ARCIMAP: KNOWLEDGE MODELING FOR CONCEPTUAL BUILDING DESIGN

Bige Tunçer[1], Sevil Sariyildiz[2], and Rudi Stouffs[3]

ABSTRACT

Within the conceptual phase of design, architects (and designers in general) collect and look at design documents. These design documents are sources of knowledge and inspiration for the designers. We have developed an information model for the conceptual design phase that supports knowledge representation and information organization in an integrated manner. This model, named Architectural Information Map (ArcIMap), uses a semantic network structure for the modeling of concepts and semantic relationships. This semantic network is used as a backbone for the organization of documents. It also acts as a semantic map in the visualization of the organizational structure. We have developed and tested four prototype applications of this model; three in architectural education and one in architectural practice.

In this paper, we present our knowledge model ArcIMap and briefly describe the methodology for using this model in the context of the conceptual design of a building. We draw upon the results from evaluating one of the prototype applications in order to discuss the relevance for the building sector and future research and development steps.

KEY WORDS

information modeling, knowledge representation, architectural design, conceptual design phase, design correspondence

INTRODUCTION

In the conceptual phase of design, architects develop one or more concepts that must prove to be valid throughout the lifecycle of the project (Heylighen and Neuckermans 2000). In order to do so, they gather information and study relevant precedents (Akin 2002, Oxman 1994). This information is usually represented as design documents and can be of any format, i.e., drawings, diagrams, pictures, texts, movies, etc., and they convey a specific aspect and viewpoint. Furthermore, architects often work in teams, also in the conceptual phase of design. Correspondence among the team members, and with members of other disciplines

[1] Assistant Professor, Chair Technical Design & Informatics, Faculty of Architecture, Delft University of Technology, Berlageweg 1, 2628 CR Delft, The Netherlands, Phone +31 15 2784092, FAX +31 15 2784178, b.tuncer@bk.tudelft.nl

[2] Professor, Chair Technical Design & Informatics, Faculty of Architecture, Delft University of Technology, Berlageweg 1, 2628 CR Delft, The Netherlands, Phone +31 15 2785997, FAX +31 15 2784178, i.s.sariyildiz@bk.tudelft.nl

[3] Associate Professor, Chair Technical Design & Informatics, Faculty of Architecture, Delft University of Technology, Berlageweg 1, 2628 CR Delft, The Netherlands, Phone +31 15 2781295, FAX +31 15 2784178, r.stouffs@bk.tudelft.nl

involved in this phase, is crucial. Finally, the knowledge created within any community, for instance an architectural office, needs to be captured and reused for future projects and new team members.

A computational environment that supports the recording and reuse of knowledge, and the organization of information, is essential. This environment must be robust but, at the same time, flexible, extensible, and easy to use. A computational environment for a collection of external design documents has a number of purposes: to create a design document library that can be searched and browsed, and the organization of the knowledge that resides in these documents that can be searched and browsed.

Design information has many inter-relationships and dependencies. Organizing this information is a complex task. Many electronic precedent libraries have been developed, most of them as image archives. These traditionally organize documents according to categories such as year, style, architect, etc. However, a system that can cognitively support designers in the conceptual phase of design through the recording of design knowledge and design ideas that at the same time serves as an information organization environment is interesting from many viewpoints.

We have developed an information model for the conceptual design phase that supports knowledge representation and information organization in an integrated manner. This model, named Architectural Information Map (ArcIMap), uses a semantic network structure for the modeling of knowledge as concepts and semantic relationships. This semantic network is used as a backbone for the organization of documents. It also acts as a semantic map in the visualization of the organizational structure. We have developed and tested four prototype applications of this model; three in architectural education and one in architectural practice.

In this paper, we present the ArcIMap model and briefly describe the methodology for using this model in the context of the conceptual design of buildings. We will draw upon the results from evaluating one of the prototype applications in order to discuss the relevance for the building sector and future research and development steps.

THE ARCIMAP MODEL

ArcIMap provides a model for a visual, flexible and extensible environment that enables the collected information to be reused in further projects. It supports the definition of associations between knowledge entities and documents, and thereby, cognitive and associative browsing. It supports the definition of subjective definition of knowledge structures, as well as structures for common use within a group, either educational or professional. It avoids a rigid organization structure that all the users need to adhere to, such as implemented in a standardization approach. It enables design correspondence among the users, because in design, designers learn from and with each other (Schön 1985). The acquisition and the organization of the knowledge that resides in the design documents are organized in a way that does not affect the organizational structure of the documents themselves. A unified representational framework is necessary for the conception and development of such an environment.

