NEXT GENERATION OF CONSTRUCTION PLANNING AND CONTROL SYSTEM: THE LEWIS APPROACH

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ABSTRACT

The traditional construction planning and control system, as described in the Guide to the Project Management Body of Knowledge published by the Project Management Institute, has been criticized in terms of insufficiency of its underlying theories and ineffectiveness of its techniques. Based on this traditional approach, major problems including separation of execution from planning and after-the-fact variance detection are typically acknowledged. It is evident that the current practices are still suffering from low productivity and high production waste. To address these deficiencies, this paper proposes a vision for the next generation of construction planning and control as multi-constraints, visual, and lean-based system. An implementation of this vision has resulted in a prototype called “LEWIS – Lean Enterprise Web-based Information System for Construction”. An elaboration on the system framework and an underpinning methodology to integrate information and constraint management with 4D planning and control system is the focus of this paper. It is anticipated that successful implementation of this system will enable generation of reliable plans and constraint-free assignments to the work face, which in turn, reduce production wastes and improve on-site productivity.

KEY WORDS

Constraint management, information system, lean construction, planning and control, 4D visualization

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INTRODUCTION

Construction planning and control is identified among the top potential areas needing improvements. A review of literature and a case study of a 120 million pounds Private-Finance-Initiative (PFI) project in UK confirms typical problems regarding separation of execution from planning and after-the-fact variance detection (Sriprasert and Dawood 2002). Several researchers agree that major causes of these problems are inadequacy of traditional project management theory and improper applications of information technologies (Ballard 2000; Koskela 2000; Koskela and Howell 2001). Currently, management is much more concerned about contract and cost rather than production at construction work face. Furthermore, a review of IT applications in construction by Sriprasert and Dawood (2001) highlights the need for tools and techniques for execution planning and management of work-face information. Without production-oriented management and supported tools, it is evident that the current practices are still suffering from low productivity and high production waste (Egan 1998; Santos 1999).

Based on the above, a necessity to treat these deficiencies is apparent and timely. This paper addresses the problems by firstly investigates major drawbacks of the traditional construction planning and control system. Then the paper identifies requirements for the next generation of construction planning and control system through a synergy of 1) an innovative construction project management paradigm namely lean construction and 2) the advanced information technologies namely web-based information management and 4D visualization. This has been resulted in a prototype called “LEWIS – Lean Enterprise Web-based Information System for Construction”. As the main focus of this paper, the system framework and the underpinning methodology to integrate information and constraint management with 4D planning and control system has been elaborated. It is anticipated that successful implementation of this system will enable generation of reliable plans and constraint-free assignments to the work face, which in turn, reduce production wastes and improve on-site productivity.

CONSTRUCTION PLANNING AND CONTROL

TRADITIONAL SYSTEM

The traditional construction planning and control system, as described in the Guide to the Project Management Body of Knowledge (PMBOK Guide) published by the Project Management Institute (Duncan 1996), has been criticized in terms of insufficiency of its underlying theories and ineffectiveness of its techniques. Regarding the underlying theories, Koskela (2000) highlights negligence of physical flow between activities in the traditional conversion model. Koskela and Howell (2001) further discusses shortcomings from the simplicity and insufficiency of two underlying theories, which are ‘management-as-planning’ for planning and execution and ‘thermostat model’ for control. These shortcomings can be summarized in three aspects including: 1) unrealistic role of planning and poor short term planning; 2) lack of systematic way of managing execution; and 3) narrow view of control as measuring and taking corrective action rather than as a process of learning.

For planning and control technique, the classic Critical Path Method (CPM) has been widely used in the construction industry since its invention in the 1950s. The CPM applications have well served project managers in preparing project proposals, managing personnel and resources, tracking delays and change orders, instituting as a basis for progress payments, and coordinating with subcontractors (Jaafari 1984; El-Bibany 1997). However, its suitability has been widely criticized and three major drawbacks can be identified as follows:

- *Inability to cope with non-precedence constraints* – In the real world, construction posses various kinds of constraints ranging from physical constraints (i.e. topology, space, safety, and environment), contract constraints (i.e. time, cost, quality, and special agreement) to resources and information constraints (i.e. availability and perfection). Unfortunately, CPM considers only time and precedence constraints among activities (Pultar 1990; Shi and Deng, 2000). Its underlying network representation is proven to be inadequate to represent and integrate more problems in construction management (El-Bibany 1997).
- *Difficulty in plan evaluation and communication* – The CPM schedule is graphically presented in either a form of Gantt chart (Bar chart with relationships) or a form of precedence diagram. To evaluate and communicate the plan, project participants must mentally associate this schedule information with the description of the physical building (i.e. drawings and/or 3D project model) as well as other technical information (i.e. specifications and method statements). This has been proven difficult especially when there is a need to analyze effects of changes to the overall sequence of construction (McKinney and Fischer 1998).
- *Inadequacy for work-face executions* – As projects enter their construction phase, detailed short term planning is delegated to engineers, superintendents, or foremen. Rather than employing the CPM, simple Bar chart or activity lists are dominant techniques for this detailed planning (Mawdesley et al. 1997). Several studies provide convincing reasons why the CPM is not widely utilised. Levitt et al. (1988) stated that the existing CPM tools do not provide adequate support for analysis of constraints at operational level. Resource allocation, smoothing or leveling procedures are incapable of ensuring full continuity for a production crew or process (Jaafari 1984). For complex projects, field personnel find the CPM schedules confusing and, therefore, less useful (Pultar 1990). Large amount of efforts are required to re-plan and redraw the network each time it was updated (Jaafari 1996). Furthermore, the CPM has inflexibility and lack of expressiveness to cope with the varied pattern of construction in the field (Jaafari 1996; Choo et al. 1999).

