Sustainable Solutions in Structural Engineering and Construction
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COLLABORATIVE ENGINEERING FOR SUSTAINABLE SOLUTIONS ASSISTED BY VIRTUAL CONSTRUCTION

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The paper outlines a decision-support environment that actively supports collaboration during decision making and problem solving. A complementary partnership was formed between computer agents and human agents; one brought selected intelligence to the solution process from "unlimited" multi-domain knowledge sources, the other brought human cognitive rationality. In particular, the proposed system articulated how domain knowledge and know-how can be shared, thereby creating a truly integrated construction team. The author's investigation measured the views of practitioners in the main building professions—architecture, engineering and construction management—before proposing the decision support system. The conclusion of the work is a conceptual model: a definition of the contractors' construction management computer agents, and a specification based on scenarios of how these agents would interact with design agents. The significance of Virtual Design and Integrated Project Delivery are also discussed in the context of improved collaboration on the construction project.

Keywords: Collaboration engineering, Integrated project delivery, Intelligent computer agents, Project management.

1 INTRODUCTION

Over the past decade we have seen rapid movements in the UK, US, and European construction industries to offer alternatives to the traditional design-bid-build contract procurement system (Martin 2011). The core to these new systems is built around trust, partnership and teaming, in an attempt to move away from adversarial contract conditions and give clients of construction services greater value. The Strategic Forum for Construction, a UK construction organization established in 2001 as the principal point of liaison between the UK government and the major construction membership organizations, made it clear in its recent report "Accelerating Change" that in future traditional non-integrated strategies for public projects will seldom be used. It also stated that integrating the project team of Architects, Engineers and Construction Managers (AEC) in the private sector demands a similar approach, observing that in the private sector it already has much greater freedom in contract procurement systems, where there is a high degree of collaboration between AEC. We now see the rapid emergence of a whole range of integrated project delivery strategies.

2 VDC, BIM, AND IPD

Virtual Design and Construction (VDC) is a process that integrates the design and construction professionals into a collaborating team that build a BIM model of the project using 3D, 4D(cost), and 5D(time) CAD visualization. A virtual object is created before construction starts so that much of the criteria and constraints associated with the project under design are analyzed at an early stage of project development. As such, it serves as a shared knowledge resource for information about a facility, thereby forming a reliable basis for decisions during its lifecycle from project inception onwards. Operating in an Integrated Project Delivery (IPD) environment becomes the key to effective project delivery, with the Integrated Project Delivery Team offering a solution-oriented approach. At a very early stage (project development, pre-draft phase), the entire planning (design) is carried out by a team that involves not only an architect and a structural engineer, but also specialists in the areas of construction management, MEP engineering, energy technology, environmental/sustainability engineers, building physics, acoustics, façade construction, and (depending on the type of project) further specialists.

This "Big Room" concept can be used to facilitate the process, where all the key project participants, including the client, collaboratively work in the same room to define the sustainability and cost goals for the project. They then evaluate prospects for satisfying some of these goals, using local resources, assessing the opportunities presented by the site itself, and selecting materials that are minimal polluters, sustainable and recyclable, etc. Similarly, just as cost and time to build components are driven down by the collaborative team effort through many iterations of considering alternative materials, layouts, component analysis, etc., the sustainability aspects can be analyzed with the goal to eliminate, reduce, and change the use of materials and components that increase environmental inefficiencies.

Next, the functional requirements of the structure are reviewed to see if it is possible to reduce demands, e.g., efficient envelope design, solar and efficient lighting, construction systems required to build, energy requirements, life-cycle maintenance costs, air quality health impact, design for safety, etc. In the "Big Room" collaborative design environment, supported by responsive decision analysis support tools, the list of possibilities to refine the design is wide-ranging. The resulting design will bear a high degree of confidence that, in terms of material and component efficiencies, sustainability, costs, and building time, will achieve its objectives. Throughout the process, and during the future use of the structure, continuous efforts will be made to reduce waste, improve health, use economical recycled and environmentally-benign materials, and reduce the generation of pollutants.

