INTEROPERABLE CO-DESIGN SYSTEM

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Abstract. Project Alliances is a new alternative to A/E/C traditional project delivery systems, especially in the commercial building sector. The interoperable model of Co-design process and systems characteristics that is required to reduce the adversarial nature of most construction projects. Interoperable Co-Design System was just used successfully to complete the Si-soft Research Center of Taiwan. This project-alliancing project was analyzed as a case study to evaluate the validity of the system. Three key paradigms of the Co-Design were reviewed and numerous examples from the management of this project were cited that support the theoretical recommendations of this model. It was concluded that the system use wild client/server network architecture embedded with peer-to-peer agent technology to provide an open, familiar and easily extended co-design system.

1. Introduction

The Architecture, Engineering and Construction (AEC) industry has a rich history of collaboration. There is an increasing trend in Taiwan to push all construction stakeholders—owners, contractors, designers, subcontractors, suppliers, and end users—to develop alternative project delivery systems that encourage higher levels of collaboration throughout the life cycle of a project The impact of misunderstanding and confrontation among construction stakeholders over the last several decades has generated management practices that inhibit industry productivity and discourage the discovery of optimal solutions to design and construction problems. Traditional design-bid-build approaches to the completion of projects have created discrimination among project team members, who have focused too narrowly on their respective contexts of involvement and have often not involved different expertise. This is in contrast to collaborative development, which improves productivity, enhances design intent, accelerates delivery time, increases quality and generally provides more value to the capital investment made by owner. These now more apparent advantages of collaboration are the main influences accelerating the integration of multiple professions into collaborative teams.

Nevertheless, allied project works face considerable hurdles before a successful or acceptable outcome can been achieved. In a large project, the project organization is highly complex and comprises a number of phases. 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 collaborative design issues amongst multi-discipline professionals co-operating in remote environments. It argues that interoperation, based upon computer supported collaborative work (CSCW), will make the AEC industry more efficient (Chiu 1997). Integration of design ideas and development by virtual Internet technology is one of the key instruments that is helping to make collaboration amongst multiple distance disciplines more successful (Rojas and Songer 1999; Stumpf and McDonnell 2002; Valkenburg and Dorst 1998). One criticism of CSCW is that it tends to prioritize the modes and performance of delivering design data and/or graphically representing the product and seems to disregard the importance and impact of interaction among the collaborators.

This paper will briefly review three main paradigms of CSCW relative works since 1962 as well as provide a web-agent based interoperable co-design framework. It will then illustrate how the Si-soft Research Center space renew project acts as an appropriate and relevant case study of shared repository, design representation and intelligent design reasoning. Finally, some benefits/limitations of the framework and future works will be considered..

2. Three paradigms for Co-design System

The earliest study of CSCW can be traced back to the 1960s. Engelbart (1962) proposed a conceptual framework to describe how computers can help a team solve problems in efficient ways. He also outlined some of the disciplines, including design, which might benefit from technology augmentation. Steven Coons first addressed the need for a computer-aided design system that enables synchronous interaction with multiple users (Coons 1963). After these two pioneering researches, numerous experiments served to further clarify the benefits of the CSCW as applied to three main paradigms named; design information sharing repository, design geographically archive representation and intelligent design reasoning.

2.1. TEXT-BASED DESIGN INFORMATION SHARING REPOSITORY SYSTEM

The text-based design information sharing repository system mainly utilizes a common data format to exchange design information and to facilitate communication amongst the team members. Most systems have focused on delivering shareable product models and databases to publish their design works (Kim et al. 1997). Product models particularly emphasize solving issues such as data accessing rights, data concurrency and data-integrity (Eastman 1999; Sun and Lockley 1997). This development has been carried out based upon the argument that some computer programs will access all of the data without error and can be processed and interpreted by human experts with their own knowledge (Khedro et al. 1993).

However, owing to social and professional contingencies, these models could fail the CSCW system in three areas. First of all, misunderstanding could arise between interdisciplinary team members whom seldom derive the same understand from information without recourse to further interaction or communication (Kalay 1999; Valkenburg 1998).

Secondly, customization amongst participants may lead to a participant feeling that a system is demanding a particular method to be followed, in perceived conflict to his or her own preferred methodology resulting in the user rejecting the system and subsequently allowing it to fail. This is the main obstacle to the successful utilization of a co-design system.