The goal of the ArcIMap model is to define a framework for creating digital applications for designers to use in the conceptual phase of design. In this way, extensible libraries of design documents can be created, and knowledge structures of designers can be recorded.

This framework can be used for educational as well as professional contexts. The process and requirements differ in a practical and educational environment. Novice designers can use the model to learn about design solutions and expand their knowledge structure in a targeted way. Experienced designers can use the model for organizing and storing visual material in a personal way. Project managers can use the model for archiving collective material using a common information organization scheme. In this model, two distinct activities are investigated: information gathering and organization in the context of conceptual design, and knowledge representation and reuse in the context of conceptual design. This model acts as a framework for the definition and implementation of computational systems, and applied in specific contexts.

The ArcIMap model creates a methodology for the separation of the organizational structure and the document structure. In its main lines, ArchIMap has two components:

Semantic structure: A semantic structure to model *concepts* and *conceptual relationships* (knowledge), conceptually derived from concept maps (Novak and Gowin 1984), representationally using aspects from semantic networks (Sowa 1991), conceptual graphs (Sowa 1984), and XML topic maps (Pepper 2002). The semantic structure acts as a backbone for the organization, decomposition and indexing of documents. Document metadata is also incorporated into the semantic structure. This network can be defined by a user or a group, can be project or institution specific, and defines a common language among users. The concepts and conceptual relationships in the semantic structure are typed, respectively through the concept type hierarchy and the relationship type hierarchy. One of the goals of ArcIMap is to support the creation subjective semantic relationships, therefore the creation of subjective relationships is allowed. These can be typed according to a set of predefined (but extensible) semantic relationships in order to support information retrieval. When relationships are not typed, the danger occurs that every relationship is unique, and retrieval result sets may be quite limited. Another advantage of typing the relationships is to make users consider the nature of the relationships they create. This will have a positive effect on the cognitive processes of users. In order to reduce the workload of users, the system should keep track of the labels used for types and suggest appropriate labels to users according to the selected semantic type.

Document structure: This structure contains a collection of multi-media design documents to be used in the information gathering phase of conceptual design. These documents are named components in the model. The document structure allows for the definition of document components for ease of indexing by content. These document components are created by dividing documents into smaller components. Components can be related to other components in other ways than component relationships: referential relationships can be defined among components. Occurrences relate components to members in the semantic structure. Occurrences are typed.

Figure 1 describes the objects and their relationships in the ArcIMap model.

A proof of concept implementation was done for the ArcIMap model as a presentation tool for analysis, using 3 Ottoman Mosques as a case study (Tunçer et al. 2002). This implementation used the concept of types and typologies in order to conceive a network of concepts and relationships for a knowledge structure. The results of this implementation were evaluated from various viewpoints: usability, technical aspects, data model. A second

application is a digital architectural analysis environment for the conceptual phase of design that was used by students in the second year design studio (Tunçer et al. 2002). The use of this environment was extensively evaluated. Next, a knowledge representation system of double-curved surface building precedents was developed and tested in education in the second year of master's education (Kocatürk and Tunçer 2004), and evaluated. Finally, an information and knowledge organization system was developed and tested in practice, in an architectural office in Delft, called Mecanoo. This use was evaluated as well. All these evaluation results were translated into the development of the final ArcIMap model.

