A WEB-BASED AGENT FRAMEWORK FOR COLLABORATIVE DESIGN-BUILD COMMUNICATION

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Abstract. The Internet connects the globe as a whole and at the same time pushes the competition increasing dramatically. Multidiscipline and distributed collaborative design-build in architecture, engineering and construction (A/E/C) companies can gain foster competitive advantage, improved designs, and more effective management of construction facilities. However collaboration can often fail, since it involves different professions who often hold different goals and also one-off organizations also build obstacles to collaboration. This paper presents a web-based agent framework to support communication, to facilitate shared understanding amongst the participants and to inspire teamwork. This paper proposes a multi-agent social interaction framework as the communication model of design-build projects. The conceptual framework emphasizes process-centric learning and the creation of group agreements within design-build collaborative activities, which help facilitate conflict migration. In addition, based upon web agent technology, this communication framework providing an intelligence distribution opportunity for the for the A/C/E industry to introduce a new and innovative paradigm of collaborative design.

1. Introduction

The increasing complexity of construction engineering projects is placing an ever-mounting burden of delivery upon architects. To meet these challenges, many companies involve a large number of professionals in design-build projects to provide a complete product or service (Luiten et al., 1998). Nevertheless, design-build projects face considerable hurdles before a successful or acceptable outcome has been achieved. In a large project, the project organization is highly complex and comprises a number of phases. The diverse and fragmented professional knowledge amongst participants within the project may cause misunderstanding within the design-build process and be an obstacle to communication and successful collaboration

(Kalay, 1999; Peng, 1999). This situation can be exacerbated should the individual professionals or knowledge concerned also be geographically separated (Huang, 1999). In recognition of this an increasing volume of research has focused upon communication issues amongst multi-discipline professionals co-operating in a remote environment. It argues that communication based upon shared understanding integrated by virtual Internet technology is one of the key instruments that is helping to make collaboration amongst multiple disciplines more successful (Stumpf and McDonnell, 2002; Valkenburg and Dorst, 1998).

To this end, researchers have mostly proposed computer-based 3D models or 4D (3D model link with temporal schedule data) related information technologies and have argued that 3D computer models can successfully simplify the complexity of design knowledge. Using visualized information can help support collaborative communication and mitigate the conflict of interest amongst the relevant disciplines, generating shared understanding which then facilitates communication (Clayton et al., 2002; Fukai and Srinivasan, 2001; Rischmoller and Alarcon, 2002).

However, most solutions are data-centric driven rather than process-centric driven. When the 3D information is presented in static and fragmented data form, it still fails to meet integrated needs. For example, if part of the design has to be changed during the detail design phase, the visualized static 3D information cannot evaluate the impact of this change upon the whole design and its influence on the construction process. Therefore, we propose an innovative communication framework, which will integrate the information of design and construction. Stimulating interaction amongst participants is the most applicable communication technique to eliminate these obstacles. Through such engaged interactive environments where people could share information based upon the same understanding of the design problem, this framework can facilitate communication (Shih and Chang, 2002; Valkenburg, 1998).

This paper intends to establish a computer-based communication framework to support multi-discipline collaboration. First, we focus on agent ontology. Refined the agent model proposed by Wooldridge (2002) and constructed a genetic agent model and web-based agent co-operative system and the architecture. . Then, proposed a genetic agent model and a web-based multi-agent system architecture based on agent on case study to analyze the following three aspects: design process, project requirements, and design knowledge or design strategy for verify the validity of the communication framework. Finally a primary discussion, conclusion and future work were followed.

2. Review of Current Collaborative Design-Build Practice

The application of computing systems to A/C/E practice can be traced to at least five decades ago. There were three main paradigms in the early stages of development of architectural CAD. Initially, computers were used to assist in performance simulation and system analysis. The process of designing buildings continued to be carried out manually and utilized computer programs to generate statistics or analysis at validation stages. The results were then applied manually to the evolving design (Mitchell, 1977). Secondly, the research in CAD shifted from analysis programs to computational representation of buildings. Serven Coons and Ivan Sutherland developed the first interactive 2D and 3D design tool. Their efforts simplified the input of design artifacts into analysis programs, and opened the floodgate for the development of CAD programs (Kalay, 1999). Lastly, beyond the design performance analysis and visual simulation, researchers resumed their quest for more powerful design communication tools, which could represent non-geometric building information. At this stage, CAD research was strongly influenced by general information technology and as a result various types of Expert Systems were gradually introduced (Carrara et al., 1994; Coyne et al., 1990; Flemming, 1994). Few of these systems survived their expectations, since the limitations of the design knowledge within the Expert System meant that it could only be used by the experts themselves (Shaviv et al., 1996).

