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Integrated Project Delivery(IPD) for a Sustainable Design and Construction

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Abstract

The paper discusses a proposal for an integrating partnership for decision making at pre-construction stages of major construction projects. The environment proposed is one that fully utilizes the strengths of intelligent collaborative computer agents that interact with the muti-discipline pre-construction team to interrogate and refine the design solution before construction commences. Better opportunities therefore exist to concurrently view the effect of environmental decisions that impinge on the many contributors. All contributors are collaboratively drawn into the design and pre-construction process. IPD and BIM form essential tools and strategies in this decision environment. IPD linked to the "Big Room" concept will be discussed. The presentation will also focus on the new "Living Building Challenge 2.0" strategy and look at some of the challenges that are presented and ways that might assist creating a greener and more sustainable environment. In the model proposed the complexities of the design process can be broken down over numerous agents in different countries. Finally, the environment is extendable to continually monitor and assist environmental decisions throughout the life cycle of construction projects. The author's investigation measured the views of practitioners in the main building professions; architecture, engineering and construction management before proposing the collaborative system that is called for. The conclusion of the work is a conceptual model of the system proposed, a definition of the contractors' construction management computer agents and a specification based on scenarios of how they would interact with design agents.

Keywords

Sustainable, Collaborative Engineering; Integrated Project Delivery (IPD); Virtual Design and Construction; Knowledge Based Engineering: Intelligent Agents; BIM; Big Room.

1. Introduction

The Construction Industries in many parts of the world have seen change to offer alternatives to the traditional design-bid-build project delivery system. This movement encouraging change away from traditional contract procurement can be traced back to Sir Michael Latham report, "Constructing the Team" 1994 and Egan 1998. Today many government agencies are insisting their construction projects are approached by a collaborative AEC team who are assisted by computer driven design tools that provide open shareable asset information. One major reason (Teichholz, 2004) found was that while other industries increased their productivity in the last half of the last century by 120 percent; the construction industry underwent a 20% decrease. A study (Gallaher, 2004) carried out at the NIST institute showed that poor data management and data exchange had a significant impact on the final cost of construction projects. Any effective decision model, including BIM, must have relevant information and knowledge delivered at the right time for fast analysis of different designs using a range of sustainable materials and assessing the impact on construction .

In the USA, the General Service Administration(GSA) through its Office of Design and Construction(OCA) is responsible for providing national leadership and policy direction in the areas of architecture, engineering, urban development, construction services, and project management. It is responsible for $1.7b of new construction work in 2012. Through its Public Building Service (PBS) in 2003 it established a 3D-4D-BIM program that is now supporting applications in over 100 projects. The UK Government Building Information Modeling (BIM) Strategy group has been debating the construction and post-occupancy benefits of BIM (Building (asset) Information Modeling and Management) for use in the UK building and infrastructure markets over the next 5-year period in terms of its cost, value and carbon performance. It has now mandated for 'fully collaborative 3D BIM as a minimum by 2016', and the need for efficiency and industry reform to realize a 'cost reduction of 20% during the term of the current parliament'. This mandate will drive considerable changes in the traditional processes and practices of the UK AEC industry since it is estimated that today less than 10% of firms use BIM software in the UK as compared with 60% in the USA. Meanwhile, a new survey of more than 300 RICS members has revealed a poor up-take of BIM with less than 5 per cent indicating any frequent use.

2. Virtual Design and Construction & Building Information Modeling

Virtual Design and Construction (VDC) is a collaborative, integrated process that considers both design and construction using a 3D BIM models in combination with schedule data (4D) and cost estimating data (5D) a virtual object is created even before construction starts. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from project inception onwards. Model, schedule and cost (GSA.2011) have to be coordinated from the beginning.