NEXT GENERATION SYSTEM

The research presenting in this paper can be best described as a ‘problem-solving research’ in which a problem from practice is identified and all intellectual resources are brought to bear upon the solution (Phillips and Pugh 1987). Aiming to treat the deficiencies of the traditional planning and control system, identification of an improvement strategy through a synergy of an innovative construction project management paradigm and the state-of-the-art information technologies could proof useful.

Among the other process-led paradigms such as construction process re-engineering and concurrent engineering, lean construction concept is chosen because of its focus on managing the production. Many practical techniques including: 1) Last Planner (Ballard 2000); 2) look-ahead planning (Ballard 1997); 3) pull strategies (Ballard 1998); and 4) transparency (Santos et al. 1998) can be adopted. By encouraging planning at crew level, measuring planning system through weekly percent plan completion (PPC), and identifying and acting on root causes of failures, an improvement of plan reliability and productivity is apparent in several trial implementations (Ballard et al. 1996; Conte 1998).

For the technology-led perspective, IT is being regarded as one of the most prevalent facilitators of process change (Chan and Land 1999). Recent works and visions for construction IT research are gearing towards the accomplishment of innovative communication and information management using model driven, life cycle thinking, internet-based, simulation, and visualization strategies (Gudnasson 2000; Sarshar et al. 2000; Amor and Betts 2001). Examples of these are a central project model that facilitated the co-ordination, exchange, and sharing of project information from a web-based repository and the use of 4D CAD and virtual reality for construction product/process simulation and visualization throughout the project life cycle.

As a result of the amalgamation of these process-led and technology-led strategies, a vision for the next generation of planning and control can be proposed as multi-constraints, visual, and lean-based system. The future system should have flexibility and agility to respond (both proactively and reactively) to variability of construction constraints affecting work status. Advanced visualization techniques such as 4D (3D + time) (McKinney and Fischer 1998) and Virtual Reality (VR) (Retik and Shapira 1999) should be utilized for more effective evaluation and communication of schedule and constraint information. In this case, the system should allow planners to simulate various construction alternatives and inform possible constraints such as technological dependencies, spatial conflicts, hazardous working conditions, as well as availability of information and resources for each alternative. Based on the lean construction concept, all constraints must be satisfied prior to releasing assignments to the work face, in turn, enhances reliability of planning and minimize production wastes.

LEWIS FRAMEWORK

An implementation of the proposed vision has resulted in a prototype called “LEWIS – Lean Enterprise Web-based Information System for Construction”. The system is proposed as a tool for endorsing production-oriented culture and bridging the gap of management, planning, and execution in the construction enterprises. It is uniquely designed as a web-based information repository that facilitates co-ordination and communication among upstream supportive organisations, planners, and work-face personnel. In this case, the supportive organisations can be informed of the current project status and requirements at the work face in real time. Planners can be informed of ability of the supportive teams to supply required information and resources in the Just-In-Time manner and, in turn, can realistically updated execution plan and assure quality assignments and instructions to the work face. Finally, work-face personnel can retrieve information and send request or discuss problems to the responsible teams promptly. An overall architecture of the LEWIS system is presented in Figure 1.

The design of LEWIS is based on a compound applications concept in which data extensibility and making use of the existing capabilities in off-the-shelf application packages can be beneficial (Heindel and Kasten 1997). The core of the architecture is a central relational database management system (RDBMS) where product model (CAD), process model (schedule), and information (i.e. drawings, specifications, method statements, resources information, etc.) are integrated. Microsoft SQL Server 2000 is chosen for the database implementation because of its wide availability, scalability, and multi-users supportability. More importantly, an ongoing research project on the development of IFC model server at VTT, Finland is based on this database system (Adachi 2001).

For data input, 2D or 3D product data from CAD software (i.e. AutoCAD 2000 or Architectural Desktop 3.3) can be automatically extracted to the database using a developed Visual Basic for Applications (VBA) macro. In a simpler way, the process data from project planning and scheduling software (i.e. MS Project or Primavera) can be extracted to the database using Open Database Connectivity (ODBC) and a built-in import/export template feature. For data regarding information, resources, and their availability, it can be input by each responsible supportive organisation as construction being progressed.

