MULTI AGENT SYSTEM (MAS) USE IN CONSTRUCTION MANAGEMENT LITERATURE

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Abstract - Multi Agent System (MAS) can be defined as a system composed of multiple intelligent agents that interact with each other to increase their own utility or to achieve a common goal. In those systems, negotiation is a basic method of interaction in reaching a common agreement on an idea or a purpose. The construction industry requires multiple parties (such as employer, designer, contractor, subcontractor and etc.) who should work together in order to execute a construction project. Considering that those parties are mostly geographically diverse and have different perspectives and/or objectives about the project, it becomes crucial to use distributed problem-solving systems with multi agents in order to simulate the characteristic of construction projects. Thus, this study aims to investigate in which topics multi agent system approach is used in construction management area by using comprehensive literature review as the research methodology. The identification and clarification of the comprehensive list of research topics will contribute to the researches by recognizing appropriate construction management topics in which MAS approach can be used.

Keywords - Comprehensive literature review, Construction management, Multi Agent System (MAS).

I. INTRODUCTION

Multi Agent Systems (MAS) consist of multiple autonomous units called agents that interact with each other to increase utility or to achieve a common goal. Multi agent systems (MAS) are also considered as a fast-developing information technology, where several intelligent agents, representing the real-world parties, co-operate or compete to reach the desired objectives designed by their owners [1]. In MAS, negotiation is a fundamental method of interaction in reaching a common agreement, purpose or plan. MAS can solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Therefore, in recent years there is an increasing tendency in construction management literature to use MAS due to their ability provide robustness and efficiency; to allow inter-operation of existing legacy systems; and to solve problems in which data, expertise, or control is distributed [1]. The construction industry requires multiple parties (such as employer, designer, contractor, subcontractor and etc.) who should work together in order to execute a construction project. Considering that those parties are mostly geographically diverse and have different perspectives and/or objectives about the project, it becomes crucial to use distributed problem-solving systems with multi agents in order to simulate the characteristic of construction projects. ın this context, the benefits of MAS for the construction industry can be summarized as below:

• MAS is a technology that supports "integrated and concurrent actions" which is one of the important requirements of the construction industry. MAS provides a framework for the various disciplines involved in the process. MAS also supports the ability of the parties to do business in an integrated way and helps the parties to solve the problems that may arise between them.

• Multi agent systems can search and find information in an environment for real-world parties. This helps to reduce the burden of information on the parties.

• The distributed problem-solving technique of MAS provides integrated solutions by modeling and combining the parties with expertise as intelligent agents. In such a system based on smart agents, decisions can be taken with the knowledge of smart agents. This method provides flexibility in decision-making.

• It is stated that use of MAS would be appropriate if data, expertise, and control are scattered [2]. As a result, multi-agent systems have considerable potential to address some of the fragmentation of the construction industry. Thus, many researchers in construction management area applied the multi agent systems in their researches for solving distributed problems along with simulating the dynamic of the industry. In this context, this study aims to investigate in which topics multi agent system approach is used in construction management area by using comprehensive literature review as the research methodology.

II. MULTI AGENT SYSTEM (MAS) USE IN CONSTRUCTION MANAGEMENT LITERATURE

Many authors have applied MAS to solve problems in construction engineering and management area.

General application of MAS methodology is used for solving construction engineering and management problems that involves a negotiation process between parties. Therefore, risk allocation, claim management, supply chain management etc. are some of the research fields that MAS is commonly used in construction management area depending the negotiation process between parties.

In Table 1, A Comprehensive list of Research Topics that Adopts MAS Approach is Presented.