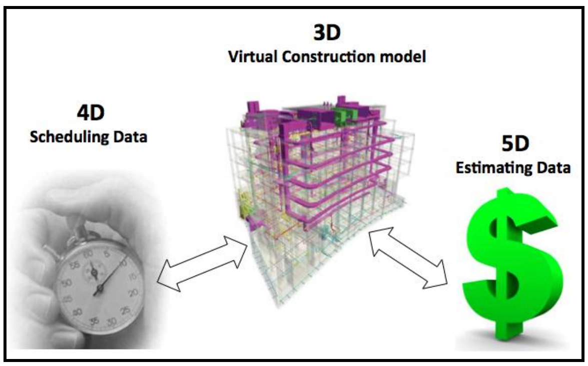


Figure 1: Relation between 3D / 4D / 5D models

Integrated Project Delivery

The Integrated Planning Team offers 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 consultants in the areas of construction management, MEP engineering, energy technology, building physics, acoustics, façade construction and depending on the type of project further specialists. The final handover of the completed building from this collaborative team is to the Facilities Management team who provides the experience for operating and ensuring economic building performance.

Link between VDC/BIM and IPD

VDC and BIM have to be implemented from the beginning of a construction project in order to increase the quality of the object, the organization and the process during the building life cycle. An important basic requirement for the model based work method is a sufficient amount of information from the very beginning of a project. In particular, the criteria and constraints of the various contributors to satisfy the client’s requirements need to start being articulated and discussed as the model builds. For the approach to work effectively the integrated planning team comes into place. It is essential to include the experience of construction consultants (e.g. construction manager, superintendent) to ensure that the new project benefits from the execution experience. The result is a win-win situation for all members of the team. Furthermore, the building owner has security in terms of cost and schedule as well as optimized operation. During this phase the 3D, 4D and 5D model with a level of detail appropriate for execution are created.

Software and Data exchange

Technically, the main challenges lie in the area of software and data exchange between the different software applications required for the generation of the model. Most of the renowned CAD software producers offer already BIM software solutions. The following table shows a limited overview of today's available software applications in terms of VDC and BIM.

Software producers	Product
Audodesk	Revit, Navisworks
Nemetschek	Vectorworks
Bentley	ProjectWise, ProjektWiseNavigator
Tekla	TeklaStructurs
Graphisoft	ArchiCAD
Vico Software	Vico Construction
RIB Software	iTWO

Regarding 4D and 5D modeling "Build in" and "Stand alone" software is being differentiated. "Build in" software (some of the products listed above) allows the creation of 4D and 5D models. "Stand alone" software solutions on the other hand import 3D BIM models to use them for the creation of 4D and 4D model. :

3. Importance of BIM today

In the study, (figure 2) completed by Skanska USA Civil and Skanska USA Building forecast a massive increase of BIM application use within the next five years. Today roughly 40% of their employees in the area of Skanska USA Building state that BIM is already very important for the construction industry. They expect double usage of BIM within the next five years. The in-house study of this construction company in 2010 (1066 interviewees) shows a clear trend for the future.

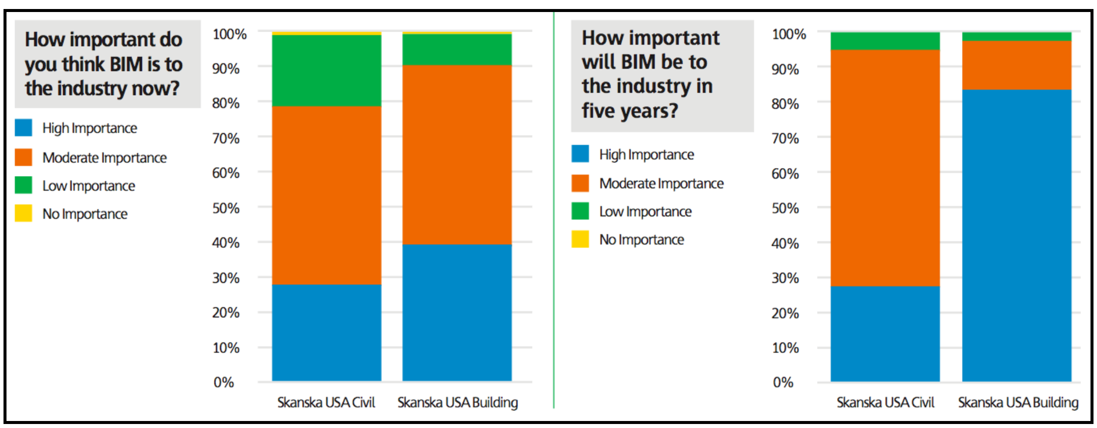


Figure 2: Importance of BIM today and in 5 years

The following results are an extract out of a study done by CIFE institute at Stanford University, called "An Integrated, Virtual Design and Construction and Lean (IVL) Method for Coordination of MEP". In all areas the application of VDC is connected to the principles of LEAN construction. It was found that up to 90% decrease of interface conflicts could be resolved and the number of RFI's and change orders could be minimized with the help of model based work method. Furthermore, improvements in pre-manufacturing could be instigated; conflicts in the field and time resolving them reduced.