These systems, as a design management tools, all made a great contribution to each respective paradigm. However, they seemed to fail as collaboration tools; they facilitated the exchanging of design information at the data level but crucially not the sharing of understanding amongst collaborators at the semantic level.

2.1. COLLABORATION NEEDS A SHARED UNDERSTANDING

The complexity and fragmental knowledge of the construction industry is increasing rapidly since the typical modern construction process has to involve many disciplines working as a team in a limited time frame. Team members work in separate domains and employ specialist knowledge required by construction projects. Therefore, by combining their abilities in a particular process, a collaborative arrangement is the key for team members to co-ordinate the larger objectives of the project.

At the same time, collaboration can also be a negative force, when individual action, that is in the best interest of a specific project goal, might not be suited for the goals with other collaborators(Kalay, 1999). Teams may benefit from improved understanding of the relationships and issues associated with group work, and team development. In brief, teams that seek to improve their performance can do so by fostering team identity and helping different disciplines to collaborate together with shared understanding (Busseri and Palmer, 2000; Valkenburg, 1998).

2.2. REFLECTIVE DESIGN PROCESS FORM A SITUATED COMMUNICATION

Most complex design-build problems can be easily deconstructed into a sequence of activities, and then sub-activities. Therefore, most construction planning or simulation techniques are based on data-centric technology for purpose of product modeling the construction process. However, many independent but small groups are critical components of the construction team. Each group will join forces with other groups to accomplish a specific and relatively short-term project. And unlike product manufacture, which has a standard production system, the design-build process is variable phenomena dependent upon the reliability of resources and the stability of the working environment. As a result, operations change dramatically and rapidly along with different situations.

'Situatedness' influences the thoughts and actions of a designer (Gero, 1998). In an efficient collaborative design process a form of shared understanding among participants is required. The designer must be able to "understand" their co-worker's design content. This understanding can serve as the basic concept of collaboration for the individual designer.

Excepting the above, there still are many different ways of perceiving a design problem. Reasoning from different viewpoints is a necessary part of most design processes as is illustrated by the reflective design model proposed by Schön (1983). We may use the see-moving-see cycle as an example. A designer who participates in teamwork perceives other designer's work from different viewpoints and tests whether their conclusions conflict with the current solution for the next step of the cycle, as well as, reviewing his own design and making the next stage of work. Therefore, reflective interaction among participants can form a situated communication that will provide high collaborative efficacy (Valkenburg and Dorst, 1998).

2.3. MULTIAGENT SYSTEM

Research in multi-agent systems currently runs alongside mainstream AI development. However, there still are many different notions of an agent, which have been proposed. One notion of agents, which distinguish between a weak and a strong agency has been proposed by Wooldridge and Jennings (Wooldridge, 2002). The characteristics of weak agency provide a means to reflect on the tasks an agent needs to be able to perform. The ability to communicate and co-operate with other agents and to interact with the material world often relies on an agent's ability to interact with the material world and on an agent's ability to acquire and maintain its own knowledge of the world and other agents.

The agent metaphor offers a means to model situations with collaborative activity on a conceptual level. Some research has combined the research areas of engineering design and multi-agent systems. For example, Campbell et al. (1998) present a theory of engineering design adapting a system of interacting software agents. They propose configuration agents to create conceptual design; instantiation agents fill in actual components from a design repository; Fragment agents and subsystem agents play an evaluation role; and lastly, manager agents maintain these four type of agents and the synthesis of the result.

McAlinden et al. (1998) show how design agents can be integrated to facilitate information and knowledge sharing. In their research, a central product model of STEP is used and they apply the STEP standard into agent knowledge exchange language, named ACL, to propagate the agent's knowledge. Their aim is to incorporate existing and legacy systems without causing delays in a design project.

In proportion to the A/E/C research areas, there has been little research that has focused on combined reflective design process with agents.

3. Web-based agent framework as a communication guide line to facilitate co-operative communication

3.1 GENERIC DESIGN AGENT MODEL

The generic design agent model illustrated was based on the horizontally layered agent architecture proposed by Wooldridge (2002). In this model the design problem provided by the client was expressed as an initial process objective and a set of initial requirements. Requirements impose conditions and restrictions on the site environment, building service functionality and perception of the design.

