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A Model for Increased Collaboration in Construction

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Abstract

The paper outlines a decision support environment that actively supports collaboration during decision making and problem solving. A complementary partnership is formed between computer agents and human agents; the one bringing selected intelligence to the solution process from "unlimited" multi-domain knowledge sources, the other bring human cognitive rationality. In particular the system proposed articulates 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.

Keywords

Collaboration, Project delivery, Accelerating change, Computer agents, Integrated teamwork

1. Introduction

Over the past decade we have seen rapid movements in the UK and European Construction Industry to offer alternatives to the traditional design-bid-build contract procurement system. The core to these new systems are built around trust, partnership and teambuilding in an attempt to move away from adversarial contract conditions thereby giving clients of construction services greater value. Sir Michael Latham report "Constructing the Team" 1994 was the prime mover; since then other reports have followed including the strategy "Accelerating Change" promoted by the Chartered Institute of Building (CIOB) that has continued the momentum towards change based on giving greater value to construction clients built on trust. More recently the U.K. Construction Minister Brian Wilson said "We want to see quality projects that deliver excellent whole life value, that excellence in design and that encompass excellence in design and functionality that are safely built and are on time, on budget and defect free" These are aims that no-one would dispute, but they demand a command of resources which is beyond the reach of the great majority of firms in the industry. Some of them of course will find places in the growing number of integrated supply chains, but even this requires a degree of sophistication relatively rare in a traditionally fragmented industry.

Prime contracting is one of the three procurement strategies commended by the United Kingdom Treasury and the National Audit Office for delivery of construction works by central government clients. For more than two years past departments have been following advice from the Office of Government Commerce that they should use traditional procurement routes such as competitive tendering only when it can be shown that they offer better value for money than Private Finance Initiatives, Design and Build, or Prime Contracting.

The Strategic Forum for Construction made it plain in its recent report “Accelerating Change” that integrating construction management in the private sector demands a similar approach, quoting with approval the government dictum that in future traditional non-integrated strategies will seldom be used. The Strategic Forum is looking forward to the time when the industry can offer a fully integrated service to its clients, delivering predicted results in all areas, under a culture of trust between all parties to the project.

For the USA construction industry changes in contract procurement strategies have been much slower and progress more cautious. Design-bid-build is still the dominant procurement system that clients in the public sector prefer however design-build and partnering strategies are making wide in-roads to traditional systems. The private sector has much greater freedom and contract procurement systems where there is a high degree of collaboration between architects, engineers and construction managers is often the preferred system.

2. Research Methodology

The processes and interactions that Architects, Engineers and Construction Managers (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. Compared to a system where there was a high incidence of collaborative decision making; such as Design-Build. Results were compared between the three participating groups (AEC) so that the consensus view could be obtained.

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:

(i) The foundation system;
(ii) The suspended floor system;
(iii) The enclosure system.

Responses reflected the various views of architects, engineers or construction managers.

2.1 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? Latham (1994), Egan (1988) and others' all said 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 find out the features that architects, engineers and contractors would like in any re-designed framework 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.

3. Research Findings

A list of the findings is tabulated in Appendix 1 (Table 2 - because of paper page requirements these findings will be introduced at the conference). The list shows areas where a decision or choice had to be made by the design team. Decisions in each of these areas then generate criteria and constraint, which influence problem solving of other participant domains. Further analysis of the findings resulted in identifying those areas, which set constraints for problem solving by the construction manager. By 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 problems were placed high in ranking order with all three professional groups, shown in Table 3.