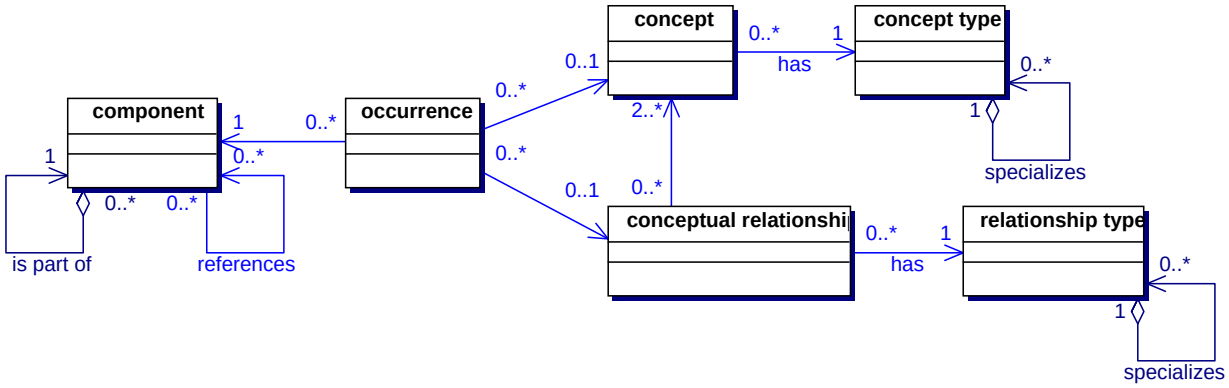

Figure 1: The ArcIMap model as a class diagram represented in UML.

THE USE OF A PROTOTYPE APPLICATION OF ARCIMAP IN AN ARCHITECTURAL OFFICE

A prototype application of ArcIMap, named DesignMap, was developed in order to test the validity and applicability of the model in a practical context. DesignMap implements parts of the ArcIMap model in a web-based collaborative environment, which is a flexible and extensible content management system, intended to be used at the early stages of design. It targets middle and small-size architectural offices. DesignMap was applied in an architectural office, Mecanoo located in Delft, The Netherlands (http://www.mecanoo.com/). The office has about 65 employees, consisting mostly of architects and engineers.

Because of the recent advances in Information, Communication and Knowledge Technologies (ICKT), architectural offices are going through a process of digitalization. It is becoming increasingly common practice for architectural offices to digitally archive their project documents and also to set up intranet sites for their employees. In this respect, offices are looking for organizational structures for their documents that are suitable in order to support an easy and fast, but also effective retrieval of their documents. This was also the case in Mecanoo.

Designers at Mecanoo look at magazines, and use search engines such as Google to find relevant information for the project at hand. They organize documents on a server according to a naming system used in the whole office. However, when people need to use an image,

they tend to copy it to the hard disk of the computer they are using. This results in many copies of an image on many computers and it causes problems of too little hard disk space.

In this particular office, a lot of aspects from previous designs are reused; this is an office policy. Images and documents are stored on servers, but there is very little recorded information available about the design rationale and the crucial concepts. Furthermore, there is a single rigid classification system that does not allow designers to use subjective terms.

The DesignMap application has three main goals: To enable a design team organize their information that they gather during the conceptual design phase in a personal, flexible and extensible manner; to enable a design team build up a common language of design concepts and relationship in order to improve their communication; and to enable the recording and reuse of design knowledge generated by a design team in other projects and other design teams. Keeping these goals in mind, the main motivating points for the development of the DesignMap tool are that such a record of the creative thought process makes it possible to accelerate and improve the quality of the design process of a given design team. It also enables the comparison between the methods different design teams use to design a given product. Recording the thought process of the design team enables the team to contribute to the design, and interact with each other's ideas, independently of any space or time constraints. This makes it possible to accelerate the lengthy and time consuming creative thought processes needed at the beginning of every design process, by building on the knowledge accumulated during the design of previous projects. This also supports the concept of precedent-based learning, where a design team adopts their successful solutions to problems similar to the ones they had to cope with in the past (Goldschmidt 1995).

A PROTOTYPE APPLICATION

The input to the prototype implementation of Design Map is a concepts hierarchy and a number of design documents. The concepts hierarchy is defined by a group of users. DesignMap has a main interface and a category editor interface. The category editor lists concepts in a collapsible format. An initial concepts hierarchy has been created by the project manager from Mecanoo Architects. This list contains physical concepts as well as abstract concepts such as 'inspirations'. Still, one can tell that the main line of thought behind this classification is the archiving of documents rather than a dynamic communication and organizational structure made up of concepts and relationships.

The main interface of DesignMap (Figure 2) contains functionality to upload documents, browse documents by concept, and search by concept. Additionally users can modify and delete documents and their properties. The bottom part initially shows all documents in the system by displaying their thumbnails. Below each thumbnail is a list of the associated concepts as hyperlinks. Clicking on a concept displays the documents associated with that concept. This allows for fast browsing of concepts and documents. The bottom part also displays the currently selected concept(s). One can drag and drop thumbnails into the two areas above to view them in bigger size. The 'search by category' option allows one or multiple concepts to be selected, and this brings up the associated documents in the main interface. Documents of all formats can be uploaded to DesignMap. Once a document is uploaded, it is visible to everyone using the system.