Figure 1 shows the composition of the processes distinguished within the component design and the types of input and output subsystem connected with environment of the web-agent system. The middle segment design process is shown to be composed of three horizontal layers: design process-remodeling layer, requirement set evaluation layer, design goal reactive layer. The design process-remodeling layer rearranges the design process by issuing information related to the current design objectives. The requirement set evaluation layer manipulates sets of requirements, on the basis of the overall design strategy, information from Requirement set, and other design object descriptions. The design goal reactive layer modifies the current design outcome by the inference results from the two design process-remodeling and design goal reactive layers.

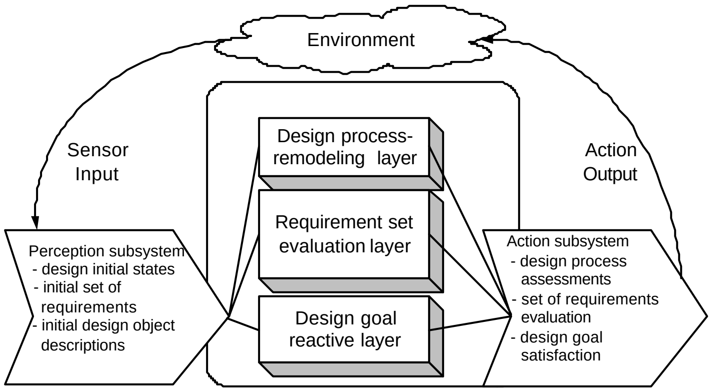

Figure 1. Genetic agent model

3.2 WEB-BASED AGENT FRAMEWORK FOR COLLABORATIVE DESIGN

A Web-based distributed computational environment provides a new possibility to form a virtual organization of the construction industry. Through basic Internet communication technologies such as email, ftp or net video/audio conference, team members can collaborate as a single organization virtually without geographic limitation and different time zone barrier. However, these technologies are all loose structured data-centric propagated approach on the Internet. In order to fulfill the needs in terms of reflective design process described above, more sophisticated technology will be needed to establish a virtual environment interactive communication system for the collaboration of problems with the distributed design.

As a result, in this section we proposed a web-based agent co-operative system, the architecture of which can been the system in Figure 2. In the construction of this system we employing use of concurrent *web-service* technology.

The system consists of three service components. The first of which is the human-computer interface service, which provides three sub-services including content portal, data and project management interface services. Secondly the design agent service provides general design problem description, definition for design situation elements, role definition. It can serve as a model connector repository, and function as a coordination/negotiation channel and general scenario builder service. The final service component is design data and the knowledge repository service. In this service, the project manager can be monitoring the project process, updating the progress by the term memory agent to reflect concurrent situation of the project. This repository will aggregate abundant design process-based knowledge ever increasing its depth and complexity further presenting itself as an increasingly valuable tool in future research.

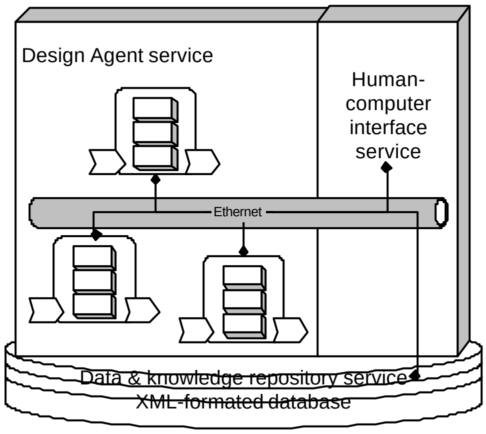

Figure 2. Web-based Multi-agent system framework

4. Case study of a design agent in a distributed collaborative design process

4.1 DESIGN INITIAL STATE

This paper was based on a parking area allocation design project in the Da-keng nature scenic area of Taiwan. The case study has been chosen because it can be used to illustrate the types of reflective reasoning required by design agents involved a distributed collaborative design process. This project entailed a distributed design process, where several participants needed to interact with each other. The design took place in the domain of nature park renew design.