Lastly, the increasing complexity of co-design knowledge may lead to a situation of data overload. All CSCW systems are intended to provide maximum information to all participants. Accordingly, data overload side effects will follow. The Internet provides a clear demonstration of the potential debilitating effect of information overload on decision-making processes. In addition, there are also a too limited number of papers that emphasize design information filtering (Haymaker et al. 2000).

2.2. VISUAL DESIGN ARCHIVES REPRESENTATION SYSTEM

Computer Aided Architectural Design (CAAD) Systems (Clayton et al. 2002; Fukai and Srinivasan 2001), construction product visualization systems (Coyne et al. 2001; Mckinney and Fischer 1998), construction process online monitoring systems (Ruffle and Richens 2001), virtual reality support design systems (Whyte et al. 2000) and design-build process simulation systems (Clayton et al. 2002; Craig and Zimring 2002; Hong et al. 2001) all focus on presentation or simulation of design knowledge in visual way.

The authors above state that the visual information contained in these systems can confidently deliver intuitive understanding of design knowledge and can be represented by hyper-graphic links to underlying design and construction information. It also can be utilized to access archived resources; support design development, analyze and resolve pre-construction conflicts and coordinate construction activities. In addition, the information is gathered and stored according to its geo-specific relationships and visually indexed by the data environment rather than through a hierarchical and abstract data structure.

However, these visually-oriented systems may involve a lot of different data formats such as CAD files (DNG, 3DS, FMZ…), Image files (BMP, JPG, PNG…), VR archives (WRL, VMO, SWF…), and Video (MPG, AVI, MOV,…). Unfortunately, without a dominating format, such multi-media information, fragmented data which does not share similar structures throughout the entire system, often increases complexity. An example would be the need to convert information to different formats for use by different professions.

2.3. AGENT-ORIENTED DESIGN SUPPORTED SYSTEM

Since 1950, design has been one of the main uses of Artificial Intelligence (AI). After that, a paradigm shift took place in the sciences and humanities and has gathered pace in the 2000's. From the 1980's onwards, user-centered and participatory design has become a widely accepted and utilized model of development. Presently, a new interesting model of AI is emerging. These models are based on new principles, such as 'situatedness', 'embodiment, emotion' and 'social interaction' (Lenart and Pasztor 2002).

Research in agent/multi-agent engineering currently runs alongside mainstream AI development reflecting changes in social paradigms. According to an agent-based engineering study, still in its early stage, there are many different notions of an agent that have been proposed. One notion of agents, which distinguish between weak and strong agency has been proposed by Wooldridge and Jennings (Wooldridge 2002). The defining characteristic of weak agency is that it provides a means to reflect on the tasks an agent needs to be able to perform automatically or semi-automatically. The ability to communicate and inter-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 maintain and co-update its own knowledge of the world with other agents.

The agent metaphor offers a means to model situations involving 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) presented a theory of engineering design adapting a system of interacting software agents. They proposed the use of configuration agents to create conceptual designs, instantiation agents to fill in actual components from a design repository, fragment agents and subsystem agents to play an evaluative role and lastly, manager agents to 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, in order to facilitate propagation of the agent's knowledge. Their studies provide a good demonstration of an agent-based co-design system in automatic/semi-automatic collaboration in a situation of distributed computation and situatedness. This was in effect the essence of interoperation. Despite this, it would seem that the agent-based system has merely formed another new closed network environment subject to it's own inherent limitations.

3. Framework of Interoperable Co-Design System

3.1. WEB-BASED AGENT FRAMEWORK

The World Wide Web is used to an ever-greater extent for application-to-user as well as application-to-application communication. A web-based distributed computational environment provides new facilities to form a virtual organization of the A/E/C industry. Through ubiquitous 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 in spite of barriers such as working in different time zones.

In accordance with the review we described above, these technologies are too loosely structured as communication tools for our needs in terms of a reflexive inter-cooperative process. More sophisticated technology will be needed to establish a virtual environment that will support an interactive communication system for dealing with construction management problems.

As a result, in this section, we will propose an open web service framework that supports cooperative activity in the field of A/E/C. The Interoperable Co-Design (IoCD) System is a duel network service system that combines two concurrent mainstream network service paradigms, client/server and peer-to-peer networking, shown as figure 1.