From interviewing general contractor Hensel Phelps they reported that 20% of the work in a construction process is dedicated to work tasks that are related to re-work. The application of BIM helped the company to decrease this percentage to 5%. A study of Mortenson Construction (Minneapolis) in collaboration with The Health Sciences Center of Colorado-Denver University project gave another example to demonstrate the efficiency of VDC and BIM linked to the integrated planning approach. Comparison of two very similar projects - biomedical facilities; the one using the conventional approach of constructing, the other using the model based method. The comparison between construction of these two similar buildings provided the following observations.

- Change orders: The number of change orders was 32% lower than average.
- RFI (Request For Information): Because of virtual planning many RFIs came up in the earlier planning phase and where solved in this phase. RFIs in the phase of foundation decreased by 74% and those in steel construction by 47%. On a total basis this is a decrease of RFIs of 37%.
- Re-work: The subcontractor reported that because of the well-coordinated planning process (including clash detection) prior to execution it led to detailed pre-manufacturing work that led to a reduction of labor cost onsite of 50%.
- Construction process schedule: With the support of the 4D model and therefore possible simulations of the construction process, the project schedule was greatly improved. The project completion happened two months earlier than originally planned and six months faster than the comparable R1 tower.

4. Collaboration of project team members

Through the collaborative usage of the BIM model and integrated project delivery, the model based 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 date that already resides in the model can be used by all participants.

When Disney Concert Hall in Los Angeles was build, 4D models were applied from the beginning. CIFE institute conducted a study within this project and concluded that through working with the 4D model the communication improved dramatically. The GC’s project superintendent, Greg Knutson, felt strongly that it was important to construct a team atmosphere, where people solve problems together. He realized that a shared, visual model to externalize and share project issues was a valuable team building tool. But not only the project members in terms of execution team experiences benefits from integrated model based work method, also the relationship between the building owner and contractor improves.

5. Information, Data and Knowledge in the system

For the VDC system to work effectively, requires domain information, data and knowledge to be brought into the system when required for solving problems and making decisions. Pohl (1993) concluded that the design process could be characterized by five functional elements:

- Information - a search for relevant information that includes past experience.
- Representation - the methods and procedures designers utilized to solve design problems relied on their ability to identify, understand and manipulate objects. Objects have a representable form that encapsulates knowledge that is conveyed as factual data, algorithms, rules, exemplar solutions and prototypes.
- Visualization – that is important since traditionally some form of graphic media is used to convey design intention, generally in the form of drawings. Drawings however are often inadequate in