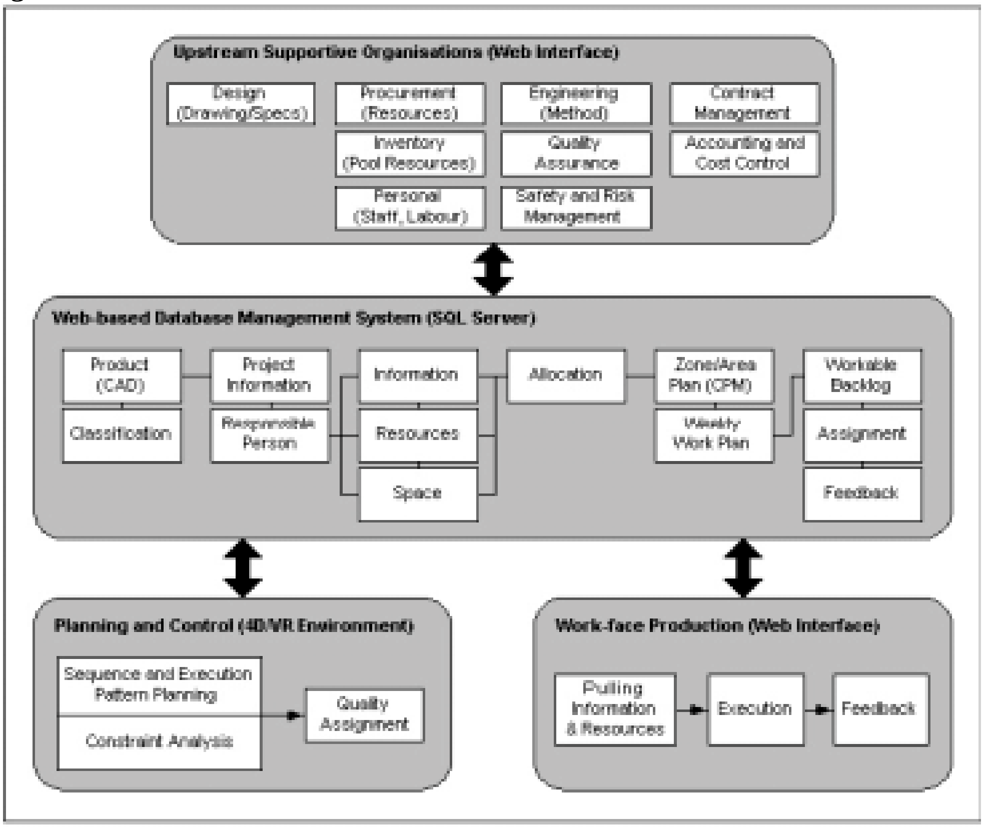


Figure 1: LEWIS System Architecture

Subject to availability of the data input, meaningful data analysis and reports such as readiness of all drawings required next week and workable backlog (constraint-free activities in this period) can be generated using Structure Query Language (SQL). Furthermore, to achieve web-based functionality, HTML, Active Server Pages (ASP), and VB Script are utilised to create web interfaces, retrieve and display data from the database, develop search capability and, last but not least, manage data security. Figure 2 illustrates web interfaces presenting a query result for constraint activities planned to execute next month.

Currently, web interface of the LEWIS contains a set of pull down menus that enable users to access different categories of project information ranging from general project information, geometrical product data, CPM schedule and weekly work plan, project documents, resources information, to 4D simulation clips (AVI files) and VRML model presenting work progress and constraints each period. Constraints regarding availability of information and resources for each activity can also be queried. These results will then serve as an input to the 4D constraint-based planning and control module (elaborated in the next section) where sequence of activities and associated constraints can be simulated, visualised, and evaluated. It should be noted that possibility to develop user-friendly interfaces for work-face personnel in mobile devices or touch screen monitors is being investigated.

