knowledge in design. Such knowledge can also eventually contribute to domain-specific search engines.

In the following section, issues related to the Net as a shared Web-based design resource are presented. Net attributes are reviewed with respect to their potential contribution to the exploitation of the Net as a design resource. On the basis of this review of characteristics, we propose a set of issues which must be addressed in order to achieve a shared Web-based representation for design knowledge.

2. Shared Design Web-Space

The Web is a large and continuously extendible information resource. As such it has certain characteristics which are problematic relative to the objectives outlined in the previous section:

- information structure and organization

The current unstructured nature of the medium limits the potential for joint projects and shared activities which require a higher level of structuring in the representation of information. Beyond collaboration, structuring is a subject which also has implications for the functionality of Web sites, in general, as well as for information bases. Information structure, the way information is displayed and organized, has further implications for navigation, browsing and search. Navigation is dependent upon the structure of linkages. Linkages are currently hand-crafted and are dependent upon the individual views of the developer. If we as a professional community wish to promote collaborative development of shared knowledge, we require conventionally accepted models behind the presentation and organizational structure of design information.

Among the issues for development which are raised by these problems are the definition of the presentational and conceptual content of designs and the way in which the organizational structure of information affects utility and cognitive performance

- domain dependent vs domain independent information bases

Given the quantity of information now available on the Web and the open introduction of information without guidelines or restrictions, finding and exploiting material

becomes extremely inefficient. One potential solution appears to be the employment of domain specific organizational media such as indices based upon domain specific conceptual vocabularies. An important methodological problem is how to acquire this knowledge and how to construct domain vocabularies.

- textual vs graphical representation

Today it is possible to make references, or to access information, primarily through textural means. Current Net tools such as Map-Edit support graphical indexing, but in a limited way. The possibility of graphical indexing is obviously of great significance to the performance of design information bases which generally contain much graphical content. Graphical indices might enable search for similarity based upon graphic content, or some code of graphic content. Conventions for the graphical coding of designs must be developed along with appropriate computational tools for graphical search.

- passive vs active presentation

The Web has so far operated as a medium for disseminating information to distributed locations. Interaction with information is still primarily static, or passive. The Internet supports the presentation of information, either in 2d or 3d, in animation, video, etc., but does not adapt and respond to specific requirements of users. With the development of new programming languages such as JAVA, there exist possibilities for the inclusion of programs and algorithms within sites which enable dynamic operative characteristics. This raises the general issue of how to effectively support the dynamic and individualized activation of diverse forms of information rather than the presentation of static documents.

We have reviewed four broad categories of Net characteristics which appear to have significant implications for Net-based design resources:

a. structure and organization in shared sites and cognitive performance;
b. domain specific indices enabling more efficient search and utility;
c. graphical indexing for more intuitive design search
d. interactive knowledge-bases.

In the following sections we consider these problems with respect to our current research.

3. Cognitive Models as a Basis for Web Representation of Design Knowledge

We have proposed a model for a Shared Design Web-Space. The model is based upon a general approach to the representation and structuring of design information. Related to the model, we also propose a basis for establishing domain-specific indices. A concept of employing the graphical content of design schema as graphical indexing for designs.

We include in the general model a cognitive model of design representations (Oxman, 1996). That is, beyond the graphical and basic textual presentation of the design itself, as is characteristic of current Web presentation, the proposed approach would provides underlying conceptual knowledge. Beyond the presentation of general information, a design information base can provide knowledge which would support the understanding, reasoning about, and re-use of a design precedent.

In recent years we have attempted to develop formalisms for the representation of cognitive-based representations of design knowledge which can be exploited in design

and design reasoning processes (Oxman,90,94). Among the forms of design knowledge representation which are as relevant candidates are the following:

- precedents (related to the computational paradigm of case-based design): this provides a presentation of the holistic solution as well as decomposition of the solution description as a set of separate design ideas (chunks). It includes a rationale for the re-use of the solution (in CBR terminology: case-adaptation).
- typologies (related to the computational paradigm of prototype-based design): in addition to the presentation of designs it is possible to provide a representation of the schema, or prototype, which underlies the specific solution. This representation might also include the refinement process, or the steps of development of a final solutions from the source schema.