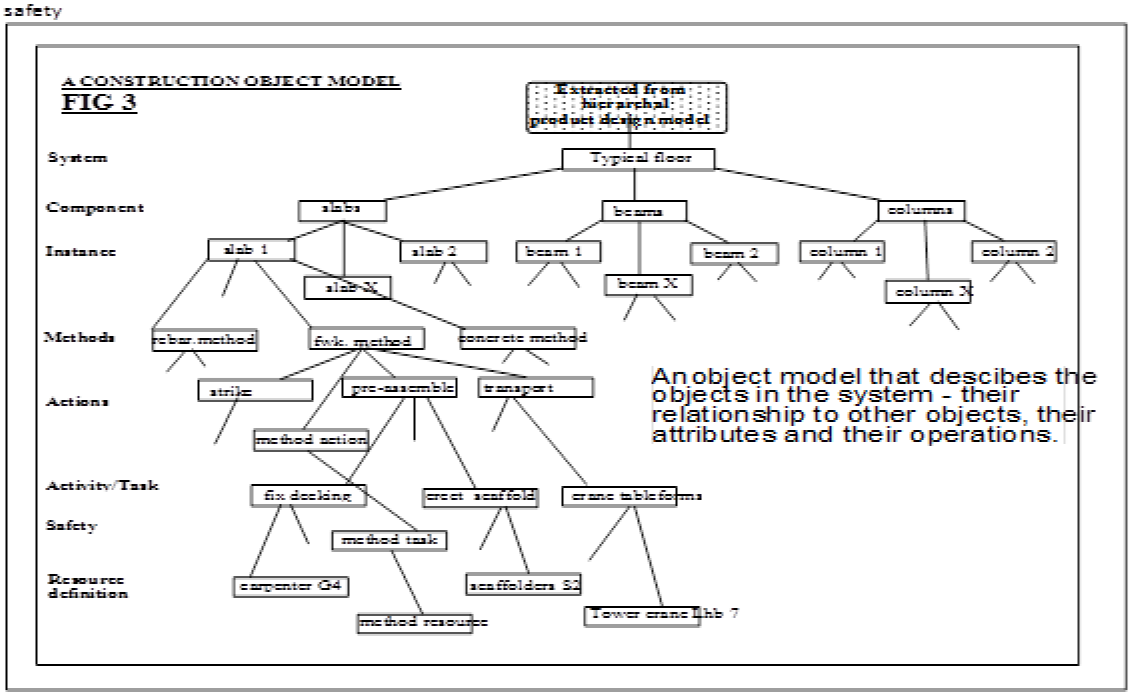
portraying information and can lead to erroneous conclusions, with many misinterpretations and inappropriate conclusions resulting.

- Reasoning - that is central to the design activity. The ability of designers to solve problems is dependent on their interpretation of the issues and the dynamic changing relationship between these issues. Often requiring different expertise to be drawn into the process.
- Intuition – which, in the design process, is often the spontaneous reaction to a thought process that diverts many areas of the human brain? The new generation of design tools e.g. Rivit and Navisworks, assist representation and visualization however bringing relevant information into the decision environment in a timely manner is a key to success.

Objects

Having the ability to view the artifacts used in the design model as a series of objects, which have implicit attributes and features, gives scope to analyze the design in depth regarding such aspects as manufacture, constructability, cost, schedule, quality, safety, etc. All participating domains reasons with objects, in various groups that can be termed super-classes, which in turn are composed of various classes e.g. methods, actions, activities, construction resources, costs, etc. Objects within each class (Figure 3 below) could encapsulates knowledge about such things as its own function, its relationships with other objects, its behavior within a given environment, what it requires to meet its own performance objectives, how it might be manipulated by the designer within a given design problem scenario, etc. This knowledge is contained in the various representational forms and protocols of the object, e.g. factual data, rules, standard solutions, etc. Object models would be common to architects, engineers and construction managers and could be added to by any of these disciplines. It represents the static, structured, data aspects of the system that can be stored in object libraries.