Table 3: Production Problems Ranking

IMPORTANCE PLACED ON THE KEY PRODUCTION PROBLEMS BY THE MAJOR PARTICIPANTS IN THE CONSTRUCTION PROCESS			
PROBLEM	Contractor	Engineer	Architect
Definition of the construction method	1st	2nd	2nd*
Establish costs and budgets	2nd	4th*	2nd*
Production of the time schedule (the program)	3rd	3rd	1st
Determination of the management team and structure	4th	6th*	5th
Assessment of work content (work packages/WBS)	5th	4th*	10th
Selection of building systems (including temporary systems)	6th	6th*	11th*
Carry out a risk analysis including safety	7th	1st	7th*
Determination of the labor resources	8th	10th*	15th
Definition of the sequence of assembly	9th	6th*	6th
Determination of the material resources	10th	14th*	11th*
Establish the standards of quality and workmanship	11th	6th*	2nd*
Establish the building & mechanical systems perf. standards	12th	10th*	7th*
Assessment of work flow patterns	13th	10th*	7th*
Determination of the major mechanical equipment	14th	14th*	11th*
Carry out a value analysis of the production system	15th	14th*	11th*
Establish the control systems	16th	18th	15th
Definition of site layout including facilities, storage & eqpt.	17th	14th*	18th
Definition of the communication systems incl. computer support	18th	13th	17th (*joint)

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 findings of the most important seven production problems (as defined in this survey) comparing all three disciplines are shown in Figure 1.

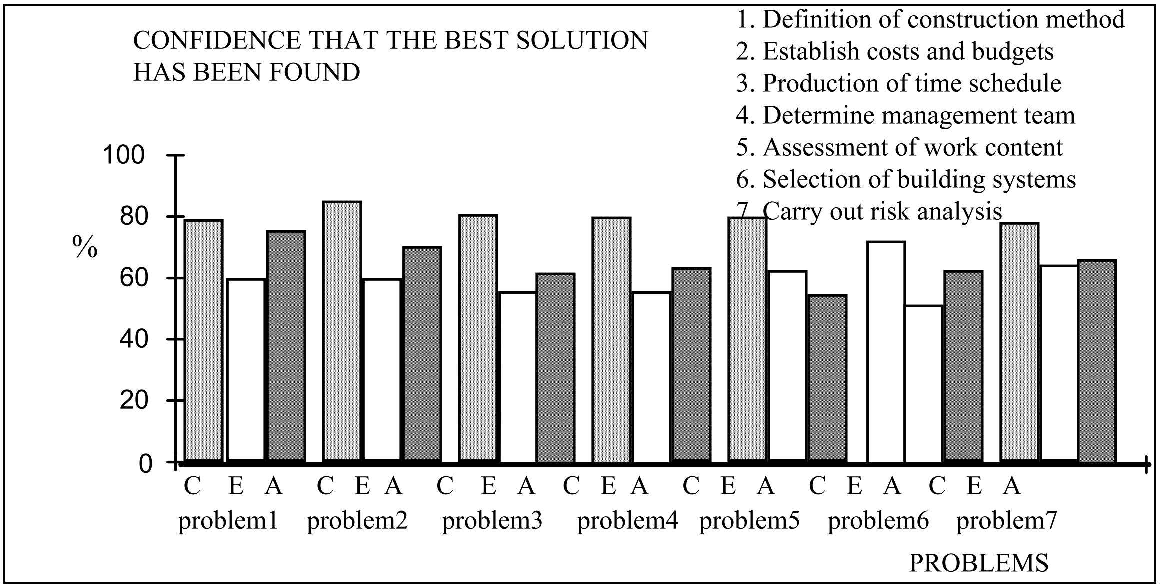

Figure 1: Survey Results – Production Problem Confidence Level

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; frequency of responses (%) from contractor (C); engineer (E) and architect (A) are measured. The results are shown in Table 4. The general consensus across the three professional groups is that four of the six most important production problems should be solved at conceptual design stage and one, establishing costs and budgets, should be resolved between all parties at the feasibility stage. There is 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.

Table 4: Stage to Consider Production Problems

STAGE TO CONSIDER PRODUCTION PROBLEM
(The shaded area indicates the consensus view across the three professional groups)

Design Stage	Feasibility			Conceptual			Preliminary			Detailed		
C = Contractor E = Engineer A = Architect PRODUCTION PROBLEM:	C	E	A	C	E	A	C	E	A	C	E	A
Define construction method	22	54	0	32	45	55	41	0	44	5	0	0
Establish costs and budgets	54	70	44	23	20	38	13	10	12	9	0	0
Production of Time Schedule (Program)	32	9	0	36	45	11	23	37	66	9	9	22
Determine management team & structure	14	10	0	27	30	44	23	30	44	36	30	11
Assess work content (work packages/WBS)	14	10	0	9	10	22	42	60	11	23	20	66
Select building systems (including temporary systems)	18	27	0	40	72	33	27	0	44	14	0	22
Carry out risk assessment including safety	22	27	12	22	18	48	50	36	24	5	18	12

