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Generating design activities through sketches in multi-agent systems

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Abstract

This study describes a multi-agent system that acts as a mediator between the designer and the information environment. The system enables designers to locate and retrieve information from distributed resources. There are three types of agents in the proposed model. The 'user agents' consist of designers, engineers, and technicians. The 'information agents' include various knowledge domains as legislation, codes, previous cases, expert domains. The 'communication agents' that identify and match agents are based on the goals and agent's interest. The communication agents working over the Web use sketches as a collaboration medium in the conceptual phase of the design process. The results of the empirical study showed that the design domain and variables; and design strategies and activities are not independent of each other. The quality of a project increases as the communication increases among collaborators during the conceptual design phase and the Internet provides a suitable medium for communication through sketches.

Keywords: Multi-agent systems; Designer; Information environment

1. Introduction

Sketches as an integral part of design store the design solutions and also aid in revising and refining ideas, generating concepts, and facilitating problem solving [1–5]. Understanding sketching has special importance to those who design human–computer interfaces, where sketches presented on computer screens can be used to determine the reasoning process during design. An agent and an environment define most of the human–computer interfaces. This paper describes a multi-agent system that acts as a mediator between the user and the information environment.

In architectural design, the designer constructs a conceptual model of the artefact by abstracting knowledge from previous experiences and information stored in the memory. These conceptual representations are linked both with the external forms of knowledge and with the internal representations of the model. Conceptual design involves two types of knowledge: abstract, conceptual knowledge and perceptually based knowledge [6].

The analyses of conceptual design have revealed that drawings are an integral part of the dialogue between the parties [7,8]. They are a kind of external

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representation, as a cognitive tool developed to facilitate information processing. They also facilitate memory and thinking. Besides sketches are considered as externalization of images. Therefore sketches are a clue to mental conceptualisation of domains. Sketches in a particular domain use a small number of segments or elements in varying combinations to produce a potentially infinite number of drawings. Sketching can be used as an active tool for communication among the agents. Besides, an agent may include both asynchronous tools as e-mail or news sections and synchronous tools as chat prompts [7].

Agent-based systems provide a collaborative environment for sharing of design information, data, and knowledge among distributed design team members. Besides, the Web technology can be used by the design team members as a medium to share data, information and knowledge. These approaches have so far been implemented in various prototype and industrial applications [9,10]. They claim that agents are best suited for applications that are modular, decentralized, changeable, ill-structured, and complex. Since the nature of design problems is considered to be ill-defined, multi-agent systems seem a suitable medium for the collaboration of the users.

Previous approaches that define the design process involve objective points of view in a rationalistic perspective, in which the situations are characterized in terms of identifiable objects and general rules. However, a design process can be identified as a series of situated acts. The initiation of a design process should involve the understanding of the issues and properties of the design problem related to that specific situation. Since design is considered as teamwork, an interactive collaborative Web site maximizes the opportunities in digital communication and cooperation of the parties.

2. Framework of the system

The framework of the proposed multi-agent based system is designed to help users to locate and retrieve information from distributed sources. Each agent is autonomous, rational and can communicate with other agents through sketches. The user agents, information agents and in between communication agents form the framework of the proposed model (see Fig. 1).

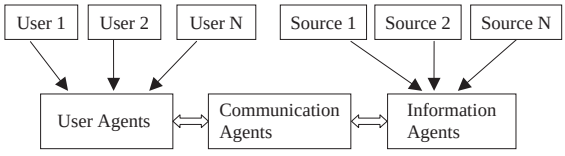

Fig. 1. Multi-agent system framework.

2.1. User agents

In conceptual design phase architectural, physical, structural and engineering knowledge is required. Therefore, there are a number of cross-domain activities where professionals from various disciplines work together. These professionals collaborate on a ‘design space’ where they share information and make alterations on the representations. Multi-agent systems model and support users in coordinating and performing cross-domain activities within the perspective of universal design. This study is concerned with the issue of designing a universal interface for different parties of the architectural design process. The interaction and collaboration of different agents involve the representation of different multi-disciplinary processes (i.e., among designer, civil engineer, etc) and also the interaction between the agents.

The user may be the designer who produces external representations or one who is giving critiques to already drawn sketches. The important issue in using these agents is to build up a knowledge base that is mostly conflict free that can develop at all possible situations and outcomes [11]. The conflicts may arise due to different requirements of the different user agents. Therefore, each user agent should involve three kinds of knowledge; namely, design knowledge, conflict resolution knowledge, and communication knowledge.