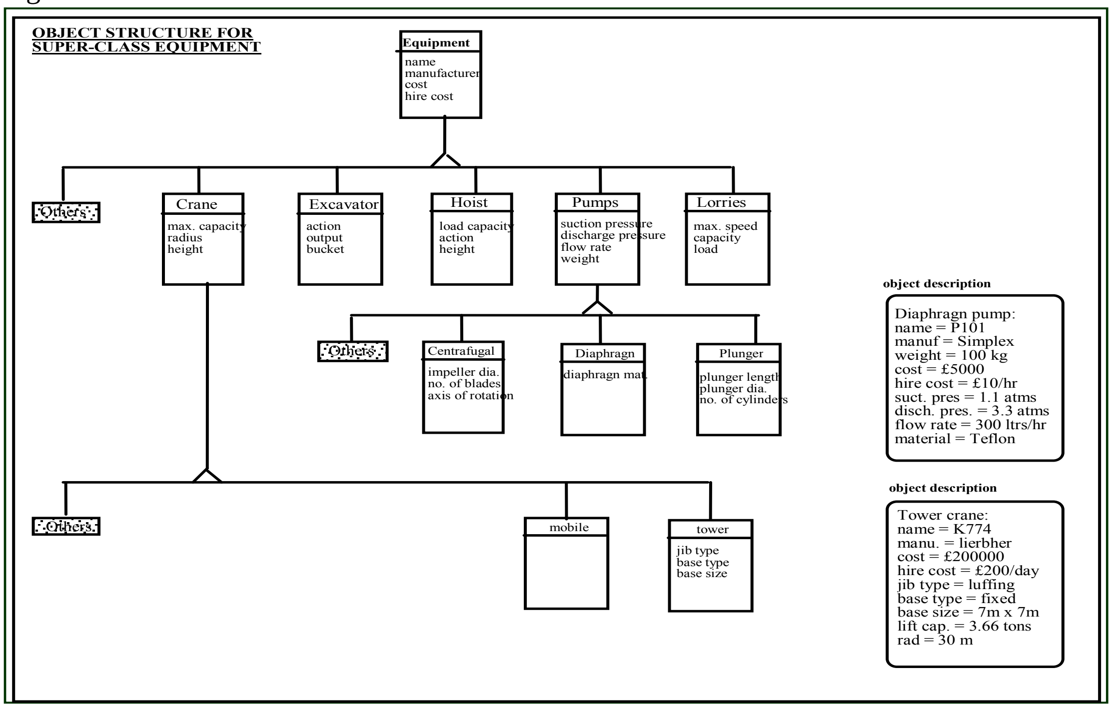
safety



A CONSTRUCTION OBJECT MODEL
FIG 3

Whereas, Figure 4 illustrates the more dynamic aspect of the system and indicates how attributes are encapsulated within construction super-class objects; in this case, the super-class "equipment" is used. Attributes include not only the shape and related geometrical features of the object, but also non-geometric properties and characteristics such as functions, materials, cost and performance. Within the super-class, ‘Equipment’ all classes of equipment can be represented (e.g. excavators, cranes, pumps, etc.). Each class might have a number of associated types (e.g. with pumps there might be centrifugal, diaphragm, etc.), many different types of attributes (e.g. flow capacity) could then be defined dependent on the level of problem solving and specification of finally generated information.

Figure 4



6. Computer Agents and Intelligent Computer Agent

Jones (1998) proposed a co-operative design agent environment composed of agent families representing the AEC participants, the client, and extendable to all the stakeholders to the project. Intelligence in the context of this research implies that the design system has some means that allows it to anticipate the data needs, information needs or knowledge needs of the human designer(in this case the integrated team). The system would act as an intelligent assistant to the evolving design, creating and aiding the collaborative team and freeing them from being overwhelmed with untimely information and knowledge. Providing such assistance requires an understanding of the various participants' knowledge requirements, the factors that constrain their decisions, and the criteria under which they work. Pohl (1993) called this an Intelligent Computer Assisted Design System (ICADS). The ICADS approach was tested in several working models (ICADS-DEMO1 (Pohl, 1989), ICADS-DEM0 2 (Pohl, 1991), AEDOT (Pohl, 1992). These have provided computer scientists and practitioners with a useful test bed for the development of a body of knowledge relating to software and hardware computer architecture, theoretical concepts and technical implementation issues.

The characteristics such computer agents would possess are:

(a) The agents would be programmed with appropriate problem solving protocols.

(b) Agents would only be considered intelligent when they possess the capacity to plan their own actions. Intelligent agents would therefore have implicit domain knowledge, knowledge of their own needs, knowledge of global goals, the ability to communicate and the ability to take action. They would also have access to objects, which are information entities, but unlike agents, cannot take action. They would bring appropriate domain information and knowledge into the VDC.

(c) Different 'Families' of computer agents can be constructed that would support each domain. See section on 'Agent Families'

(d) Sub-tasks resulting from decomposing the problem are distributed to different domain agent families with the intention that these agents assist the human integrated team participants (termed in the research 'human agent').

(e) Each domain family of agents would operate in a narrow domain providing support to requests for assistance. These agents would range from simple to complex processing units each rationally working toward a single global goal or towards separate individual goals that interact. Acting independently in a self-regulating manner, they exist to express opinions about the current state of the design solution in regard the key criteria and constraints of that discipline. The intention is to change incrementally the current state of the design through the interaction among the various agents within the environment. However, the goals are set by the human agent with advice from various autonomous agents that include agent representation of the client. The criteria and constraints of the various participants would be continually analyzed to find a best solution.