2.1 Collaboration of the Project Team

Through the collaborative usage of the BIM model and IPD, this work method leads to a collaborative, integrated and transparent construction process. All communication goes back to the central model. The model is shared among all project team members, and it serves as a common, rich database where all information is structured managed and maintained. Therefore, the amount of redundant data is reduced, and repetitive data that already resides in the model can be used by all participants. A shared, visual model to externalize and share project issues also acts as a valuable team-building tool.

This rich data model on the completion of the project can be handed over to the Facilities Management team, who provides the experience for operating and ensuring economic building performance.

3 RESEARCH METHODOLOGY

In the author's research, the processes and interactions that AEC use when making key project decisions were studied. Research data was collected from 54 companies in the USA and 39 in the United Kingdom. Scenarios of typical design and production problems were used to measure the differences in making key decisions in the traditional method of project delivery (design-bid-build) that will be called the sequential process. This was compared to a system with a high incidence of collaborative decision making, such as Design-Build. Results were compared between the AEC to obtain the consensus view. Participants were asked to define the processes they used when working to find solutions to three specific problems associated with a typical reinforced-concrete office building. The problems posed were related to making decisions regarding (1) the foundation system, (2) the suspended floor system, and (3) the enclosure system.

3.1 Survey Objectives

The survey was designed to collect information related to four areas:

(1) To ascertain the problem-solving processes traditionally used by the three main groups under investigation together with their interactions. They were asked how they would break down the problem into manageable parts, described as sub-problems, and then describe the interactions they would expect to have with the other disciplines to arrive at a solution. The strategies of collaboration that were presently employed were also of interest. (To re-design the present solution development process required direct knowledge of how each of the groups currently solves its domain problems).

(2) To discover the constraints each group imposed on others, and determines how those constraints affect other groups. (In the literature review it was found that all three groups tackled problem solving by first breaking the problem into sub-sets and then progressively trading off constraints to produce a solution. It was important to measure how this happened and to what degree this was successful).

(3) To learn the requirements of architects, engineers and contractors to the greater levels of collaboration under consideration. What do the practitioners want? Other research has indicated that greater integration was needed in the construction industry, but to justify making changes to the present process required evidence from all the key participants that they wanted it.

(4) To discover the system features that architects, engineers and contractors would like that enhanced collaboration. The literature review identified many key features that past researchers indicated were desirable, but it was important to find out what the actual users wanted. Also participants were

asked when was the best time in the project development to make these key decisions.

4 RESEARCH FINDINGS

The process used by various members of the design team to arrive at design decisions was first analyzed and tabulated. Once a design decision was made, it then generated criteria and constraints that influenced the problem solving and solution development of other participant domains. Further analysis of the findings resulted in identifying those areas, which set constraints for problem solving by the construction manager. Indicating each major area in this way gives a good indication of the level of collaboration that should be taking place.

A further question asked participants to rate the importance they placed on the list of production problems. This was asked to see if there was some consensus across the professions - construction management, engineers and architects. The top seven of eighteen problems were placed high in ranking order with all three professional groups. Another question measured how confident participants were that the best solution was being found for each production problem. The results showed that contractors have a high level of confidence, ranging from 65% to 80%. However, engineers did not share this optimism; their confidence level across all solutions ranged from around 50% to 70%. Architect's confidence varied with a range of around 40% to 70%, but with the production problems that architects specifically identified as the most important, confidence level was generally higher than engineers.

The next question asked all groups at what stage in the design process the production problems defined should be first considered. The problems were arranged in the order of importance as defined in Table 3, measuring the frequency of responses (%) from contractor (C), engineer (E), and architect (A). The general consensus across the three professional groups is that four of the six most important production problems should be solved at the conceptual design stage and one, establishing costs and budgets, should be resolved between all parties at the feasibility stage. There was a high consensus that eight of the next ten important production problems should be solved at preliminary design stage. The remaining four problems should be solved at the detailed design stage.

Survey participants were then asked to indicate on a scale of 1 to 5 what they considered were the present levels of interaction and what level they would like to see. The six most important production problems (the ranking is taken from fig1) were used. These were: Problem 1 = Definition of the construction method; Problem 2 = Establishing costs and budgets; Problem 3 = Production of the time schedule (the program); Problem 4 = Determining the management team and structure; Problem 5 = Assessment of work content (work packages); Problem 6 = Selection of building systems (including temporary systems).