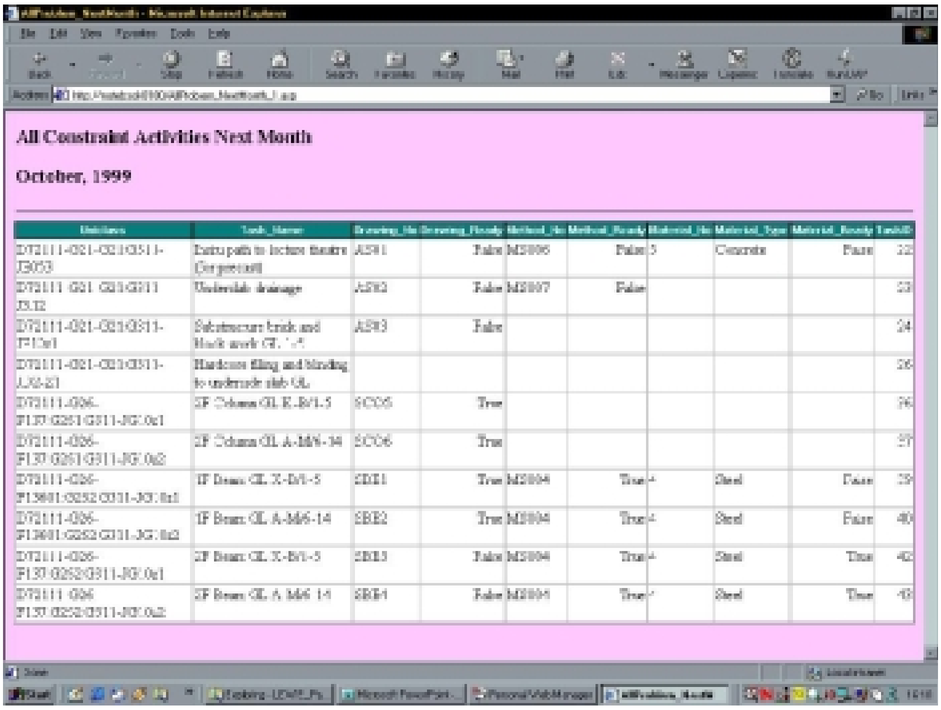


Figure 2: Web Interface Presenting a Look-Ahead Query for Constraint Activities

4D CONSTRAINT-BASED PLANNING AND CONTROL SYSTEM: A PROPOSED SOLUTION

SYSTEM FRAMEWORK

A prototype called 4D constraint-based planning and control system is proposed to fulfil the requirements of being multi-constraints, visual, and lean-based system. This system is a major part of the LEWIS – Lean Enterprise Web-based Information System for Construction presented in the previous section. A framework of the system is illustrated in Figure 3. Input of the system is information generated throughout the construction phase by upstream supportive organizations (i.e. designers, engineers, con-tractor head office, suppliers, and subcontractors). The information consists of: 1) design information (2D/3D CAD drawings or the IFC product model); 2) managerial objectives (i.e. to achieve least-cost, least-time, limited resource schedule or any feasible combinations of the three (Alkayyali and Minkarah 1993)); and 3) information from the LEWIS main repository that gathers various constraint information and feedback from the work face. Based on the managerial objectives and available information, planners will be able to set priority and select active constraints (subset of all constraints) to be concerned in the planning and scheduling process (Shi and Deng 2000). In other word, when project information becomes more detailed with construction progress, the planners will be able to select more active constraints (i.e. weather condition and availability of resources) for a particular set of critical activities (weather sensitive and resource-constrained activities). With assistance from supportive systems (including constraint detection knowledge, algorithms for constraint satisfaction, and constraint visualization), the planners can then generate the first feasible baseline plan. During construction, when more information is available, short-term look-ahead planning can be performed in order to check the active constraints and request for co-operations from the supportive organizations to satisfy all the constraints prior to releasing activities into workable backlog (constraint-free activities).

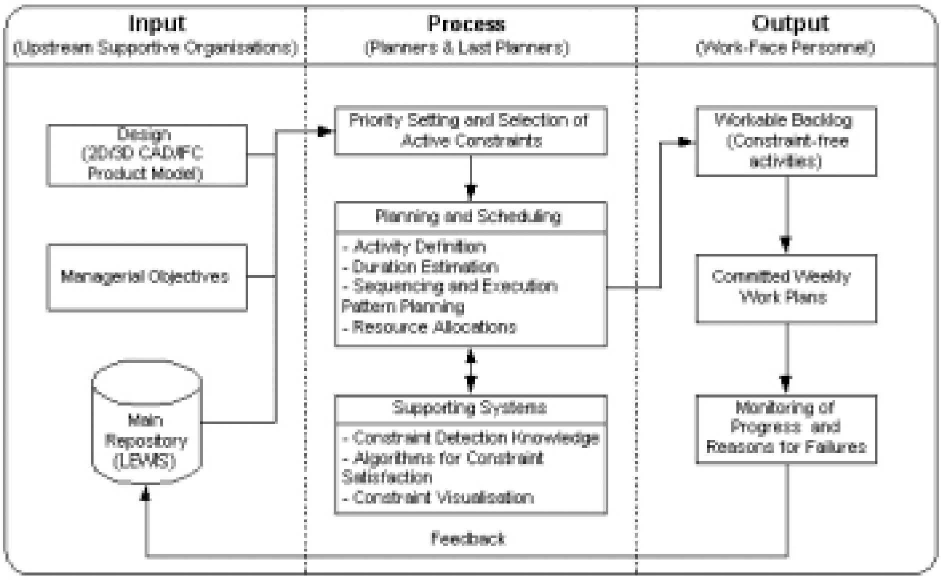


Figure 3: 4D Constraint-Based Planning and Control Framework

From the workable backlog, the last planners (i.e. foremen) can generate weekly work plans and make commitment on what they 'can' do rather than what they 'should' do. Finally, completion of the weekly work plans will be monitored and reasons for failures will be fed back to the LEWIS. As a consequence, the upstream supportive organizations will be informed of the actual status and, in turn, be able to prioritize their deliverables to the work face in the Just-In-Time manner. In addition, the planners will be able to analyze impact against the baseline plan and update it accordingly.