(f) Agents representing many disciplines would use their local expertise and available resources to work in parallel on different or co-coordinating tasks to arrive at a solution in the following ways:

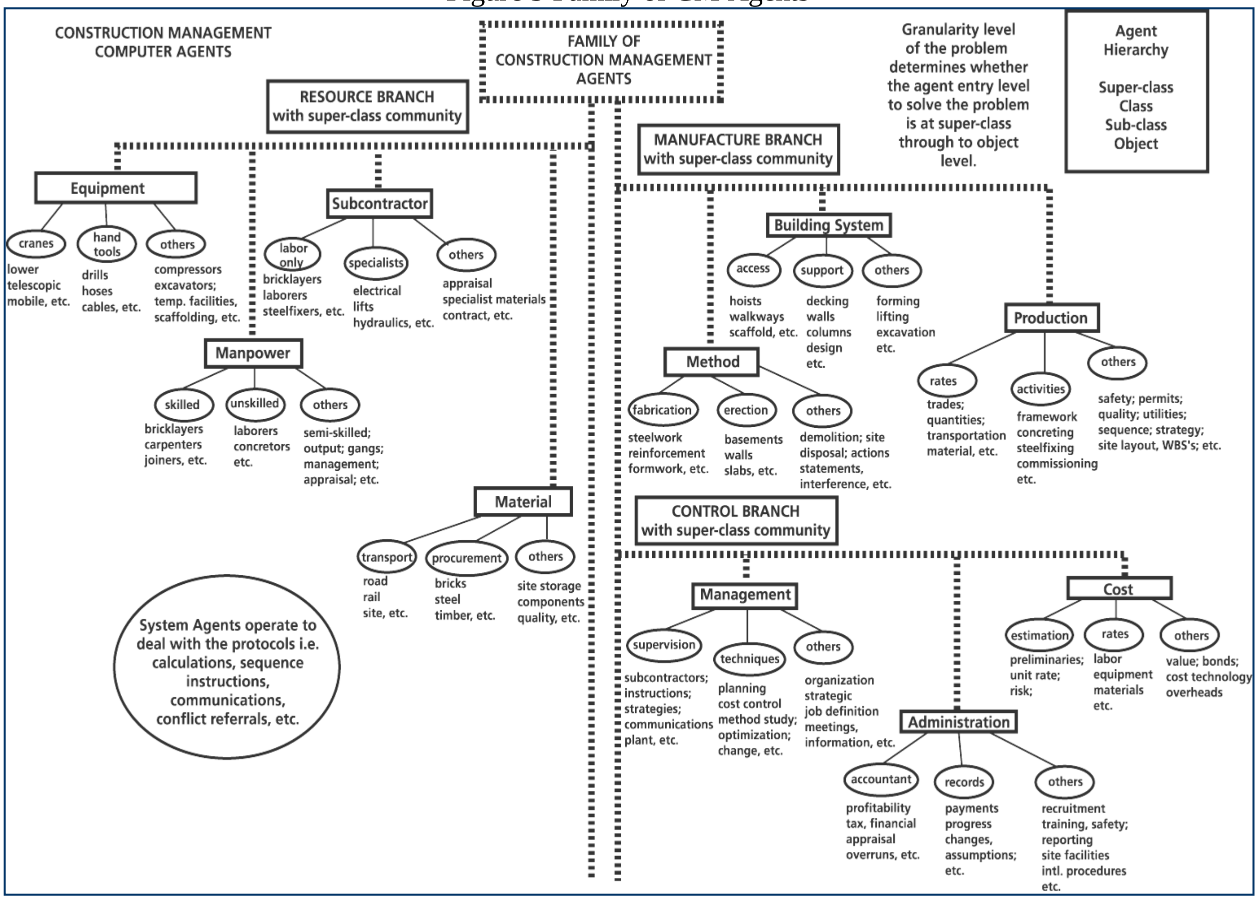
> (i) They would act as co-operative search agents that liaise with information knowledge bases in the search for alternative solutions.
>
> (ii) Alternatively, they would act as evaluators and solution proposers to express opinions about the current state of the design solution.
>
> (iii) Alternatively, they would give continuous background monitoring and evaluation of the evolving design solution including conflicts.
>
> (iv) They would be designed to have implicit domain knowledge, knowledge of their own needs, knowledge of global goals, the ability to communicate and the ability to take action.
>
> (v) Typically, each agent would be represented at the level of detail at which the design facilitator or human agent wishes to reason about the designed system.