Figure 2. The main interface of the DesignMap prototype.

EVALUATION OF THE PROTOTYPE APPLICATION

In general, we have received highly positive reactions from the participants at Mecanoo about the use of this environment in their office. They especially appreciated the fact that the organizational structure can be modified and extended without affecting the already stored documents in the environment. This experiment ran for approximately 3 months. Because of the heavy work load of the designers and project deadline constraints, and financial considerations, it was treated as a pilot project and was used by two individuals in the office: the general project manager who tested the system and prepared the concept hierarchy, and a designer who input documents.

In order to evaluate the prototype and its use, we have conducted a 4.5 hour workshop at Mecanoo. The participants in this workshop were four members from the design and development team of DesignMap, the project manager from Mecanoo and five designer architects from Mecanoo. The participants from Mecanoo had received the planned schedule of the workshop beforehand and had prepared for it. Among other preparations, the five designers had gotten themselves familiar with the application before the workshop, but they had not actually used in their design process.

The workshop consisted of three main sessions. It started by a presentation of the main designer and developer of DesignMap describing the program, its functionality, its intended use, and its goals. This was done with the help of prints with snapshots of the interface hanging on the wall.

Next, there was a presentation of the general design process flow at Mecanoo. The design flow at Mecanoo has three main stages: Idea development stage, design stage, and execution stage. The idea development stage starts with meeting up with the client and identifying the project requirements. This is followed by visiting the site of the project and getting a feel to the size and environment of the project. Then, brainstorming sessions are done with teams from different projects to set up a number of plans for the project. One of these is chosen after a discussion with the client. The design stage starts by setting up a team of architects to perform the design process. The chief architects in Mecanoo have input on all projects and give freedom to have different ideas. The design stage progresses like a wave: it begins with a lot of input information (for example viewing lots of pictures), then gradually the idea gets fixed and the design is done. The execution stage is concerned with the actual construction of the design. Mecanoo distinguishes itself as an architecture office by getting involved in both the design as well as the execution of a project. During the execution of a project, more technical and less architectural expertise is needed, as opposed to the design stage of a project, where more architectural and less technical expertise is needed.

The second part of the workshop consisted of a brainstorming session on how the DesignMap application can be implemented in a running project at Mecanoo. Participants used notes to quickly come up with ideas and put them on the wall near another idea that is related. Later, these were further grouped together, themes were derived, and these were discussed.

The main conclusion of this brainstorming session was that DesignMap can be applied in two different ways:

1. As a structured database: Currently, Mecanoo uses a special directory tree structure as a database, and use a web search tool such as Google as a way to retrieve information. This approach is good enough for their needs, besides being well known and easy to use. However, it has the following disadvantages. Large pictures consume large amount of hard disk. The solution they use is to archive old projects. There is no standard setup, making it difficult to retrieve old information. The solution they use is to refer to recent projects only.

A database system must address the following issues: Ease of use (very important); saving disk space by unifying picture resources, using consistent keywords to easily retrieve information from old projects

2. As a means to communicate ideas: Currently, there is no such system being used at Mecanoo, or any other office they are aware of. The architects seem to be very much interested in such a tool.

A number of possible improvements to the first DesignMap prototype that came up during the brainstorming session were:

- Concepts should semi-automatically match each other in order to create clusters of related concepts
- Addition of visualization tool for the concept network, to visualize the concepts and relationships
- Ease of use in terms of uploading pictures into the system. For example, a folder with pictures having the name “inspirations” can be automatically uploaded and given the

keyword “inspirations”. Another example is to define an area (such as a button) with the label “inspirations” and be able to drag and drop documents into such an area in order to upload them.

The workshop ended with a discussion of the meeting and drawing conclusions. One of the conclusions was that the system should be used both as an archive database and as a communication system.