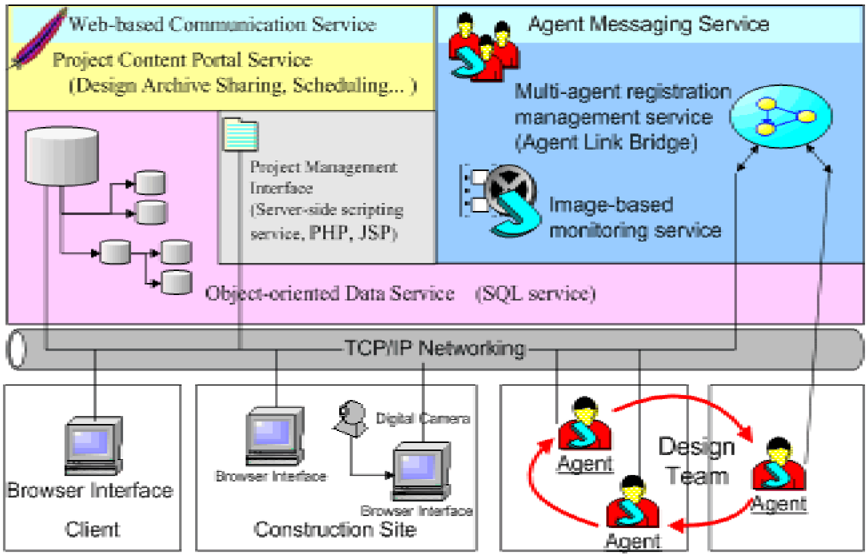

Figure 1. Duel-Network Service Framework.

3.2. IMPLEMENTATION

The system consists of two different kinds of service components. The first is a web-based communication service following the Client/Server model. It is also a dynamic Object Oriented (OO) based open-architecture portal script, written in PHP. Before this paper was submitted, five major modules were completed to support the co-design project. These are 1) a user privilege module, 2) a meeting scheduling module, 3) a group discussion module, 4) an events tracing module and 5) a design archive repository. These all provide a convenient web service interface that participants can use without installing additional software but rather, can access directly through a normal web browser.

The second is the agent messaging service, which extends from the Web-based situated communication model proposed by Shih (Shih 2003; Shih and Chang 2002). Two sub-services, including ‘Second’, which is a role-play service, provide a general script repository, a role definition repository, a model connector repository, a coordination/negotiation channel and script builder services. Last is a service, which allows full interaction with the project. In this service, the project manager can monitor the project process, update progress reported by field managers to reflect the concurrent situation of the project or use an emergent agent technology to evaluate the project performance automatically.

4. Case Study

4.1. BRIEFLY DESCRIPTION OF THE CASE.

- Project name: Si-Soft research center construction renew project
- Site location: HSIN-CHU Science Park, Taiwan
- Site area: 80,000 m^2
- Original usage of the site: CRT manufacture
- Objective of Project: Change the entire site (and form of usage) from a CRT manufactory into an IC design house (office) building.
- Professions involved: 1) Architect, 2) Civil Engineer, 3) Structural Engineer, 4) Interior Designer, 5) Electrical Engineer, 6) Fire control Engineer and 7) Building materials provider. (They are my team members for in the co-design process).
- The main challenges in order of priority are: 1) time constraints 2) complexity: there are 7 professions, more than 18 types of work and around 250 workers working together everyday. In this case, extensive and open communication is a priority condition of participation for everyone. However, face-to-face meetings fail the job in two ways; it is time consuming and geographical barrier prevent it. In addition, the meeting itself cannot often resolve all the issues that need to be discussed. This paper is derived from the need to find a computational way to reduce the need for face-to-face discussion but still maintain communication and, at the same time, enabling the project manager to maintain control of concurrent developments on site.

4.2. PRIVIOUS WORKS PROBLEM REFLECTION

Reflections on the problems revealed in the review section (2.1 to 2.3) of this paper. There is 1) misunderstanding; 2) customization of work tasks and information; 3) data overload; 4) non-unified information formats and fragmented visual data; 5) open agent-based systems.

1. Misunderstanding: face-to-face meetings can almost deal with any kind of misunderstanding. To reiterate, there are many limitations to the method of holding meetings every few minutes. This paper describes the use of a ‘wild open’ communication system which supports ‘virtual’ meetings instead of face-to-face talks. For example, five modules have been completed, which are described in section 3.2.
2. Customization: This system is a dynamic object oriented based architecture portal script written in PHP. It is easy for the user to model the system in accordance with their different requirements. For example, the home module can be changed as frequently as the job to make it reflexive and efficient.