SYSTEM DEMONSTRATION

The 4D constraint-based planning and control prototype has been developed using Visual Basic for Application (VBA) embedded in the Autodesk Architectural Desktop 3.3 (IFC 1.5.1 supported) environment. Currently, by utilizing information from the LEWIS, sequence of activities and associated constraints can be simulated and visualized in the 4D and VR fashions. Details of the schedule, constraints, related information, and workable backlog can also be annotated. The prototype has been primarily tested with real product and process data from an 8 million pounds, School of Health Project at the University of Teesside. Technical details on the data capture and methodology to create the 4D model are reported in Dawood et al. (2002a, 2002b). Since the prototype is emerged after the completion of this project, data regarding availability of information and resources is assumed in the primary model. The full scale testing on two real-life projects including a 1.6 million pounds primary school project and a 6 million pounds sport center project will be conducted. Figure 4 illustrates main input for generation of 4D constraint-based model including 3D product model, project schedule, and constraint information from the LEWIS system.

Figure 5 illustrates the prototype interfaces including 4D simulation console, list of progressing and finished activities, browser of product-based work breakdown structure, and annotation window for information and constraints. A sample comparison among baseline, actual, and forecasted 4D models is also presented. It should be noted that, in order to visualize space overload, this system can obtain outputs from the VIRCON critical space analysis tools (North and Winch 2002).

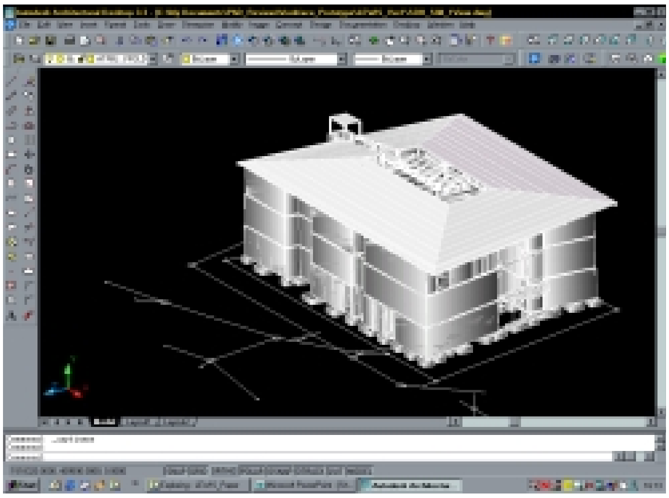
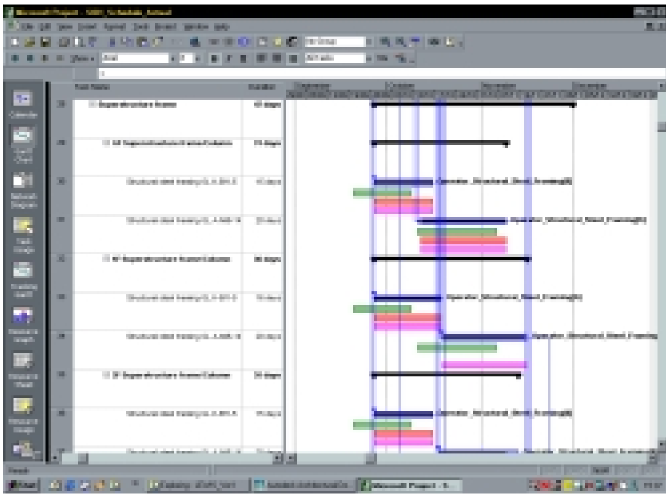
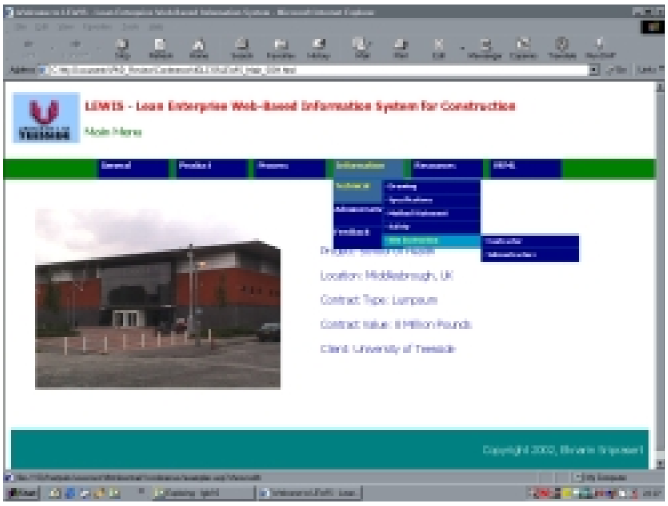
	**3D Product Model** The presented 3D product model is developed in the Autodesk Architectural Desktop Version 3.3 (IFC 1.5.1. Supported) The model is divided into several groups (i.e. GF Column GL 1-5 and GF Column GL 6-14) reflecting construction sequences and execution patterns.
	**MS Project Schedule** The product-based work breakdown structure based on the Uniclass classification is used as an approach to organise activities (Dawood et al., 2002a). The schedule is represented by four different bars including progress tracking, baseline, actual, and forecasting bars.
	**Web-based Information and Constraint Management System** The figure presented the main interface of the LEWIS. This system functions as an information hub where supportive organisations can inform ability to supply information and resources (dynamic constraints) for each scheduled activity.