2.2. Communication agents

Indexed, retrieved, or applied knowledge is not enough for design processes. Clancey [12] claimed that human knowledge should be viewed as a capacity to coordinate and sequence behavior, to adapt dynamically to changing circumstances due to its ‘situated’ nature. Therefore, knowledge is not a set of descriptions but an analytic abstraction. In the conceptual design phase, there are four stages of the

design process as starting with concrete experience, followed by observations and reflections that lead to formation of abstract concepts and generalizations and testing implications of concepts in new situations through the medium of sketches. This is a circular process in which the activities are repeated until an optimum design solution is found [13,14].

Each communication agent transforms information from one type of mental representation to another and incorporates an image record (sketch) which represents past inputs. First, it defines how information flows between the agents. Second, it defines the form and content of the different types of mental representations handled by each system. The communication agents should store the information as a segmentation scheme considering that a subject solves a problem in terms of an hierarchy of sub-goals.

2.2.1. Segmentation and coding of domain knowledge

The design process has a reflective nature in the sense that the members develop their designs by reflecting on their new ideas and solutions in each step as a result of the critiques. As Schon [15] stated, the design situation is shaped by the designer while creating and modifying design representations and the designer reflects them on the actions and consequences and plans following the actions. Also, the design process has a situated perspective. The members are required to redesign their design project according to a new situation. As Akin [16] said, architects use a greater variety of representations and for a longer period of time during the design process.

In this study, problem and solution spaces as determined by Maher and Tang [17] are found in the segments of design critiques. In an asynchronous design critique process, there are comments, references or questions related to the representation of a design. Thus, the domain space may be related to the design problem (P), design solution (S), or design representation (R).

The domain variables can be based on function (F), behavior (B), or structure (S). This is a formal representation of the process of designing, as Gero [18] stated it as the FBS framework. Functional aspects include layout and functional space or object. The behavioral aspects are related to the use, circulation routes, and obstacles. Construction systems and materials used for the space or object are involved in structural aspects. This study is focused on sketches as mentally manipulated drawing acts and externalized images that emerged from the cognitive actions.

2.2.2. Segmentation and coding of design strategies

As Gero and Mc Neill [19] stated, the critics should analyze a solution, propose a solution or refer to explicit strategies in their comments. ‘Analyze a solution’ (A) has subcategories as justification, rejection of a solution, warning about a missing issue, clarifying a problem about the actual future use. Also, a critique may be related to certain comparisons or references to the previous solutions. It may be questioning a design concept, space or object within the space or representations in the drawings. In ‘proposing a solution’ (P), the critique may provide a new solution, choices of new solutions or leave the solution to the designer. ‘Explicit strategies’ (E) are related to the knowledge of application, requirements of design domain, or design strategies.

The requirements of a design problem can be related to high level (HL) or low level (LL) design activities. HL design requirements include critiques about layout, circulation, dimension given, shape, geometry, construction systems, accessibility issues. LL design requirements include critiques about lighting, material, furniture, signs, and accessories.

2.2.3. Collaboration Web site

In the collaborative design process, knowledge and information can be shared in discussions through a network environment while developing alternative solutions. Collaboration Web site is a shared workspace in which collective efforts are made by team members for navigation through research resources, interaction and exchange of information to discuss and decide on alternative design solutions at the conceptual phase of a design process (see Fig. 2). Web and Internet provide an environment for exchanging ideas and critiques. The interaction of team members in collaborative design environments on the Web enables flexibility in time and place constraints during the design process. The members can collaborate both in synchronous and asynchronous systems, as well as have a chance to share different points of view related to their individual designs [20–22]. The tools for communication can be decided based on the collab-

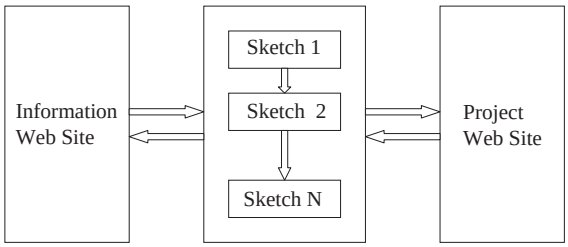

Fig. 2. Communication agents.

orator's profile, design brief, and technological potential [23].

The provided Web site should convert sketches to Drawing Web Format (DWF) to be viewed. A DWF file can be defined as a vector image and an electronic plot that has special viewing properties when displayed in a Web browser window and can be marked up (see Fig. 3, [24]). These drawings form the base for critiques of the team members. These marked up files are saved as a redline file in a local drive. Each sketch has a simple design diary in which modifications made, removed items and/or additions to designs are noted. Every step of the design process for each drawing is archived in the database of the Web site. The completed ones are transferred as an information agent of previous cases.

2.3. Information agents

These agents act as information source representatives or providers. Knowledge can be predefined during the development of an agent but Russell and Norvig [25] argued that knowledge could also be attained during the operation. According to Russell and Norvig the term autonomy stands for the ability of an agent to base its behavior on both its own experience and the built-in knowledge used in constructing the agent for the particular environment in which it operates. The situated behavior of design agents has to be considered among the information agents.

