Integrated project delivery (IPD) for maximizing design and construction considerations regarding sustainability

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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. IPD and BIM form essential tools and strategies in this decision environment. IPD linked to the “Big Room” concept will be discussed. The paper will focus on some of the challenges that are presented and ways that might assist in creating a safer, greener, more sustainable environment. The environment proposed is one that fully utilizes the strengths of intelligent collaborative computer agents that interact with the multi-discipline pre-construction team to interrogate and refine the design solution before construction commences. All contributors are collaboratively drawn into the design and pre-construction process. Time is saved because a concurrent problem-solving approach is adopted rather than a sequential problem-solving approach that has typified pre-construction activities in the past. In particular, the system proposed will assist the design process to deliver safely-built sustainable buildings. 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 safer, greener, more sustainable environment. 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

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1. Introduction

Over the past decade we have seen rapid movements in the UK, USA 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 teaming in an attempt to move away from adversarial contract conditions, thereby giving clients of construction services greater value. Sir Michael Latham’s 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), based on giving greater value to construction clients built on trust, that has continued the momentum towards change. More recently the U.K. Construction Minister Brian Wilson said that “[they] 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, yet 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 initially 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. We now see the rapid emergence of a whole range of integrated project delivery strategies.

2. VDC, BIM, and IPD

Design and Construction (VDC) is a collaborative, integrated process that considers both design and construction using 3D BIM models in combination with schedule data (4D) and cost estimating data (5D) (Fig. 1); a virtual object is created even before construction starts. 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 the project’s inception and onwards. Model, schedule and cost (GSA.2011) have to be coordinated from the beginning. For best results it is essential that VDC and BIM are implemented from the start 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 start of a project. In particular, the criteria and constraints of the various contributors need to be articulated and discussed as the model builds. For the approach to work effectively it is essential to include the experience of construction managers to maximize project benefits from the execution experience; indeed in the USA construction firms are leading the delivery of IPD. 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 or 5D models with a level of detail appropriate for execution are created.
2.1. Integrated Project Delivery (IPD)

Integrated Project Delivery (IPD) from conceptual design stages is the key to full consideration of the many criteria, constraints and features of the final design solution. The Integrated Project Delivery 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, other specialists. The “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 the satisfaction of some of these goals through using local resources, the assessment of the opportunities presented by the site itself, and the selection of the materials that are minimal polluters, sustainable and recyclable, etc. Similarly, just as the cost and time to build aspects are driven down by the collaborative team 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 cause environmental inefficiencies. Next, the functional requirements of the structure are reviewed to see if it is possible to reduce the demand from that standpoint, i.e. 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 which in regard to material and component efficiencies, sustainability, and cost and time to build will achieve its objectives. Both throughout the process and during 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.

![Fig. 1. Relation between 3D / 4D / 5D models.](image)

2.2. Collaboration in 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 amongst 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 whilst data that already resides in the model can be utilized by all participants. It also acts as an excellent team building tool: a shared, visual model to externalize and share project issues is invaluable in this regard. This rich data model on the completion of the project can be handed over to the Facilities Management team which provides the experience for operating and ensuring economic building performance.
3. Research methodology

In the author’s initial research 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:

- The foundation system
- The suspended floor system
- The enclosure system

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

3.1. Survey objectives

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

- 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).
- To discover the constraints each group imposed on others, and determine 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).
- To learn the requirements of architects, engineers and contractors to the greater levels of collaboration under consideration; what do the practitioners want? Latham [24], Egan [7] and others all said that greater integration was needed in the construction industry, but justifying making changes to the present process required concurrence from all the key participants.
- 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 as desirable, but it was important to find out what the actual users wanted. Also, participants were asked when the ideal time was to make these key decisions in the project development.

4. Research findings

The results were first analyzed and tabulated. Developing a design solution in each of these areas then generate criteria and constraints, which influence the 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. 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 queried to see if there was some consensus across the professions: construction management, engineers and
architects. The top seven of eighteen problems were placed in ranking order with all three professional groups, shown in Table 1.

Table 1. Production problems ranking.

| PROBLEM                                                   | Contractor | Engineer | Architect |
|-----------------------------------------------------------|------------|----------|-----------|
| Definition of the construction method                     | 1*         | 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%. The confidence of architects varied with a range of around 40% to 70%, but with the production problems that architects specifically identified as the most important, their confidence level was generally higher than that of engineers. The findings of the most important seven production problems (as defined in this survey) comparing all three disciplines are shown in Fig. 2.
The next question asked all groups at what stage in the design process the defined production problems should be first considered. The problems were arranged in the order of importance as defined in Table 3; the frequency of responses (%) from contractor (C), engineer (E) and architect (A) are measured. The results are shown in Table 2. 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 in particular, 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.

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 = Establishment of costs and budgets
- Problem 3 = Production of the time schedule (the program)
- Problem 4 = Determination of 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 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:

- Data on the levels of interaction/collaboration they found presently existed
- 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 domains. However, the perception of present levels of interaction differed by domain. For instance, contractors and architects concurred on the present levels of collaboration achieved between them but when contractors and engineers were compared, engineers felt that a much lower level of collaboration presently 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. 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. 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 proposed computer agent environment, 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.

For the system to interact effectively between the design intent and computer assistance, there has to be a full description of the objects. This description should resemble the designer's real world as closely as possible by including the object’s 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 as 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 [37] 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. 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.

Table 2. Stage to consider production problems.

| Design Stage: | Feasibility | Conceptual | Preliminary | Detailed |
|---------------|-------------|------------|-------------|----------|
| C = Contractor E = Engineer A = Architect |
| PRODUCTION PROBLEM: |
| 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 & 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 |

It must be stressed that this design assistance using computer agents is not intended to automate the design process. Agents would assist the designer or the 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

6. 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, 1994). The integrated partnership environment proposed for an agent hierarchy in the domain of Construction Management is shown in Fig. 2 above. 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 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 opportunities to take advantage of technology in communication systems (co-operative distributed, broadband, 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 proposed environment could be extended to continually monitor and assist throughout the life cycle of construction projects.

7. Conclusion

The results are conclusive that in comparison to the present process of construction development, all participants would prefer greater levels of collaboration to review and resolve design and construction problems to find the best solution. This is required at much earlier stages of the project than currently occurs.

To achieve the outlined performance improvements, 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 desirable. The research demonstrates that 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 client’s 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.

Furthermore, the integrated model-based approach will positively impact construction in the 21st century. Many positive experiences and case studies exist and many of these new collaborative practices are becoming standard. 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 [15] 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 is 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 (akin to what 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
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