  These two forms of representation, along with their rationale for re-use of information, would enhance the possibilities for active rather than passive representation of knowledge.
- indexing through design schemas can potential support graphical indexing for references of similar designs.

4 The Web as a Design Case-base

CBD (Case-based Design) (Maher et al., 1995) has developed as a domain-based application of CBR (Case-based Reasoning) (Kolodner, 1994). CBR is a cognitive computational theory which has been applied to the modeling of design. A foundational research priority in CBR is to model human reasoning in re-use of past solutions. Since the re-use of the experience of prior solutions in all of its complex phenomena is characteristic of design, CBR is a highly relevant technology for design fields. In order

to differentiate CBD, we refer to it as Precedent-based Design, since design precedents are prior design solutions which have something to contribute to current design problems.

In the behavior of Web users as well as in the construction of sites, we can observe case-based phenomena. For example, indexing, browsing, down-loading and re-use of material are all phenomena which have an analogous relationship with CBR (Oxman, 1996). This affinity of the Net as a resource-base and its relationship with Case-based Reasoning suggests possibilities for a new form of development of design resources within the Net. CBR has developed a rich experimental and applicative technology which has recently resulted in CBD systems in different tasks in design. In constructing design resources within the Net, we can derive much experience from approaches in CBR including search and adaptation paradigms.

With the development of Network technology CBD appears to be entering a phase of new developmental potential. The Net already functions as a large case-based system (Oxman, 1996). What is required in order to enhance the performance of the Net as a world-wide CBD system? What foundational work is necessary in order to enable collaborative activities towards this end. Should we entertain the idea of an international research program to develop a global Shared Web Design-Space? If this is a desirable objective for our community, should this effort be conceived of as a collaboratively developed global case-based site?

Certain issues are relevant to advancing this possibility:

- the Web as a global design case-base: large scale case bases, their function and performance requirements must be defined;
- collaborative development and usage of design cases: the possibility of a jointly constructed and collaboratively maintained design resource site requires development of conventionalized models, norms and specs;

- standardization of the representation of information in a format which provides more than the presentation of visual information: this requires the acceptance of a cognitive model;
- design search engines based on semantic taxonomies for design: how to develop semantic, or conceptual, taxonomies to support linkages and browsing; can semantic Nets of design issues and design concepts furnish convenient category sets for a global indexing schema?
- design search engines based on graphical design ontologies: graphical indexing and browsing potential and the indexing of designs according to a graphical design ontology require development;
- automation of indexing and linkage: the process of index creation can be automated;
- case acquisition in the Net how are new cases acquired and introduced; legal issues: legal problems related to the re-use of intellectual property in the form of designs, design representations, etc.;
- interactive design: if interactivity within the site is possible, how can it be achieved?
- adaptation engines: how can we achieve the dynamic and interactive activation of information, for example, in the provision of rationale for the re-use of design knowledge in current design problems.

5. ICF as a Formalism for Shared Design Work Space

5.1 BACKGROUND

The term design precedent has been employed in our work on design knowledge representation (Oxman, 1994) in order to designate that particular design case conceptual knowledge which has something to contribute to current design problems. One of the distinctive problems in representing designs is the richness and complexity of their descriptive content. Each design contains many related chunks of information which are often difficult to describe or to decompose. Furthermore, not all of the information embedded in complete and exhaustive records of existing designs may be immediately relevant for aiding in current design problems. A design chunk is defined as an original annotation of an entity of conceptual content which characterizes the uniqueness of a specific part of the design solution in a design precedent.

We have attempted to identify the kinds of knowledge which exist in design precedents and to formalize their representation. The representation formalism which we have developed was termd ICF (Issue-Concept-Form). A typical ICF formalism provides explicit linkages between design issues of the problem, a particular solution concept, and a related form description of an element of the design solution. In our research we have developed the ICF formalism in order to make these conceptual linkages of design ideas explicit. The ICF model addresses these problems of representation. It is based upon a decomposition of holistic case knowledge into separate chunks of design knowledge. Each design chunk represents the linkage between design issue, concept and form in a design precedent. The chunks are defined as components in a structured memory according to a semantic network of issues, concepts, and forms.