Table 1. List of research topics that adopts MAS

Research Areas	Research Topics	References
Claim Management	• Claim negotiation • Dispute resolution	[4], [5], [6], [7], [8], [9], [10]
Supply Chain Management	• Supply Chain Coordination • Modelling supply chain management systems	[11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26]
Risk Management	• Risk-allocation and cost-sharing • Risk-mitigation decisions	[27], [28], [29], [30]
Design Management	• Distribute collaborative design	[31], [32], [33], [34]
Time Management	• Project schedule changes • Distributed multi-project scheduling	[35], [36], [37], [38], [39]
Construction Material Management	• Construction material procurement	[40]
Construction Equipment Management	• Effective equipment management • Construction material procurement • Traffic congestion of equipment	[41], [42], [43], [44], [45]
Resource Management	• Resource Allocation	[46], [47], [48]
Safety Management	• Workers' safety behavior coordination • Safety performance of construction projects	[49], [50], [51]
Enterprise Resource Planning	• Enterprise resource planning (ERP)	[52], [53]
Investment Decisions	• Government Investment Decision • Feasibility analysis of public investment projects	[54], [55], [56], [57]
Knowledge Management	• Knowledge Management	[58]
Financial Management	• Debt terms' bargaining	[59]
Facility Management	• Emergency evacuation simulation • Energy consumption simulation	[60] [61]

According to Table 1, "Claim Management" and "Supply Chain Management" were found as the prominent research topics that adopts MAS approach. Detailed explanations of MAS use for each research topic can be found below.

A. Claim Management

In construction projects, negotiations between project parties are carried out in order to finalize the claims. Industry practice also shows that claims negotiation is one of the most time and energy consuming activities in claims management. The major problems of claims negotiation are inefficiency, late client intervention and complex human factors [2]. In construction management literature, among the automated systems for claim negotiation, MAS appear to have a significant contribution towards helping project parties to save time and human resources during this long and energy consuming process [3]. For example, El-adaway and Kandil [4] created an innovative formal logic algorithm and multiagent system for construction dispute resolution (MAS-COR) that implemented technologies for generation of legal arguments based on precedent construction disputes. It is an arbitration system for construction claims that focuses on the outcomes of the precedent dispute causes to generate legal arguments to overcome some of the limitations of the previous studies. Ren et al. [5-10] a multiagent system for construction claims negotiation (MASCOT) in order to facilitate construction claims negotiation among different project participants. Agents try to reach settlement through making offers, counter offers and concessions. MASCOT has the integration of Zeuthen's bargaining model with a Bayesian learning mechanism, which addresses the characteristics of

construction claims negotiation. The underlying reason of this integration is the ability to learn enhances agents' negotiation power and speeds up the rate of convergence between agents.

B. Supply Chain Management

In the real world, the supply chain is the net made up of several independent or semi-independent entities, every of which has its function and structure and is responsible for implementing the behaviors related to the material flow and the information flow. How to make the entities act independently and cooperate with each other is a big difficult issue for supply chain management. Supply chain is a typical distributed system, and MAS is efficient for this task. In this context, Zhang et al. [14] established a model of supply chain multi-agent with learning capability. Likewise, Li et al. [11] proposed a simulating model based on multi-agent method under analysis of the cooperation and decision-making problems between partners in construction supply chain. Supply chain coordination is a critical success factor for supply chain management. Therefore, Xue et al. [12] integrated the construction organizations in construction supply chain and multi-attribute negotiation model into a multi-agent system. They also designed a multi-agent based multi-attribute negotiation framework for construction supply chain coordination (MANCSCC) that integrated the specialty agents (contractor agent, designer agent, supplier agent, owner agent, etc.) and service agents (coordinator agent, monitor agent, name server agent) to improve decision-making efficiency since different members in construction supply chain have different preferences on decision-making attributes, such as cost, time, quality, safety and environment [13]. Lu and Chen [15] also presented a self-adaptive and multi-agent model of supply chain system based on self-organized criticality theory and multi-agent technology, in which an avalanche mechanism enables innovation and adaptability of the system and a disaster mechanism controls the system fitness and dimensions. Jin and Li [16] proposed a system that involves multiple agents that delegate organizations to autonomously perform tasks through exchanging information. It had increasing the number of participants due to the increasing scale and complexity of construction projects. As a result, the management among the participants becomes a challenge that is vital to the performance of construction supply chain and the value to the client. Xue et al. [17] presented a relative entropy method for improving agent-based negotiation efficiency (REANE) in a construction supply chain that provide a path forward to help negotiators reach an acceptable solution when other methods fail; the key insight is the use of relative entropy to measure the relative degree of consensus among parties and hence minimize necessary compromises. Lou et al. [20] argued that dynamic and quick reconfiguration is one of important characteristics of an agile supply chain and agile supply chain management is one of the key technologies of agile manufacturing based on dynamic alliances. With this argument, they presented a general architecture of agile supply chain management based on a multi-agent theory, in which the supply chain is managed by a set of intelligent agents for one or more activities. Tah [21] also developed a modelling and simulation platform, which provides an inexpensive and risk-free environment for organizations to experiment with emerging supply chain management practices prior to implementation. Li and Kim [22] evaluated MAS application domains for supply chain management from five different perspectives. The review suggests the MAS approach represents a feasible framework for designing and analyzing real-time manufacturing operations, since the approach is capable of modelling different levels of agent behavior and dynamical interactions. Min and Bjornsson [23] presented an agent-based construction supply chain simulator (CS^2) that leverages computer agent technology for modeling a virtual construction supply chain. Wu [24] addressed the problem of coordination among multiagent systems. Several multi-agent systems for knowledge management were summarized. The issue of coordination problems in supply chain was presented and how to design multi-agent systems to improve information and knowledge sharing was highlighted.