The target site was allocated in an ecological recreation area (shown as figure 3). This area was a branch of the Da-Tun mountain chain. It is the biggest mountain recreation area and also is the most important ecological education zone around Taichung city (shown as figure 4, gray spot illustrate the ecological habitat and gray line illustrate the foraging rote of wild animals). It services the central Taiwan and near to 3 million people.

The project challenge can be briefly summarized to three major points. First of all, the ecological issue: how do we to preserve the ecological balance whist also successfully allocating and integrating a park area, which will service increasing tourism at the same time. These requirements are not only proposed by the client but are legal requirements. Secondly, architectural issues: how can we make the park area fit in with the natural mountain environment whilst also developing parking functions is the major trade-off problem of architectural designers. Lastly, the construction issue: the mountain area makes it logistically difficult to reach mobilize resources. This issue can also be regarded as the major factor of the total cost.

To meet this challenge, a number of designs of different domains are needed: A project manager, a scenic architect, a biologist and a construction engineer.

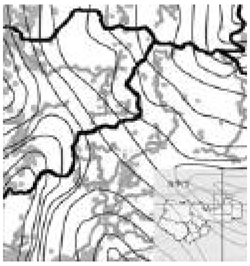

Figure3. A nature park site with contour map and main road

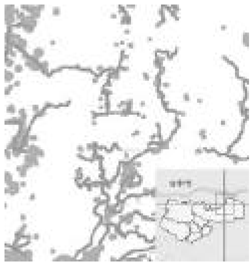

Figure4. Habitat spot and foraging route

4.2 REQUIREMENTS ACQUISITION

Once an interview was concluded with the team members, the he design project requirements were summarized as below.

- The site should be kept within 10 to 30 meters of the main road.
- As a parking lot, the slop of the land should not greater than 5%.
- The minimum area should provide not less than 100 cars and 20 buses.
- The maximum area should provide not more than 200 cars and 50 buses.
- An information and service center should be considered.

Early in the project the architect made a quick assessment and proposed two candidate designs. The dominant methodology of his profession guided the architect to scrutinize only those aspects of scrutiny that fell within his recognized area (the service of parking) rather than other areas, which were out of his professional field of expertise. He thereby failed, for example, to gain from understanding how a biologist would have perceived the problem and how he would have had to make necessary changes to his proposal..

Using the Web-based agent framework as a communication guideline a more mature result was acquired. For example:

- Biological aspects:
  - The parking lot area should not be within 20 meters of habitat spots.
  - The parking lot area should not be within 10 meters of foraging routes.
- Architectural aspects:
  - Considering the information center we need to take account of the availability of the facilities, electric power and water resources for example.
- Constructional aspects:
  - Considering the drainage, the material of the floor should be break rather than concert.

4.3 DESIGN GOAL REACTION

Based on reflective reasoning, each designer made his or her own submission to the concurrent result and prepared for the next cycle. The project manager played an important role at this stage. A final design decision needed to be made to meet the project time constraints.

5. Discussion, conclusion and future work

This paper presents the process-centric and reflective design process communication framework for design-build collaboration. The situated communication model provides an interactive approach to compose the script of human participants, which becomes a situated plan structure of the design-build project. A valid communication model can be formed through a process of collaborative composing in comparison to top-down planning/programming approaches. In addition, conflict can be mitigated after through successful coordination/negotiation processes. The script also can be a guideline when the project is operating, updating the communication model from the real case study feedback and refining the scenario to fit to the real world directly.

A case study has been presented to demonstrate the situated communication model for design-build projects. The findings of the case can be refined in relation to greater assessment feedback. From the brief description above, we can see that the agent communication model can help facilitate the collaborative design process.

In the case, we started from a description of the initial design state to reveal the primary project process models and then determine the subsequence of each participant. Furthermore, we identified a set of properties of the requirement through the reflective design process, in order to clarify the requirements and the dependency of the role in the project. Team members not only benefited from their own design knowledge, but also got stimulation from different viewpoints expressed through reflective communication. In summary, the situated communication model presented in this paper can mitigate communication conflicts and increase the efficiency of the collaboration.

A preliminary genetic agent model of web-based agent communication system architecture has been proposed. In this system architecture, we use the concurrent web service technology to facilitate role interaction through the Internet. A further study works will be essential for the implementation of the genetic agent model and the web-based multi-agent system.