3. Data overload: We save every thing into an easily recalled database and catalog results in a reasonable way to facilitate the of re-use them.
4. Non-unified formats: Using an image-based monitoring system instead of streaming video serves as a precise example. On the server side, that we physically place the web-cams to provide a full spectrum view of the construction site. Then each web-cam is programmed to take still images and save them to the server. On the client side we provide a construction monitor agent (robot) that continuously retrieves the server image through the agent messenger service (agent link bridge). This is a physically undemanding (on the server) and robust lightweight image-based monitoring system.

   The benefits we have received from use of this system have been:

   4.1) Low cost: The web-cam server can be any P.C. with an Internet link and does not require any server side programs to be installed making it low cost and easy to operate.

   4.2) Lightweight: the client side agent program could possibly run on a cell phone acting as a computation application. This means information can be easily distributed to a parties which require it.

   4.3) Easy computation: When we need detect changes in the remote site, (construction sites can be typified by rapid progress and change), we just need to set up the start and stop date time of the image capturing program and then compute the gray scale differences of any concurrent images through their associated pixels. Counting the proportion of the image that has been changed significantly will indicate pace and progress of changes in the construction process.

   4.4) intelligent agent: Following section 4.3, we add some heuristic rules into the agent knowledge base after which the agent can act as a construction risk detector.

   4.5) Access privilege: Any agent communication tasks need an agent messaging service to help find the target agent addresses. The agent messenger is the gateway and also the firewall of the agent communication channel.
5. Open agent-based system: Currently, only a few research groups (Aunmba et al. 2002; Bandini et al. 2002; Campbell et al. 1998; Maes 1994) are working on various fine-grained spatial models, simulating the interaction of individual actors across different professions. These still fail to satisfy requirements since they all eventually establish a new closed system. The user has to be forced to learn to use a new tool before he or she can overcome problems associated with the new technology. In our case, the agent messaging service is embedded in the web site and not openly utilized by the user. There is no new program or interface to be learnt – the service runs invisibly behind ‘traditionally’ structured web

pages. For details please refer to the paper proposed by Shih (Shih 2003; Shih and Chang 2002).

5. Conclusion

Through a review of previous of computer supported cooperative work and design an IoCD system framework and implementation has been proposed. This paper demonstrates a unified and integrated approach to modeling the system and uses real project experiences as proof that the IoCD system can facilitate communication amongst team members in a truly interoperable co-design process. In addition, participants can communicate through the IoCD system instead of to holding face-to-face time-consuming meetings. It boasts a customizable user interface through dynamic object-oriented technology, the efficient organization of mass data by object-oriented database management and unification of visual information formats by an agent-driven service in low-cost, lightweight, user friendly manner. It has highly intelligent capabilities and provides high levels of privileged access. Lastly, we use wild client/server network architecture embedded with peer-to-peer agent technology to provide an open, familiar and easily extended co-design system.

The IoCD system presents a new exciting challenge to the development of communication models and systems for co-operation in design –build projects. It challenges conventional paradigms that place too heavy an emphasis upon technology without considering the effects of the introduction of that technology upon it's potential users – people, from different professional backgrounds and with different experiences and prior use of technology. Potentially, the IoCD system, could be used as a communication and development model for a very wide range of applications, not just within the construction industry. Any group of professionals carrying out a project where the individuals involved are geographically dispersed can potentially co-operate far more efficiently towards a mutually acceptable outcome, providing value for investment, both in time, expertise and materials. Examples might be interior design, cultural projects such as movies and artistic events and the staging of large international events such as the Olympics and other sports events that require large infrastructure modifications or development. The simplicity of the IoCD system means that it would not require a vast technical staff to set up and operate and significantly reduce the time required to train staff in it's use. New mobile phone technology such as 3G or 4G will make the system even more mobile and reflexive. Certainly, the IoCD system has the potential to replace much redundant technology such as conferencing equipment, which have in the past have been susceptible to high costs, frequent maintenance and less than reliable performance in addition to requiring much fixed equipment that ultimately reduces it's advantage, especially when applied to multiple and especially external environments.