Design issue: the design issue is domain-specific semantic information related to goals and issues of the problem. It may be a point related to the design task which is deliberated by the designer. Such points may be formulated by the programmatic statement, the intrinsic problems of the domain, or by the designer himself.

Design concept: the design concept is a domain-specific formulation of a design idea in relation to an issue. It is a form of ideation related to the design task. It is a verbal statement of a solution principle. The way to a solution, rather than the explicit physical description.

Design form: the form is the specific design artifact which materializes the solution principle. It is a physical design, particularly related to the structure of design objects.

This tri-partite schema has significant implications for memory organization, indexing, and search. It contributes to an indexing system which supports issue and concept related search in the design precedent representation. Furthermore, this approach enhances the capability of browsing within memory and can support cross-contextual indexing by exploring the net of concepts, and following it back to appropriate structural descriptions.

5.2 ICF ON THE WEB

The ICF formalism has been exploited to promote a conventionalized and structured representation for design information in the development of a shared site of design projects in the Web. Beyond the simple objective of presenting design objects, the formalism provides a structure of representation which emphasizes the encoding of design rationale and method as well as the formal and functional elements of the design. Given the structured nature of the representational set, and the significantly developed relationship between textual and graphic presentation in ICF, this ontology preserves a high level of specific representational flexibility within sites while providing the essential structure to support queries, search and exploration of ideas through the networked linkages between sites.

In the following chapter, we provide a description of an experimental case study. In our experiment, a set of domain-specific semantic information related to design issues is explicated and employed as part of the indexing system for cases in the Web.

Design concepts employed in a collection of design precedents exemplify conceptual approaches to the conceptual resolution of these issues in selected examples of regional architecture (Work by Mat Sand, Ruth Rotenshtreich, Shoshi Bar-Eli).

5.3 CASE STUDY: REGIONALISM IN ARCHITECTURE

In the current system precedents have been drawn from case studies of the Mediterranean House, a sub-class of regionalism for which the case-base provides a collection of important precedents as represented by their conceptual contributions. Within the casebase specific formal elements are identified which provide structural, or conceptual, solutions for the significant issues.

Among typical issues are: topography, controlling the view, content of elements, content of vernacular architecture, regional attention to natural physical forces such as light, spatial institutions such as contained private space, the spatiality of the wall, materials and technology, etc. The collection of examples which constitute a case-base for the Mediterranean House provide, through the convention of the ICF model, a means to address certain of the theoretical issues in constructing structured, shared design Web-space sites.

The model also addresses other issues which were outlined above such as domainspecific indexing. That is, the contribution of the multiple independent site designers working within the convention of ICF can contribute to a body of taxonomic content which constitutes a conceptual vocabulary for the specific domain, Regionalism in Mediterranean Architecture. This vocabulary can then function as a domain specific index and support search for relevant design ideas. The index is automatically updated as the site is expanded.

5.4 SYSTEM DESCRIPTION

We have implemented a system which contains knowledge which constitutes a precedent base for the Mediterranean House, and for its design. Figure 1 illustrates the current implemented version of the system. The system currently consists of a set of formatted Web pages. The format includes four frames. Each frame contains a specific representational formalism or presentational media. The frames of a typical page are:

a. Title window

The title window is at the upper right corner of the page and contains the title of the current subject and its related content described by text. For example, Web page b. presents in the title window the name of a selected issue and provides a textual description of its related concepts. In figure 1. the title of the selected issue is: "relation to local architecture".

b. Top-down representational window

The top-down representational window is located at the upper left corner of the page. It contains a relevant part of the ICF complete semantic map which supports browsing linkages from a higher level of abstraction to a lower one. For example, issue no. 2 - "relation to local architecture" is linked to its related concepts: concept no.2."controlled use of local elements" and: concept no.3. "planting an element from local vernacular architecture". Each top down window contains its own explanation box which is the description window below the net diagram.

c. Bottom-up representational window

The *bottom-up representational window* is located at the bottom right corner of the page. It contains a relevant extracted part of the ICF complete semantic net which supports browsing linkages from a lower level of abstraction to a higher level. For example, concept no. 3 - "planting an element from local vernacular architecture" is linked back to its related issues such as "relation to local architecture" and "building and site relation".