In this study, we are not intending to propose another smart information-retrieval system for the A/E/C industry. Beyond that, we are trying to reveal a new direction for the design-build service system. This system integrates data-services, communication services and human-computer interface services as an integrated design-build management service system. As an ongoing research project, the situated communication model presented in this paper is at the core of the construction management service, a first step and fundamental to the further development of an integrated service system.

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References

Busseri, M.A. & Palmer, J.M.: 2000, Improving teamwork: the effect of self-assessment on construction design teams, *Design Studies*, **21**, pp. 223 - 238.

Campbell, M.I. et al.: 1998, A-Design: theory and implementation of an adaptive, agent-based method of conceptual design, In: J.S. Gero and F. Sudweeks (ed.), *Artificial intelligence in design'98 (AID'98)*, Kluwer Academic Publisher, Dordrecht, pp. 579 - 598.

Carrara, G. et al.: 1994, Knowledge-based computational support for architectural design, *Automation in Construction*, **3**(2,3), pp. 123 - 142.

Clayton, M.J. et al.: 2002, Virtual construction of architecture using 3D CAD and simulation, *Automation in Construction*, **11**, pp. 227 -235.

Coyne, R. et al.: 1990, Knowledge-based design system, Addison-Wesley, Reading MA.

Flemming, U.: 1994, Case-based design in the SEED system, *Automation in Construction*, **3**(2,3), pp. 123 - 133.

Fukai, D. & Srinivasan, R.: 2001, PCIS Revisited: A Visual Database for Design and Construction, In: W. Jabi (ed.), *Proceedings of ACADIA'01*, Gallagher printing, Buffalo, New York, Oct. 01, pp. 372 - 379.

Gero, J.S.: 1998, Conceptual designing as a sequence of situated acts, In: I. Smith (ed.), *Artificial intelligence in structural engineering*, Springer, Berlin,

Huang, J.: 1999, How do distributed design organizations act together to create a meaningful design?, In: B.d. Vries, J.P.v. Leeuwen and H.H. Achten (ed.), *Proceedings of the CAADFutures 2001*, The Netherlands, Eindhoven, pp. 99 - 115.

Kalay, Y.E.: 1999, The future of CAAD: From computer-aided design to Computer-aided collaboration, In: G. Augenbore and C. Eastman (ed.), *Proceedings of the CAADFutures'99*, Kluwer Academic, Atlanta, Georgia, USA, pp. 13 -30.

Luiten, G.T. et al.: 1998, Project-modelling in AEC to integrate design and construction, *Computers in Industry*, **35**, pp. 13 - 29.

McAlinden, L.P. et al.: 1998, Information and knowledge sharing for distributed design agents, In: J.S. Gero and F. Sudweeks (ed.), *Artificial intelligence in design'98 (AID'98)*, Kluwer Academic Publisher, Dordrecht, pp. 537 - 556.

Mitchell, W.J.: 1977, Computer-aided architectural design, Van Nostrand Reinhold, New York.

Peng, C.: 1999, Flexible generic frameworks and multidisciplinary synthesis of built form, *Design Studies*, **20**, pp. 537 - 551.

Rischmoller, L. & Alarcon, L.F.: 2002, 4D-PS: Putting an IT new work process into effect, In: C. Aarhus (ed.), *CIB W78 International Conference - Distributing Knowledge in Building*, Denmark, pp. 1 - 6.

Schon, D.A.: 1983, The Reflective Practitioner: How Professionals Think in Action, Basic Books, New York.

Shaviv, E. et al.: 1996, Simulation and knowledge-based computer-aided architectural design (CAAD) system for passive and low energy architecture, *Energy and Buildings*, **23**, pp. 257 - 269.

Shih, S.C. & Chang, T.W.: 2002, Web-based Situated Communication Model for Construction Management, In: Z. Turk (ed.), *Proceedings of the ECPPM 2002*, Poetoroz, Slovenia, pp. (to appear).

Stumpf, S.C. & McDonnell, J.T.: 2002, Talking about team framing: using argumentation to analyse and support experiential learning in early design episodes, *Design Studies*, **23**(1), pp. 5 - 23.

Valkenburg, R. & Dorst, K.: 1998, The reflective practice of design teams, *Design Studies*, **19**(3), pp. 249 - 271.

Valkenburg, R.C.: 1998, Shared understanding as a condition for team design, *Automation in Construction*, **7**, pp. 111 - 121.

Wooldridge, M.: 2002, An Introduction to Multiagent Systems, John Wiley & Sons Ltd, Chichester, England.