References

Aunmba, C.J. et al.: 2002, Collaborative design of structures using intelligent agents, *Automation in Construction*, 11, pp. 89 - 103.

Bandini, S. et al.: 2002, Dealing with Space in Multi-Agent Systems: a model for Situated MAS, *AAMAS 2002 First International Joint Conference on Autonomous Agents and Multi-Agent Systems*, Bologna, Italy, pp. 1183 - 1190.

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),* Dordrecht, pp. 579 - 598.

Chiu, M.L.: 1997, The Design Guidance of CSCW: Learning from Collaborative Design Studios, *in* Y.T. Liu et al. (ed.), *the Proceedings of CAADRIA'97 conference,* Hsinchu, Taiwan, pp. 261 - 270.

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

Coons, S.: 1963, An Outline of the Requirements for a Computer-Aided Design

System, *Proceedings of the 1963 Spring Joint Computer Conference,* Baltimore, pp. 299-304.

Coyne, R. et al.: 2001, Applying web-based product libraries, *Automation in Construction*, 10, pp. 549 - 559.

Craig, D.L. & Zimring, C.: 2002, Support for collaborative design reasoning in shared virtual spaces, *Automation in Construction*, 11(2), pp. 249 - 259.

Eastman, C.M.: 1999, Building Product Models: Computer Environments Supporting Design and Construction, Boca Raton, Fla. CRC Press.

Engelbart, D.: 1962, Augmenting Human Intellect: A Conceptual Framework, *SRI Project Numbre 3578, Menlo Park: Stanford Research Institute,*

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

Haymaker, J. et al.: 2000, Filter mediated design: generating coherence in collaborative design, *Design Studies*, 21(2), pp. 205 - 220.

Hong, Z. et al.: 2001, Visual modeling and simulation for construction operations, *Automation in Construction*, 11, pp. 47 - 57.

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,* 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,* Atlanta, Georgia, USA, pp. 13 -30.

Khedro, T. et al.: 1993, FCDA: a framework for collaborative distributed multidisciplinary design, *in* Gero and Maher (ed.), *AI in Collaborative Design,* Menlo Park, CA., pp. 67 - 82.

Kim, I. et al.: 1997, Managing design data in an integrated CAAD environment: a product model approach, *Automation in Construction*, 7(1), pp. 35 - 53.

Lenart, M. & Pasztor, A.: 2002, Constructing Design Worlds - Changing paradigms, *in* J. Gero (ed.), *Artificial Intelligence in Design'02,* Dordrecht, pp. 65 - 88.

Maes, P.: 1994, Agents that Reduce Work and Information Overload, *COMMUNICATIONS OF THE ACM*, 37(7), pp. 31 - 40.

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)*, Dordrecht, pp. 537 - 556.

Mckinney, K. & Fischer, M.: 1998, Generating, evaluating and visualizing construction schedules with CAD tools, *Automation in Construction*, **7**, pp. 433 - 447.

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

Rojas, E.M. & Songer, A.D.: 1999, Web-centric systems: a new paradigm for collaborative engineering, *Journal of Management in Engineering,* pp. 39-45.

Ruffle, S. & Richens, P.: 2001, Web Based Construction for Cambridge University's Building Program, *in* W. Jabi (ed.), *The Twenty First Annual Conference of the Association for Computer-Aided Design in Architecture,* Buffalo, New York, pp. 366 - 371.

Shih, S.-C.: 2003, A WEB-BASED AGENT FRAMEWORK FOR COLLABORATIVE DESIGN-BUILD COMMUNICATION, *The 8th Conference on Computer Aided Architectural Design Research in Asia (CAADRIA2003),* Patumtani, Thailand, pp. 55 - 65.

Shih, S.-C. & Chang, T.W.: 2002, Web-based Situated Communication Model for Construction Management, *in* Z. Turk (ed.), *Proceedings of the European Conference of Product and Process Modeling (ECPPM 2002),* Poetoroz, Slovenia, pp. 523 - 528.

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.

Sun, M. & Lockley, S.R.: 1997, Data exchange system for an integrated building design system, *Automation in Construction,* 6(2), pp. 147 - 155.

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.

Whyte, J. et al.: 2000, From CAD to virtual reality: modelling approaches, data exchange and interactive 3D building design tools, *Automation in Construction,* 10, pp. 42 - 55.

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