C. Risk Management

Karakas et al. [27] also developed a MAS that simulates the negotiation process between parties (mainly contractor and client) about risk allocation and sharing of cost overruns in construction projects. The MAS was developed using three different negotiation protocols: time-dependent concession, Zeuthen's strategy, and Zeuthen's strategy with Bayesian learning. Taillandier et al. [28] proposed a multi-agent model coupled with a stochastic approach (SMACC) with the aim of evaluating risk impacts for each stakeholder and for the whole construction project. Proposed model would test different risk mitigation strategies in order to measure their interest and then to support risk management decisions. Chengshuang and Guochang [29] created a MAS based risk management system for construction projects in terms of the analysis of risk characteristics and management process of construction projects. Li and Ren [30] discussed the general procedure, the principles of risk allocation between the public client and the private consortium in a PPP project. They

suggest that Bayesian approach, which is considering the responding information from the opponent, is more suitable in dynamic decision making for risk allocation.

D. Design Management

Anumba et al. [31-32] presented a MAS that is intended to form a basis for integrating the distributed cross-functional activities for collaborative design in the construction industry. Lou et al. [33] developed a multi-agent system to support collaborative design in 3D virtual worlds, facilitating the level of communication not readily available in conventional computer-aided design (CAD) systems. Liu et al. [34] proposed a multi-agent collaborative design system in which human designers and software agents interact with each other, exchange design information and keep track of state information to assist with collaborative design.

E. Time Management

Kim and Paulson [36-37] presents a novel agent-based compensatory negotiation methodology to facilitate the distributed coordination of project schedule changes wherein a project can be rescheduled dynamically through negotiations by all of the concerned subcontractors. The methodology consists of a compensatory negotiation strategy based on utility of timing, multilinked negotiation protocols, and message-handling mechanisms. Molinero and Núñez [38] proposed a methodology to simulate every small task of a site-work with a multi-agent system that handle resources to perform transformations on their world. The system simulates the construction of a building through the definition of the atomic elements of the system. Simultaneously running multiple projects are quite common in construction industry. The limited availability of the global resources coupled with compelling schedule requirements at different projects leads to resource conflicts among projects. Adhau et al. [39] proposed a novel distributed multi-agent system using auctions-based negotiation approach for resolving the resource conflicts and allocating multiple different types of shared resources amongst multiple competing projects.

F. Construction Material Management

Hadikusumo et al. [40] proposed a decentralized database system equipped with electronic agents for material procurement with the assumption of conventional material purchasing has some problems related with solicitation process, such as searching for suppliers and obtaining product data information. Results showed that this system can be used to assist human purchasers to carry out solicitation in identifying suppliers, searching materials, and preparing purchase orders.

G. Construction Equipment Management

Zhang et al. [41] proposed collaborative multi-agent systems for real-time monitoring and planning on construction sites. A multi-agent system framework is discussed to support construction equipment operators by using agents, wireless communication, and field data capturing technologies. The potential advantages of the proposed approach are considered as more awareness of dynamic construction site conditions, a safer and more efficient work site, and a more reliable decision support based on good communications. Tatari and Skibniewski [42] introduced an agent-based equipment management system aiming to increase integration and automation, and to minimize decision errors. The proposed application makes use of the current databases of the firm and adds wireless technology to construction equipment for automated data integration. Kim and Kim [43] developed a multi-agent-based simulation system to evaluate the traffic flow of construction equipment in construction site. In order to describe behavioral characteristics of construction equipment by identifying changes in a dynamic environment, the study simulated earthmoving operations. Hammad et al. [44-45] had investigated a novel approach for improving the productivity and safety of construction projects integrating Automated Machine Control/Guidance with a multi-agent system and the real time simulations.