Designers did not initially show much interest in DesignMap, because of lack of time, and because they did not understand its potential as a design correspondence tool. Designers are not interested in a predefined keyword structure that they need to abide by. Designers were initially introduced to the concept hierarchy that their manager had constructed, and they thought that this was a fixed structure that they needed to abide by in their design process. This was not very interesting for them and they did not see the added value of this in the design process. On the contrary, they very much liked the idea of a concept network that they design collectively that reflects their thought processes in the conceptual phase of design. Once they understood the added value of the approach, they became very enthusiastic. On the other hand, in order to use the system for archiving images for the whole office, a more ‘rigid’ classification system is needed.

Other two main points brought up for improvement concentrated on initially filling the system in the least cumbersome way with precedent based information for allowing immediate browsing at searching at the beginning of a project, and the ease of use of the user interface.

In order to fulfill the use of DesignMap both as an archive environment and as a communication tool, two types of concept structures are needed: one specific to each project and/or design team, and a filtering mechanism that filters all the networks and fits them into a mediated archival classification system.

In this context, a new partial implementation of DesignMap was done. However, this has not yet been used and evaluated. The graphical user interface has never been completed, but the synchronization mechanism and the data structure are complete.

CONCLUSIONS AND FUTURE WORK

The applications of ArcIMap are intended for use by a group of designers. This group consists of a relatively small number of cooperating participants. Applications of this model can be conceived and developed in educational and practical contexts. In order for the use of application to be successful, an analysis of the organizational and process aspects of the context in which the implementation is foreseen needs to be done, and the outcomes that result from this analysis need to be included in the design of the implementation. The system that is implemented needs to be rooted in the context that its users operate in. This entails that in education, the educational processes must be supported by the system. In practice, the input process and other processes, and the interactivity must be designed in such a way that minimum effort is required from the users when using and interacting with the system.

It is a challenge to apply the results of this research in practice, where the “time is money” syndrome is widespread, and where immediate profit is generally expected from the

use of such a system. There is an enormous time and financial pressure on the designers working in architectural offices. The uptake and use of such systems require an investment from the designers, as well as from the managers. Designers and managers need to be convinced of the advantages of the use of such systems in the long term, and not immediately reject their use because they cannot see an immediate short term profit. In our conversations with professional designers, the first obstacle in the acceptance of such a system is distinguishing the use of such a system from the use of magazines or web search engines.

A rigid classification structure that they must adhere to in the organization of their documents is also not of interest to designers. However, once the points that designers can model and enter their own subjective concepts into the classification structure and that they can freely organize their documents get across, the enthusiasm level of the designers highly increases. By defining designers as active organizers of the knowledge and inspirations in a design context, the focus shifts from a pre-structured use of design precedents to an environment that facilitates and encourages the designer in creating her own structured body of design knowledge. The evaluation of the working prototype application DesignMap, which was used at Mecanoo Architects in Delft demonstrates this.

Designers appreciate the fact that ArcIMap allows for a flexible and extensible definition of information and knowledge structures. When using a practical application, when they need to modify or change the knowledge structure, this does not directly affect the information structure and vice versa. This feature saves a lot of time and concern for the designers. Additionally, the fact that ArcIMap allows for the indexing of parts of documents is also appreciated by designers. They can focus on certain knowledge in a document, and index the part of the document that contains this specific knowledge. This is very practical and efficient for them.

Such a system can be used for two purposes in an office: in order to create a common knowledge structure for use in the whole office, and in order to aid the design process of small project groups by having them cooperate through temporary project-based knowledge structures. Project managers are generally highly interested in the first use, and designers in the second. In order to transfer knowledge and information from these temporary structures to the main knowledge structure, ArcIMap foresees translation and mapping mechanisms. This enables ease of use for the wishes of designers as well as managers.

However, there are a number of improvements that would increase the chance of success of an application of ArcIMap especially in the context of its use in an architectural office. One important requirement for an information system to be used in practice is that it should have as little impact on daily work as possible. This concerns the user interface; it needs to be as user friendly as possible, and the user interaction needs to be very smooth. Additionally, the main problem of attempts to capture and make available knowledge during design is the additional workload that is generated by the capture process and how one can justify this to designers and managers. In order to decrease this workload, a number of tools must be developed and implemented. These tools can be used, for example, for the inputting and indexing of documents, for automatic initial taxonomy generation, and for inferring new knowledge from a knowledge structure. This latter one can be achieved by using inference mechanisms that are widely used in the knowledge representation field.

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