d. Description window

The description window contains textual and graphical illustrations. It is located at the bottom left part of the page. It is usually linked to presentation pages by textual and/or graphical references. At each level, the description page contains the relevant material. The explanation window contains a textual explanation of the related abstraction. For example, an explanation of concept no.3. "planting an element from local vernacular architecture" is the following: "Using elements of local vernacular architecture in design is an act of quotation: - copying an element derives from the need to preserve, or respect, the importance of local buildings, methods and elements that were developed through the years. By quotation, or emulation, the architects creates an immediate connection to local architecture that can easily be traced and understood". Key words in the text can also be employed as mouseable indices.

5.5 SYSTEM OPERATION

In contrast with a system with highly structured networks of objects and linkages from design object to design object (coarse level of indexing), we experimented with conceptual indexing (finer level of indexing) in order to support associational search and browsing exploiting the principle of semantic nets. The system has provided a means

to test certain of our theoretical assumptions regarding both cognitive behaviors in information bases and the conditions for shared design Web sites. We are continuing development of a large scale system (The Modern Chair) for the continuing development of the approach and the validation of research assumptions.

An example of browsing and exploration modes in the ICF system is illustrated in figures 1 and 2. The first step is the selection of an issue from the set of all currently exisiting domain issues. Once an issue is selected, the second page appears with related concepts. The user selects relevant conceptual linkages by activating the top-down window. Related concepts appear and cross-contextual linkage can be established. At this stage the partial ICF map of concepts related to forms appears on the screen. In the same fashion, the linkage which has been discovered may introduce the discovery of another design concept associated with the form element of another precedent. Similar concepts may activate several designs. By activating a top-down window which connects concepts to forms the user may explore how a similar design concept may be realized by different form elements in two designs.

Browsing supports the exploration of cross-contextual linkages in both directions. By activating the top-down and the bottom-up windows there exists the possibility to search and browse the whole semantic network. The user can go forward by selecting the topdown window or go back to a previous page by activating the bottom-up window and select any relevant domain category. Top-down navigation is illustrated by the arrow on the left side of the figure. Bottom- up navigation is illustrated by the arrow on the right side of the figure. For example, a selection of issue no. 2 - "relation to local architecture" activated its related concepts. Further selection of one of the concepts, for example, concept no. 3 "planting an element from local vernacular architecture" provides a link to its related forms. The selection of one of the forms, e.g., form no. 1 "roofs" links to its related precedents. The selection of one of the precedents links to the specific precedent pages. For example, the selection of precedent no. 1 "the Bonet House" links to its precedent presentation page.

A bottom-up navigation process can be supported at any stage. By selecting a specific abstraction at the bottom right-hand side of the screen, the system links the page which describes the selected abstraction. For example, the selection of issue no. 2 - "relation to local architecture" of the concept page "planting an element from local vernacular architecture", links back to other concepts of the same issue, to provide for a selection of another concept such as - "controlled use of local elements".

5.6 COMPUTATIONAL TOOLS

In the following section we provide a preliminary review of the tools which we have employed in the pilot program as well as some comments on current technological developments and constraints.

In our current work we have employed the following Internet tools: an HTML language for textual descriptions, and the construction of HTFP references. We have employed Map-Edit for the editing of forms and image maps in order to achieve graphical indexing and interactivity. This tool employs geometrical entities such as squares, rectangles, polygons etc. for the editing of specific objects and image maps. The disadvantage of Map-Edit is that it requires a re-identification of objects. What we might expect from a more flexible referencing tool is the ability to identify a certain object or grouping of objects interactively. This probably requires a link with a VRML tool which is employed for visual presentations and graphical descriptions. We are currently considering the use of JAVA for achieving dynamic icons and animation processes. The installation of more complex process-related descriptions, such as typological schema and algorithms for both refinement of schema and adaptation of cases are still in a research stage.