Determine labor resources	9	11	0	0	0	12	33	11	0	59	77	84
Define assembly sequence	5	10	0	37	40	0	47	50	33	10	0	66
Determine material resources	22	22	0	14	27	38	23	22	38	42	22	25
Establish quality & workmanship standards	13	20	11	32	30	11	29	40	33	29	10	44
Establish performance standards for building and mechanical systems	14	20	0	23	30	22	45	30	44	14	20	33
Assess work flow patterns	5	12	24	27	12	24	41	50	25	29	25	50
Determine major mechanical equipment	9	0	11	14	20	22	29	30	33	50	50	33
Perform value analysis of production system	5	18	0	27	18	13	45	18	50	23	45	38
Establish the control systems	9	0	0	23	20	0	40	27	63	29	50	38
Define site layout	14	20	12	32	30	38	18	10	0	36	40	50
Define communication systems, including computer support	9	0	0	14	9	33	27	36	22	50	36	44

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 Fig.1) were used. These are:

Problem 1 = Definition of the construction method
Problem 2 = Establish costs and budgets
Problem 3 = Production of the time schedule (the program)
Problem 4 = Determine the management team and structure
Problem 5 = Assessment of work content (work packages)
Problem 6 = Selection of building systems (including temporary systems)

Results are plotted (Figures 2, 3 and 4 shown in Appendix 2 - because of paper page requirements these findings will be introduced at the conference) for each problem that is 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:

1. Data on the levels of interaction/collaboration they found presently existed;
2. The increased levels of joint problem solving they wanted with the other domains.

It can be seen from the results that for all six-production problems significant increases in collaboration were called for by all three domains. However the perception of present levels of interaction differed with domain. For instance contractors and architects concurred on the present levels of collaboration achieved between them but when contractor and engineer were compared than engineers felt that a much lower level of collaboration presently existed.

4. Building the Collaborative Model - Collaborative Agent Partnerships

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. 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, e.g. 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. This knowledge is contained in the various representational forms of the object (e.g. factual data, algorithms, rules, etc.).

Within the computer agent environment proposed, problem solving is seen as a co-operative process with mutual sharing of information to produce a solution. The resulting design solution is seen as an assembly of construction objects, e.g. bricks, walls, floors, windows, etc., these are assembled by human and machine agents to satisfy project specific criteria, e.g. quality, environmental, cost, safety, etc. 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. But for the system to interact effectively between the design intention and computer assistance there has to be a full description of the objects. This description should resemble as closely as possible the designer's real world by including the objects physical appearance, attributes, context and relationship to other objects.

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. The frames in such a project model could represent geometric, physical and administrative attributes of a project's components together with their topological structure. All of this information about the structure of a project and the local values of its component attributes are then available in a representation easily accessible by computer tools for solving or assisting with design tasks. 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.

There is an inevitable need for interaction between all the participants who input to complete the final project. Pohl *et al.* (2000) suggested that the computer system should reflect the more realistic situation of a design team that interacts by co-operation and persuasion. The concurrent engineering concepts apply here. Therefore, 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. and 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 'Quality' 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 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 are evaluators and solution proposers acting as system agents who operate in a defined domain. 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. It should support the designer by providing adequate information about the current design state, its design objects (i.e., data-objects and object-agents), their relationships and how they satisfied the design requirements. Each agent would provide two kinds of support; intermittent foreground responsiveness to requests for information initiated directly by the designer, and continuous background monitoring and evaluation of the evolving design solution.

The human agent's role in such an environment is seen as:

- Evaluating the current state, independently or with the support of other agents,
- Participating in the process of changing the design state through manipulation of the design objects, i.e. introducing new data-objects to the CAD environment, modifying attributes, etc.
- Modifying the design goals if seen necessary,
- Directing and guiding the effort of the other agents to advance the current state towards an acceptable design.