H. Resource Allocation

Liu and Mohamed [46] presented overview of the main components of Multi-Agent Resource Allocation models. Horenburg et al. [47] introduced MAS approach both for processes and resources in order to allocate resources to critical processes. Taghaddos et al. [48] developed a simulation-based multi-agent approach which can schedule the fast-track modular construction projects with limited data available. The developed system can do effective resource leveling and schedule resources (e.g., space, crew) effectively based on various shifts and calendars.

I. Safety Management

Zhang and Hammad [49] presented a MAS based approach to provide real-time support to crane operators of construction projects in order to avoid Collision. Lu et al. [50] explored an agent-based simulation of construction safety performance in response to safety investments. As a result, they identified cost-effective safety investments under different construction scenarios for delivering optimal safety performance. Nasirzadeh et al. [51] proposed a

hybrid framework with the integration of system dynamics and agent-based modelling in order to evaluate the safety behavior of different working groups involved in the project. The achieved simulation results show how the value of unsafe behavior of different agents is varied throughout the project duration due to the interactions with other agents as well as the safety-related regulations that exist in the site.

J. Enterprise Resource Planning (ERP)

Lea et al. [52] proposed a prototype multi-agent enterprise resource planning (MAERP) system that utilizes the characteristics and capabilities of software agents to achieve enterprise wide integration. Dahiya et al. [53] also proposed the architecture, detailed design and implementation of multi agent enterprise knowledge management system for a public sector unit.

K. Investment Decisions

Jo et al. [54] proposed a hybrid system with the combination of system dynamics and agent-based modeling in order to provide a valuable and flexible framework for analyzing project feasibility in a dynamic environment. Yilin [55] established a new paradigm of the project governance theory to improve the management performance of agent construction system, including three routes: internal project governance, external project governance and government supervised mechanism. Yan and Zhou [56] constructed an agent system for the government investment projects that has an important role for the investment system reform in China. Cao et al. [57] also constructed an agent system for the government investment projects based on fairness theory. The equilibrium solution at the fairness condition demonstrates that agents can work harder, and government also can save supervision cost and get more expected benefits.

L. Knowledge Management

The strategic implementation of innovative, collaborative and integrated information is essential for the construction industry. Chow et al. [58] proposed a real-time knowledge support framework that can solve dynamic logistics process management problems.

M. Financial Management

Zhu et al. [59] developed an agent-based debt terms' bargaining model to simulate the negotiation process and improve the negotiation inefficiency in PPP projects.

N. Facility Management

Sharma [60]presented a multi-agent system (AvatarSim), for simulating emergency evacuation scenarios. It models human behavioral parameters which brings a sense of reality during emergency evacuations. Klein et al. [61] presented a multi-agent comfort and energy system (MACES) to model alternative management and control of building systems and occupants with the aim of reducing building energy consumption. It coordinates both building system devices and building occupants through direct changes to occupant meeting schedules.

CONCLUSION

MAS is a computerized system composed of multiple interacting intelligent agents that can solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Considering features of construction industry such as its dynamism, distributed problems and the distributed parties with different perspectives and/or objectives in it, an integrated and distributed problem-solving become more desirable for managing. As a result, agent-based technology becomes a powerful tool for construction management and engineering applications. Thus, this study aims to identify MAS application trends in construction management area. Therefore, a comprehensive literature review was conducted as the research methodology. This study can be used to identify construction management literature gap in terms of MAS applications. Also, the readers can deduce the types of research questions which can be solved via MAS. Frequencies of the research areas adopting MAS showed that claim management and supply chain management were the main research topics adopting MAS approach. Besides, it is seen that application of MAS methodology were applied for solving construction management problems such as resource allocation, site management, risk allocation etc. Surprisingly, the study showed that studies, which adapt MAS, have been frequently published before 2010. This result refers that the construction management literature does not have completely awareness about MAS. For further studies, integration between MAS and bidding, investment, risk management, energy management and facility management can be performed because there were little interests related to these subjects in the literature.

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