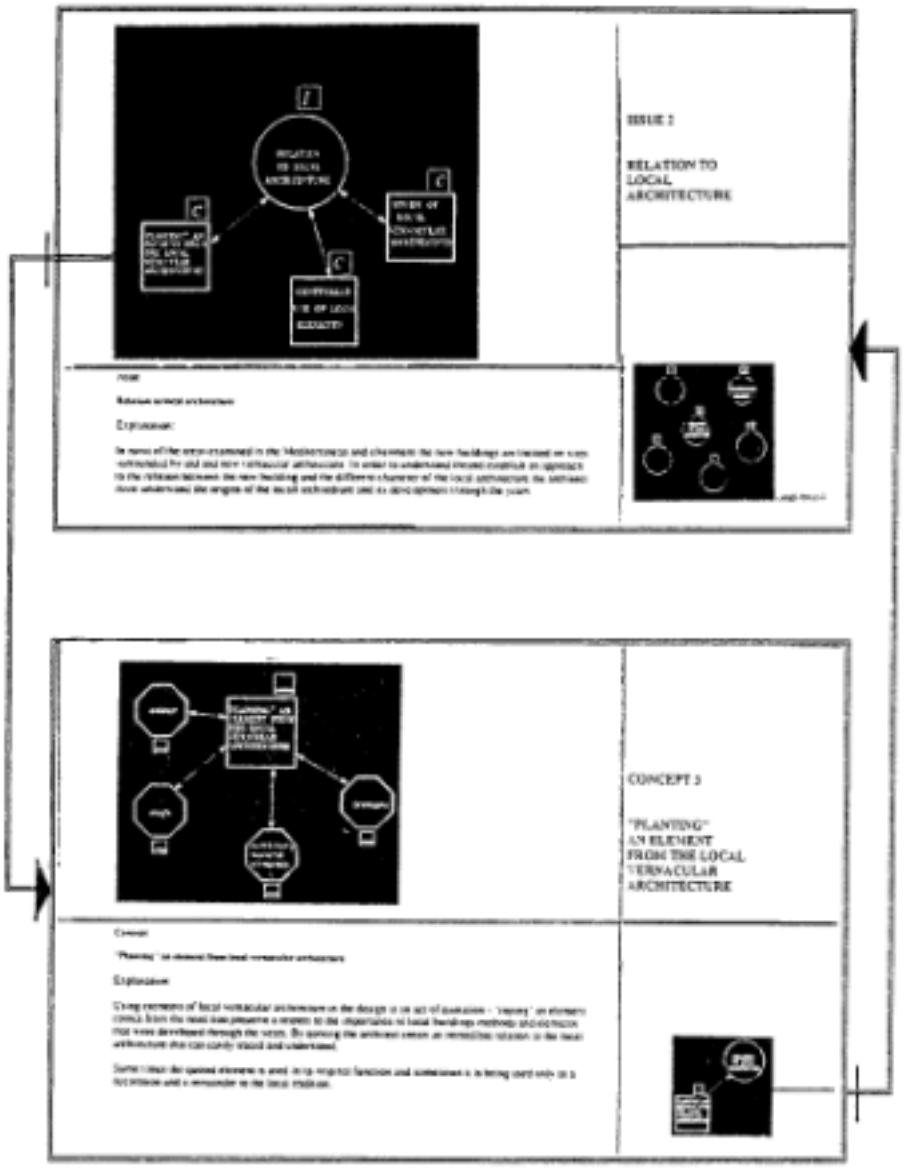

Figure 1. System operation of top-down window and bottom-up window for issues and concepts