<u>Agent Families</u>

Complete 'families' of computer-agents that represent a particular domain will be built e.g. architect, interior designer, structural engineer, client, landscape architect, safety manager, quality manager, environmental manager, stakeholders, mechanical and electrical engineer, construction manager, project manager, etc. For instance, the family of computer agents and objects would represent the construction management domain (fig 5) and their problem solving activities associated with the production problems of a specific project. 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 'Safety' 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. Project solution development assisted by computer agents is not intended to automate the design process but rather to pool contributing domain expertise in the search for the 'best-value' solution.

This environment would include representation from all the built environment disciplines, agencies and most importantly the Client agent. This interaction enriches the environment with information about the current design state and how it relates to project requirements. In this process the integrated team would direct and guide the efforts of all computer agents to advance the current state of the project solution towards a best-value design solution that is acceptable to all domains computer agents' and the inter-disciplinary project team. The role of the designer or project leader would be that of principal long term or strategic planner while agents would focus mainly on short-term activities.

Figure 5 Family of CM Agents



<u>Family Tree -'Construction Management Agents'</u>

As stated, a family of Construction Management agents that would be designed to sit co-operatively among architectural, engineering and a variety of other specialized agent families. This research has identified three branches of super-class agents (fig 5) that reside under the Construction Management family:

(i) Resource branch.

(ii) Manufacture branch.

(iii) Control branch.

Each branch would include domain specified super-class agent communities that would divide into agent classes, which represent the entire problem solving activities of that super-class. Each super-class is divided into classes and sub-classes with their relevant object libraries. In the investigation (Jones, 1998), agents representing activities associated with a reinforced concrete building are used. However, once built this family of agents can be used again on other projects and is expandable by adding agents' or changing agents' for other types of buildings.

7. Conclusion

The integrated model based approach will positively impact construction in the 21st century. As discussed many positive experiences and case studies exist. Central to this visual system is now 4D and BIM. Many governments around the world are insisting design delivery and project management use these tools. This has accelerated the formation and strategies of Integrated Project Delivery. 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. At the end of the project all captured information can be organized and passed to the facility operations team. The development in the near future as follows:

- 3D, 4D and 5D methods will further establish within construction companies
- BIM tools with integrated construction management function will spread wider
- New professional roles, like the one of a BIM manager, will become more and more important
- Interfaces between ERP and BIM systems will be created
- Suppliers will be integrated into the processes of the construction industry (like it is already happening in the automobile industry)
- Pre-manufacturing which has become possible through BIM will increase
- The application of BIM in the field of modular construction will advance this kind of construction
- More and more building owners will ask for BIM as part of the contract
- Contract and remuneration terms will be impacted by BIM
- Standardization will find its way into the construction industry

Definitions

<u>Building Information Modeling and Management BIM(M)</u> *is a managed approach to the collection and exploitation of information across a project. At its heart is a computer-generated model containing all graphical and tabular information about the design, construction and operation of the asset.*
<u>Integrated project delivery (IPD),</u> *is a collaborative alliance of people, systems, business structures and practices into a process that harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency and effectiveness through all phases of design, fabrication, and construction. IPD can be considered as Lean Project Delivery.*
<u>Intelligent Computer Agents</u> - *is a collection of domain specific system agents that anticipate, generate, synthesize, analyze, evaluate, criticize, recommend, explain and optimize design related information (e.g. layout generator agent, lighting agent, cost agent, safety agent, etc.).*
<u>Computer Agent</u> - *is an executable entity working in a computer-based environment that has the ability to initiate actions internal or external to its domain and is able to interact with other agents.*
<u>Virtual Design and Construction (VDC)</u> *is the management of integrated multi-disciplinary performance models of design-construction projects, including the product (i.e., facilities), work processes, and organizations of the owner-design-construction-operation team in order to support explicit and public business objectives. Generally, based on a BIM, the models are logically integrated in the sense that they all can access shared data and if a user highlights or changes an aspect of one, the integrated models can highlight or change the dependent aspects of related models.*

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