Figure 4: Main Input for Generation of 4D Constraint-Based Model.

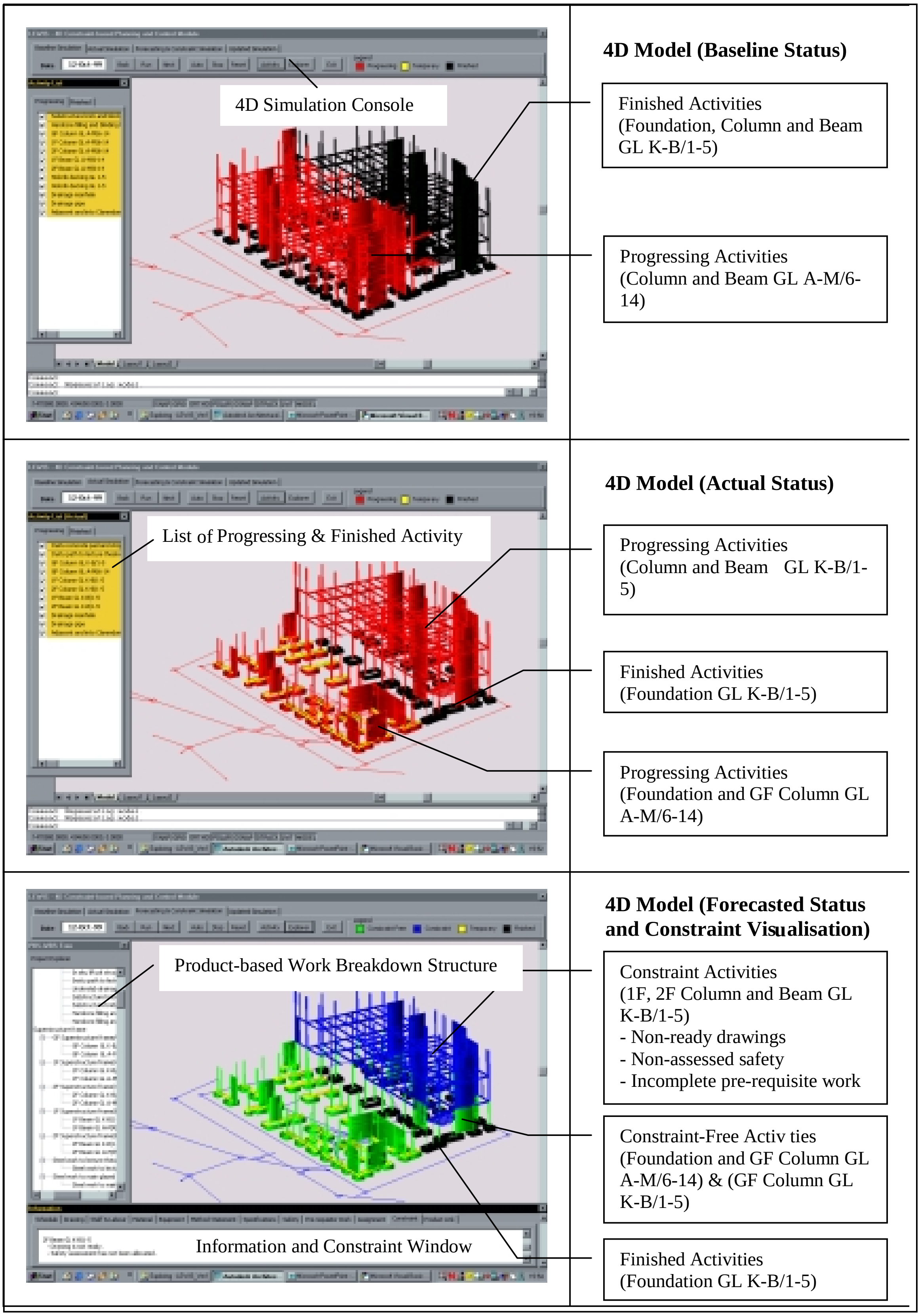


Figure 5: 4D Constraint-Based Planning and Control System.