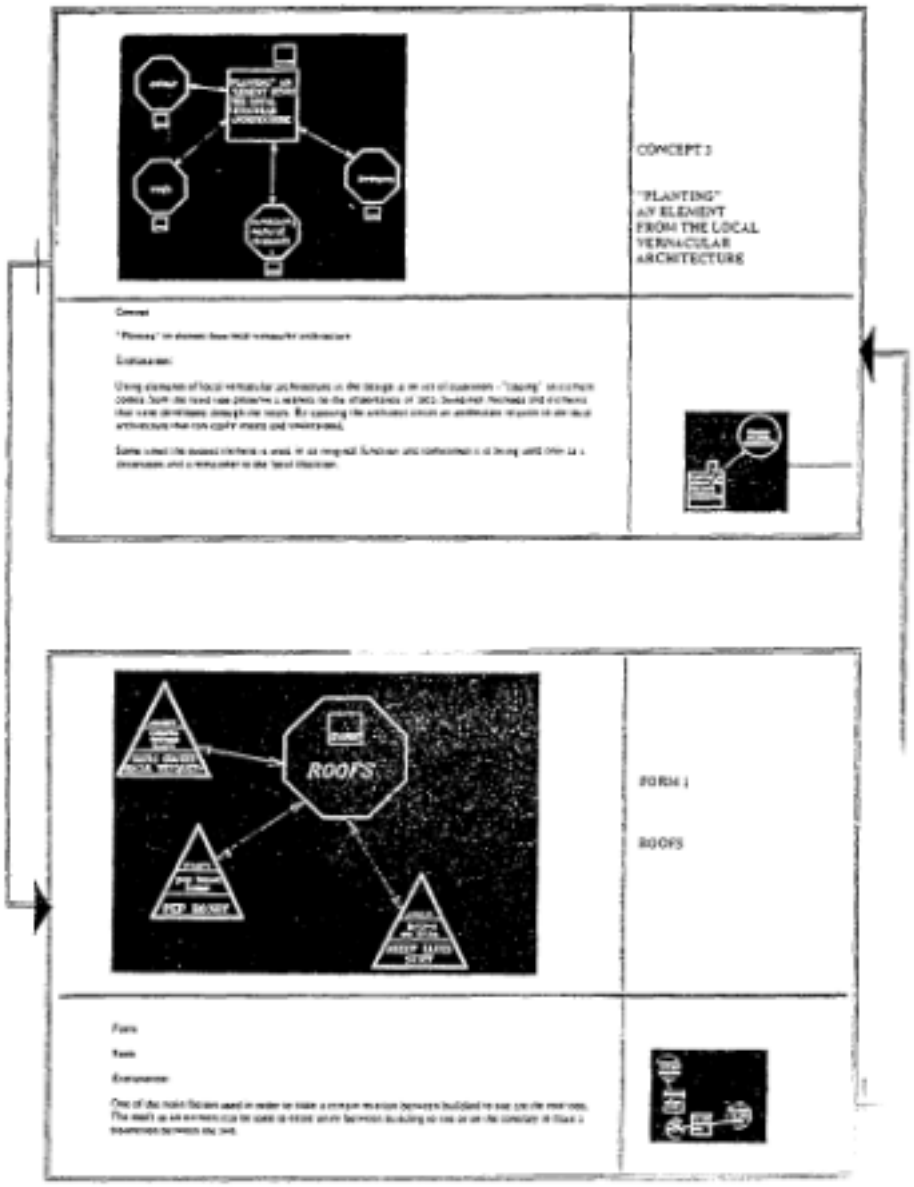

Figure 2. System operation of top-down window and bottom-up window for concepts and forms

6 SUMMARY AND CONCLUSIONS

In this paper we have considered the Web as an environment which provides resources for developing and using design knowledge bases. It is an approach which integrates the characteristics of the net with certain problems and potential of design information systems. The nature of the Internet as a medium for the representation, storage and accessing of design knowledge was explored and various research issues were introduced. The potential of this new medium as a resource for design collaboration and the sharing of knowledge construction imperatives attempts to exploit certain intrinsic potential of the new communication technology. We have elaborated on the appropriateness of certain characteristics of the medium as a potential environment for a new interactive way of doing design by exploring design ideas. Considerations of the Web as a collaboratively constructed and maintained design resource were explored, but there remains work to be done before an international program can be launched.

We have proposed the use of cognitive models in order to support cognitive behaviors in search , browsing and concept expansion. Our particular approach utilizes case-based reasoning as a possible general model for design knowledge bases. We have extended the inter-relationships between theoretical issues in case-based design and their potential application in the Internet. Finally, a report was given on a pilot program demonstrating how the exploitation of the model structured around design chunks can support the construction and maintenance of shared design sites. These developments show great potential for the development of new resources for the design professions. They do not simply extend the nature and logic of pre-computer design; they are truly of the computer. The great challenge is to exploit this potential intelligently. Whether we can act collectively to create global design resources is perhaps one of the greatest challenges of our work as a design community.

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