Results were plotted for each problem as indicated as problems 1 to 6 on the horizontal axis. The vertical axis shows the level of interaction ranging from 1, the lowest, to 5, the highest. Each of the three domains was asked to provide: (a) data on the levels of interaction/collaboration they found presently existed, and (b) the increased levels of joint problem solving they wanted with the other domains. From the results it was found that for all six-production problems, significant increases in collaboration were called for by all three AEC domains. However, the perception of present levels of interaction differed with domain. For instance, contractors and architects concurred on the present levels of mutual collaboration, but when contractor and engineer were compared, engineers felt a much lower level of collaboration existed.

5 COLLABORATIVE AGENT PARTNERSHIP

The advances in the concept of an object as a high-level information source led to the paradigm of object-oriented modeling and the development of object-oriented computer languages (Pohl 2000). The premise is that a crucial element in the decision making process that human designers utilize to solve problems is the reliance they place on their ability to identify, understand, and manipulate objects. For example, architects develop solutions by reasoning about location, sites, buildings, floors, spaces, walls, windows, doors, and so on; the contractor does likewise. Each of these objects encapsulate knowledge about its own nature, its relationships with other objects, its behavior within a given environment, what it requires to meet its own performance objectives, and how it might be manipulated by the designer within a given design problem scenario.

Within the computer-agent environment proposed, problem solving is seen as a co-operative process with mutual sharing of information to produce a solution. Objects are information entities only whereas computer agents are active and have knowledge of their own nature, needs, and global goals. Objects are accessible by agents but cannot take action. Within the computer environment, agents also have the ability to communicate and take action. Typically, each agent is represented at the level of detail to which the collaborative team wishes to reason about the designed system in the building project. A coordinator should be capable of invoking a procedure for resolving conflict conditions based on consultation. The agents use their specialized expertise and available resources to work in parallel on different or coordinating tasks to arrive at a solution concurrently.

Complete families of computer-agents that represent a particular domain should be built, e.g., architect, interior designer, civil engineer, landscape architect, safety manager, quality manager, environmental manager, mechanical and electrical engineer, construction manager, project manager, etc.. Within each family, specific agents would monitor and offer assistance regarding criteria and constraints imposed in the areas of environmental, quality, safety, cost, production time, etc. For instance, there could be a "Sustainability" agent residing in a number of domains, i.e., Architect, Construction Manager, Project Manager, Quality Manager. each would be representing the criteria and constraints of that domain.

It must be stressed that this design assistance using a computer agent is not intended to automate the design process. Agents would assist the designer or collaborative partnership by acting as co-operative search agents, having the ability to liaise with knowledge bases in the search for alternative solutions. They exist to express opinions about the current state of the construction solution. The intention is to change incrementally the current state of the design through the interaction among the various agents within the environment. This interaction enriches the environment with information about the current design state and how it relates to the design requirements. Each agent would provide two kinds of support: (1) intermittent foreground responsiveness to requests for information initiated directly by the designer, and (2) continuous background monitoring and evaluation of the evolving design solution

6 CONCLUSION

In the collaborative environment proposed, the use of families of domain-specific intelligent agents linked to Virtual Design and Construction tools allows alternative design and construction solutions to be rapidly generated. Linking this model to IPD and the "Big Room" concept opens up new ways of exploring client solutions that satisfy the many criteria and constraints that are sought by the key stakeholders of the project. Further, the integrated model-based approach will positively impact construction in the 21st century. Many positive experiences and case studies are beginning to exist, and many of these new collaborative practices are becoming standard for some clients. The results of the author's earlier work in Intelligent Computer Agents (Jones 1998) are linked to present-day VDC. In this way a collaborative team has the tools and information to interrogate and solve many of the cost, constructability, time, quality, sustainability, environmental, safety, etc. issues before construction commences, and continue that monitoring throughout the construction process. Also, at the end of the project, all captured information can be organized and passed to the facility operations team.

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