COMPARISON BETWEEN LEWIS AND OTHER LEAN-BASED SYSTEMS

Prior to the development of LEWIS, two main systems have been built based on the lean construction concept. The first system, 'WorkPlan', was developed as a standalone database application for specialty contractors to develop weekly work plans based on the Last Planner concept (Choo et al. 1999). This system was further integrated with 'Deplan' system to extend its applicability to the planning, scheduling and control of design (Hammond et al. 2000). Furthermore, the system was also integrated with 'WorkMovePlan' system for distributed planning and coordination and space scheduling (Choo and Tommelein 2000). The second systems, 'Integrated Production Scheduler', was developed as a web-based look-ahead scheduling tool (Chua et al. 1999). A useful concept in buffer management, which helps managing uncertainties in the supply chain and information flow, was later incorporated into the system (Chua and Jun 2001).

The LEWIS system, in complementary with the above two systems, has been attempting to integrate upstream management systems with planning and downstream production management systems. The system incorporates product data and information management functionality (input for planning) and has potential to send JIT instructions to work-face personnel (output from planning). For the planning, 4D constraint-based system that can evaluate and visualize both physical constraints (i.e. technological dependencies and temporal/spatial aspects) and enabler constraints (i.e. availability of information and resources) has been introduced. The system is also in line with standard classification system (Uniclass) and specification for computer-based information exchange (IFC), therefore, facilitates communication and information exchange across platforms.

CONCLUSIONS

Aiming to overcome typical problems of separation of execution from planning and after-the-fact variance detection currently experienced in the real practices, a vision for the next generation of construction planning and control is proposed as multi-constraints, visual, and lean-based system. An implementation of this vision has been resulted in a prototype called "LEWIS – Lean Enterprise Web-based Information System for Construction". The system framework and an underpinning methodology to integrate information and constraint management with 4D planning and control system are elaborated in this paper. A demonstration of the system using real case's product and process data with assumption for resources and information constraints is also presented. Two real life case studies will be conducted so as to obtain lessons on system improvement and realize benefits of the system. It is anticipated that the typical problems will be overcome by a successful implementation of this system which, in turn, reduce production wastes and improve on-site productivity.

REFERENCES

Adachi, Y. (2001). "Introduction of IFC Model Server." *VTT-MEMO-ADA-05*. <http://cic.vtt.fi/projects/ifcsvr/index.html> (last visited: 04/2002).

Alkayyali, O. J., and Minkarah, I. A. (1993). "An Automated Cost Planning System (ACPS) for Construction Projects." *Proceedings of the 5th International Conference on Computing in Civil and Building Engineering*, ASCE.

Amor, R., and Betts, M. (2001). “Information Technology for Construction: Recent Work and Future Directions.” *Proceedings of CIB w78 Conference,* CSIR, South Africa, 1-1 – 1-12.

Ballard, G., Casten, M., and Howell, G. (1996). “PARC: A Case Study.” *Proceedings of the Fourth Annual Conference of the International Group for Lean Construction (IGLC-4)*, Birmingham, UK.

Ballard, G. (1997). “Lookahead Planning: The Missing Link in Production Control.” *Proceedings of the Fifth Annual Conference of the International Group for Lean Construction (IGLC-5)*, Gold Coast, Australia.

Ballard, G. (1998). “Implementing Pull Strategies in the AEC Industry.” *LCI White Paper-1*, Lean Construction Institute.

Ballard, G. (2000). *The Last Planner System of Production Control*. PhD Thesis. University of Birmingham, UK.

Chan, P. S. and Land, C. (1999). “Implementing reengineering using information technology.” *Business Process Management Journal*, 5 (4) 311-324.

Choo, H. J., Tommelein, I. D., Ballard, G. and Zabelle, T. R. (1999). “WorkPlan: Constraint-Based Database for Work Package Scheduling.” *Journal of Construction Engineering and Management*, 125 (3) 51-160.

Choo, H. J., and Tommelein, I. D. (2000). “WorkMovePlan: Database for Distributed Planning and Coordination.” *Proceedings of the Eight Annual Conference of the International Group for Lean Construction (IGLC-8)*, Brighton, UK.

Chua, D. K. H., Jun, S. L., and Hwee, B. S. (1999). “Integrated Production Scheduler for Construction Look-Ahead Planning.” *Proceedings of the Seventh Annual Conference of the International Group for Lean Construction (IGLC-7)*, Berkeley, CA.

Chua, D. K. H., and Jun, S. L. (2001). “Constraint Modeling and Buffer Management with Integrated Production Scheduler.” *Proceedings of the Ninth Annual Conference of the International Group for Lean Construction (IGLC-9)*, Singapore.

Conte, A. S. I. (1998). “Last Planner, Look Ahead, PPC: A Driver to the Site Operations.” *Proceedings of the Sixth Annual Conference of the International Group for Lean Construction (IGLC-6)*, Guaruja, Brazil.