The designer in the knowledge building process finds it easier to refer to specific examples of cases, consisting of his decisions together with rules and facts (such as legislation and codes). Then he can induce rules from those examples. A designer constructs a conceptual model of the built environment by abstracting knowledge from previous experiences and information stored in memory. Knowledge may be the truth or rule of thumb that usually does not change over time, while the latter can be modified according to the designer. There are other major knowledge sources as knowledge available from designers,

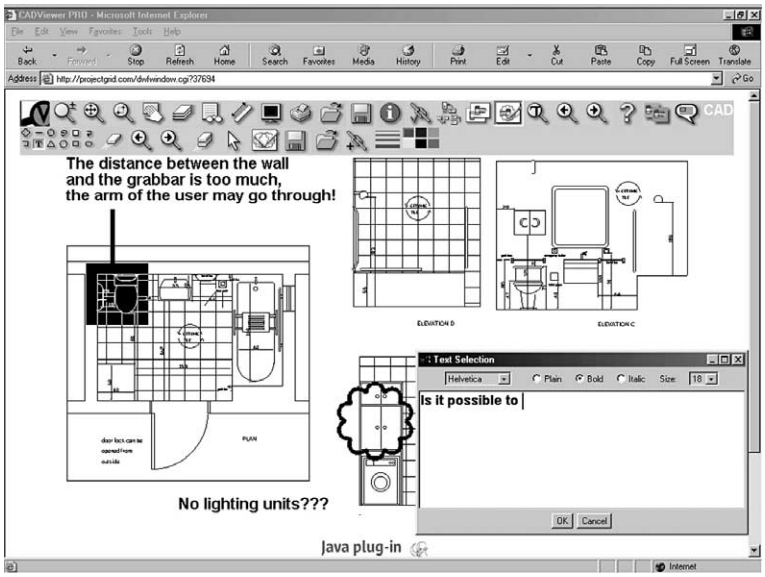

Fig. 3. A screen shot of the Web browser.

experts, and clients or knowledge encoded in books, drawings, codes, journals, and videotapes [6].

3. Architectural design experiment

3.1. Design brief

The design brief for the experiment was the renovation of a residential complex that is composed of a main residence, the guesthouse, and the garden. The small building with an approximate area of 60 m^2 had to be converted into a guesthouse. The larger one that is composed of three sections were to be adapted as the main residence. The grounds are approximately 1500 m^2 in area and covered with trees.

It was required to design the guesthouse considering issues as lighting design, surface treatments/finishes, window treatments, color and material selection, and the design or selection of furniture, upholstery, doors, accessories, etc. The main house and the outdoor areas had to be designed while giving special attention to the conceptual connection of these areas with the guesthouse as well as inside–outside relationships. The house is customized for a family with five members, composed of adults and children. One of the family members has a talent to entertain (playing instrument, dance, cooking, etc.) Accordingly, the design had to be articulated to accommodate such an entertainment activity. The required space components are: entrance hall, living area, dining area, area of entertainment, sleeping quarters, food preparation area, bathrooms, exercise area, laundry/maintenance, and outdoor areas as patio, garden, recreation, walkways, parking, and driving.

3.2. Collaborators and the project site

There were 11 groups of collaborators where participation was on a voluntary basis. Each group was made up of four members consisting of two interior architects, one architect, and one industrial designer. Since it was a renovation project, one interior architect was designated to be the team leader in each group.

ProjectGrid (www.projectgrid.com) was used as the project site for design collaboration with a server built-in Cad Viewer. The information Web site was prepared and a lecture was given to all participants consisting of the basic instructions for collaboration system and use of the system. The information about tools and schedule for collaboration was prepared and distributed to the participants as well as published in the Information Web site. The design project completed in five weeks with feedback obtained through asynchronous critiques provided by the group members. Every step of the design process for each group was archived in the Projectgrid database.

3.3. Data analysis

Critiques of the members stored in redline files were analyzed. Their content related to problem domain and design strategies were discovered. The segmentation method was used to observe and analyze the critiques given during the collaborative study. Each redline file including the comments and critiques of the team members was parsed into small units called ‘segments’ in order to encode the design process. Any comment addressing the same or a new part of the design issue was considered as a new segment. Each segment was analyzed in terms of problem domain and design strategies. Table 1 shows an excerpt from the protocols of a subject in the redline files.