5. The Proposed Decision Support Environment - the Collaborative Model

In the collaborative environment the facilitator's role would be one of searching, evaluating and modifying the current design state with the support of different domain computer agent families (Jones and Riley, 1994). The integrated partnership environment proposed for an agent hierarchy in the domain of Construction Management (Appendix 3) is shown. In this process the human agent would direct and guide the efforts of all computer agents to advance the current state towards a best construction solution that is acceptable to all domains agents' and the human control agent.

A family of computer agents and objects would represent each domain in a similar way and their problem solving activities associated with the design and production problems of a specific project. As other problems arise so the agent environment would extend or should the project be of a different construction then a new agent family would be appropriately designed.

A total solution development environment where the knowledge and intelligence of all domain-contributing agents can be employed, better opportunities therefore exist to concurrently view the effect of decisions that impinge on the many contributors and their constraints. All contributors are collaboratively drawn into the solution development process. Time is saved because a concurrent problem solving approach is adopted rather than a sequential problem solving approach. Experts can still be geographically or functionally distributed, this also presents the opportunities to take advantage of recent technology in communication systems (co-operative distributed, broad band, etc.). The complexities of the design process can be broken down over numerous agents; problems can be decomposed to achievable sub-problems. Systems architecture for computer support of the design process can be more efficiently designed. Finally, the environment proposed could be extended to continually monitor and assist throughout the life cycle of construction projects.

6. Conclusion

To achieve the performance improvements outlined, the starting point is to create an environment where greater collaboration between the main parties to the project team can be practiced. Because of the wide range of criteria to be satisfied by the participating groups an agent assist environment is seen as bringing essential domain knowledge for sharing amongst the many participants. The research demonstrates that such an environment can be built that assists an AEC collaborating team in their search for alternative solutions which satisfy the criteria and constraints imposed by a clients project requirements. The computer environment explored is extendable to include all project participants whose input to the design process is desirable. The problem-solving domain of construction management is represented in such an environment (Appendix 3).

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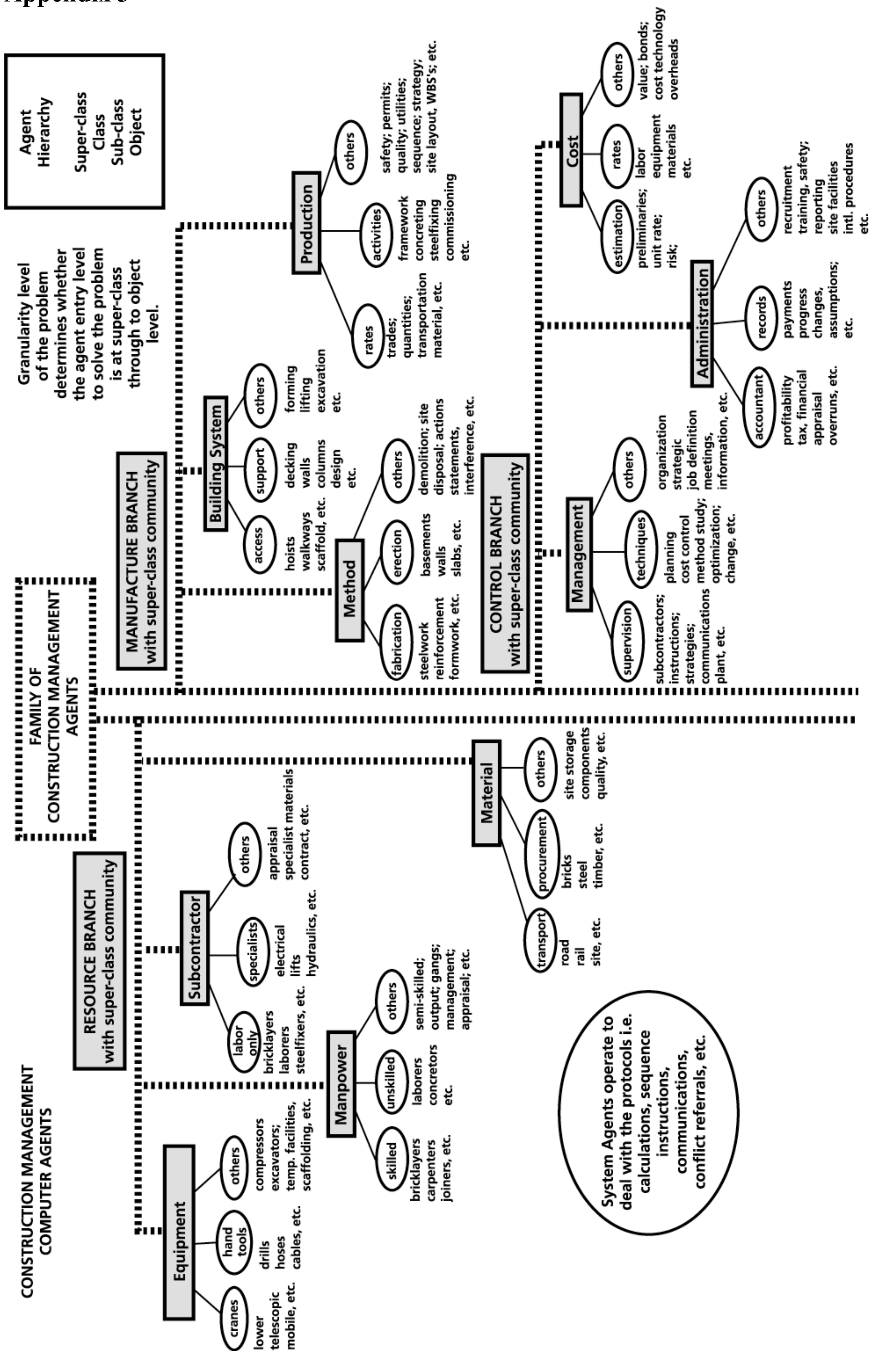
Note: Appendix 1 and 2 will be given at the conference due to the limit in the length of paper.