Dawood, N., Sriprasert, E., Mallasi, Z., and Hobbs, B. (2002a). “Development of an Integrated Information Resource Base for 4D/VR Construction Process Simulation and Visualisation.” *Proceedings of CIB w78 Conference*, Aarhus, Denmark.

Dawood, N., Sriprasert, E., Mallasi, Z., and Hobbs, B. (2002b). “4D Visualisation Development: Real Life Case Studies.” *Proceedings of CIB w78 Conference*, Aarhus, Denmark.

Duncan, W. (Director, Standards Committee) (1996). *A Guide to the Project Management Body of Knowledge.* PMI Publications, Sylva, NC.

Egan, J. (1998). “Rethinking Construction.” *Report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction.* DETR, London. <http://www.construction.detr.gov/uk/cis/rethink/index.htm> (last visit: 08/2001).

El-Bibany H. (1997). "Parametric Constraint Management in Planning and Scheduling: Computational Basis." *Journal of Construction Engineering and Management,* 123 (3) 348-353.

Gudnasson, G. (2000). *Construction Information Technology 2000: Taking the Construction Industry into the 21st Century*, Icelandic Building Research Institute, ISBN 9979-9174-3-1.

Hammond, J., Choo, H. J., Austin, S., Tommelein, I. D., and Ballard, G. (2000). "Integrating Design Planning, Scheduling, and Control with Deplan." *Proceedings of the Eight Annual Conference of the International Group for Lean Construction (IGLC-8),* Brighton, UK.

Heindel, L. E. and Kasten, V. A. (1997). "P++: A Prototype PC-Based Enterprise Management System." *International Journal of Project Management*, 15 (1) 1-4.

Jaafari, A. (1984). "Criticism of CPM for Project Planning Analysis." *Journal of Construction Engineering and Management*, 110 (2) 222-233.

Jaafari, A. (1996). "Time and Priority Allocation Scheduling Technique for Projects." *International Journal of Project Management,* 14 (5) 289-299.

Koskela, L. (2000). *An Exploration towards a Production Theory and its Application to Construction.* Dr. Tech. Dissertation, VTT Publication, Espoo, Finland.

Koskela, L. and Howell, G. A. (2001). "Reforming Project Management: The Role of Planning, Execution and Controlling." *Proceedings of the Ninth Annual Conference of the International Group for Lean Construction (IGLC-9),* Singapore.

Levitt, R. E., Kartam, N. A., and Kunz, J. C. (1988). "Artificial Intelligence Techniques for Generating Construction Project Plans." *Journal of Construction Engineering and Management*, 114 (3) 329-343.

Mawdesley, M., Askew, W., and O'Reilly, M. (1997). *Planning and Controlling Construction Projects.* Longman, London.

McKinney, K., and Fischer, M. (1998). "Generating, Evaluating and Visualizing Construction Schedule with CAD Tools." *Automation in Construction*, 7 (6) 433-447.

North, S., and Winch, G. M. (2002). "VIRCON: A Proposal for Critical Space Analysis in Construction Planning." *Proceedings of ECPPM Conference, Slovenia, 9-11 September 2002*, Balkema, Rotterdam.

Phillips, E. M. and Pugh, D. S. (1987). *How to Get a PhD*. Open University Press, UK.

Pultar, M. (1990). "Progress-Based Construction Scheduling." *Journal of Construction Engineering and Management*, 116 (4) 670-688.

Retik, A., and Shapira, A. (1999). "VR-Based Planning of Construction Site Activities." *Automation in Construction*, 8 (6) 671-680.

Santos, A. D., Powell, J., Sharp, J., and Formoso, C. T. (1998). "Principle of Transparency Applied in Construction." *Proceedings of the Sixth Annual Conference of the International Group for Lean Construction (IGLC-6)*, Guaruja, Brazil.

Santos, A. D. (1999). *Application of Flow Principles in the Production Management of Construction Sites.* PhD Thesis. University of Salford, UK.

Sarshar, M., Betts, M., Abbott, C., and Aouad, G. (2000). *A Vision for Construction IT 2005-2010*, RICS (Royal Institute of Chartered Surveyors), Research Papers Series, December 2000, 1-42.

Shi, J. J., and Deng, Z. (2000). “Object-Oriented Resource-Based Planning Method (ORPM) for Construction.” *International Journal of Project Management*, 18 (3) 179-188.

Sriprasert, E. and Dawood, N. (2001). “Potential of Integrated Digital Technologies (IDT) for Construction Work-Face Instruction.” *Proceedings of AVRII and CONVR 2001 Conference*, Gothenburg, Sweden.

Sriprasert, E. and Dawood, N. (2002). “Lean Enterprise Web-Based Information System for Construction (LEWIS): Justification and Framework.” *Proceedings of CIB w78 Conference*, Aarhus, DK.