3.4. Assessment of the projects

Two experts assessed and graded the project of each team independently; thus the possibility of affecting each other was eliminated. For the validity

Table 1
An example for the coding of the redline files

Segment	Domain space (P/S/R)	Domain variables (*F*/*B*/*S*)	Micro strategy (A/P/E)	Design activities (HL/LL)
This coffee table doesn’t serve anyone since it is too far from the seating units.	S	*B*	A	HL
Not adequate entrance hall, where am I going to hang my coat?	P	*F*	A	HL
Take the faucet to one of the sides.	S	*F*	P	LL
You should have left 30 cm free space on the latch side of the door.	S	*B*	E	HL

of performance scores, instead of using the assessments of a single person, the raw average scores of two experts were considered. The projects were graded with highest grade 'A' where quality-point equivalent is 4.00 while the lowest grade is 'F' and quality-point equivalent is 0.00. The grading system uses letter grades with pluses and minuses.

3.5. Results

3.5.1. Results related to problem domain

The analysis of data with respect to design space showed that the highest percentage of segments was related to solution space (67.3%). Problem (22.27%) and representation space (10.43%) followed it. Further analysis of problem, solution, and representation spaces with respect to function, behavior, and structure was done. The number of segments belonging to each cell is shown in Table 2. It is found that design variables ($F/B/S$) are not independent of domain space (P/S/R) (χ^2=121.201, df=4, p>0.00).

The correlation between the number of critiques of the three domain variables ($F/B/S$) of solution space was analyzed among the eleven teams. It was found that function and behavior were highly correlated (correlation coefficient=0.834). Multiple regression was used to estimate how well the teams would perform in a design project if they have a certain number of critiques with respect to solution space in terms of design variables ($F/B/S$) (see Table 3). Maher and Simoff [26] stated that the evaluation of the individual participation could identify both the amount and content of their contribution to the project. The regression equation is:

$$\text{Quality} - \text{point} = 2.66 + 0.239\ F + 0.0009\ B - 0.156\ S$$

To answer the following questions: how good is the estimation as a whole; or how much might the success for the teams vary from the predicted; the coefficient of determination (R-sq) which is 71.2%, was considered. This means that the equation explains 71.2% of the variation in the number of segments belonging to F or B or S. The remaining 28.8% is the percentage of variance in success amount that is left unexplained.

Table 3
Data related to $F/B/S$ in the solution space and the quality-point of the teams

Team no.	Quality-point	Solution space		
		Function	Behavior	Structure
1	2.3	1	15	2
2	3.3	3	13	1
3	3.7	4	25	1
4	3.3	6	31	5
5	2.7	3	18	1
6	3.7	4	26	1
7	3.0	5	29	6
8	3.3	7	29	6
9	2.7	2	12	4
10	3.0	2	10	2
11	2.7	1	16	2

3.5.2. Results related to design strategies

When the total number of segments were analyzed according to the design strategies, it was observed that the majority of the critiques are about design analysis (64.3%); where explicit strategies (29.4%) and proposing a solution (6.3%) are following it. As seen in Table 4, each category was analyzed in terms of activities as low or high level. It is found that micro-strategies are not independent of design activities (χ^2=27.973, df=2, p>0.00).

The highest correlation was found between 'analyze a solution' and design activities (correlation coefficient=0.804; 0.865, respectively, for high and low level activities).

Table 2
Contingency table for problem domain

	Function	Behavior	Structure	Total
Problem	60	22	12	94
Solution	38	215	31	284
Representation	1	40	3	44
Total	99	277	46	422

Table 4
Contingency table for design strategies

	Analyze	Propose	Explicit	Total
High level	154	11	37	202
Low level	91	13	75	179
Total	245	24	112	381

3.6. Discussion

The results of the analysis of redline files showed that in the critiques the collaborators refer to solution space more than problem space and representation. The low number of critiques to representations supports the notion that the collaborators did not have difficulty in communicating design through the Internet. The behavioral aspects of the design and design elements were mostly discussed during the design communication to test and criticize the design solutions. As Gero [27] stated, behavior and structure variables are produced in response to various situations encountered by the designer.

It was observed that as the number of critiques increased so did the quality-point of the project. Then, the data was used to find out a relationship between quality-point and domain variables ($F/B/S$) of the solution space. The determined equation explained that 71.2% of the success was based on the number of segments of the domain variables. The remaining percentage was dependent on various other parameters.

Also, the results showed that design strategies and design activities are not independent of each other. 'Analyze a solution' micro-strategy is highly correlated with high and low level design activities. A systematic organization is essential to provide a useful collaborative design environment, so the collaborators can benefit from the advances provided by computer media.

4. Conclusion

This framework provides a new foundation for the development of intelligent agent-based architectural design systems. The integration of concepts from cognitive sciences makes the framework better suited to analyzing design activities. This study proposes a shift from the static view of communication towards one that is based on the dynamic nature of design problems. Sketches that are used as a cognitive tool to interact through the design process are also used as an agent in this framework. Analyzing this kind of medium might propose new forms of interaction between mental imaging and simulation in digital media. Re-inventing the nature of cognitive processes involved in such a medium might support development of conceptual computer-aided softwares.

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