Appendix 3



CONSTRUCTION MANAGEMENT COMPUTER AGENTS
RESOURCE BRANCH with super-class community
FAMILY OF CONSTRUCTION MANAGEMENT AGENTS
MANUFACTURE BRANCH with super-class community
Granularity level of the problem determines whether the agent entry level to solve the problem is at super-class through to object level.
Agent Hierarchy
Super-class
Class
Sub-class
Object
Equipment
cranes
lower telescopic mobile, etc.
hand tools
drills hoses cables, etc.
others
compressors excavators; temp. facilities, scaffolding, etc.
Manpower
skilled
bricklayers carpenters joiners, etc.
unskilled
laborers concretors etc.
others
semi-skilled; output; gangs; management; appraisal; etc.
Subcontractor
labor only
bricklayers laborers steelfixers, etc.
specialists
electrical lifts hydraulics, etc.
others
appraisal specialist materials contract, etc.
Material
transport
road rail site, etc.
procurement
bricks steel timber, etc.
others
site storage components quality, etc.
System Agents operate to deal with the protocols i.e. calculations, sequence instructions, communications, conflict referrals, etc.
Method
fabrication
steelwork reinforcement formwork, etc.
erection
basements walls slabs, etc.
others
demolition; site disposal; actions statements, interference, etc.
Building System
access
hoists walkways scaffold, etc.
support
decking walls columns design etc.
others
forming lifting excavation etc.
Production
rates
trades; quantities; transportation material, etc.
activities
framework concreting steelfixing commissioning etc.
others
safety; permits; quality; utilities; sequence; strategy; site layout, WBS's; etc.
CONTROL BRANCH with super-class community
Management
supervision
subcontractors; instructions; strategies; communications plant, etc.
techniques
planning cost control method study; optimization; change, etc.
others
organization strategic job definition meetings, information, etc.
Administration
accountant
profitability tax, financial appraisal overruns, etc.
records
payments progress changes, assumptions; etc.
others
recruitment training, safety; reporting site facilities intl. procedures etc.
Cost
estimation
preliminaries; unit rate; risk;
rates
labor equipment materials etc.
others
value; bonds; cost technology overheads