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Integration of 4D and Model-Based Scheduling

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Abstract
This paper explores the possibility of combining two important scheduling paradigms: 4D scheduling and model-based scheduling. 4D scheduling emphasizes the animation and visualization of schedules by adding the time dimension to 3D building models. "Model-based" scheduling refers to a process where the user builds a model-based schedule by structuring it according to a well-established methodology or, in some cases, using/modifying a template schedule. One may well say that CPM represents the first generation of model-based scheduling since it directs the planner to think carefully the dependencies between activities. Some of the later developments such as LoB (Line-of-Balance), Last Planner and ALoB (Advanced Line-of-Balance) directly address the characteristics of construction operations in addition to their logic. Basically, the main objective of these solutions is to reach an optimal solution, i.e., the longest path through a network in the case of CPM (resulting in the minimum project duration), and the optimum use of resources in the case of LoB (resulting in the minimum project duration alongside a smooth and efficient use of resources).

This paper first reviews the characteristics of the 4D scheduling paradigm and discusses the related research and development efforts. Next, model-based scheduling and its applications are described. Finally the paper focuses on the hypothetical concept of combining these two paradigms.

Keywords
Scheduling, Line of balance, Information system, 4D modeling

1. Introduction

Schedule animation communicates the logic of schedules in a novel and effective manner and can naturally lead to improved schedules as it seems to nicely meet practitioners' needs for more communicative solutions compared with traditional Gantt charting. Additionally, 4D scheduling allows managers to assess the quality of a schedule and to detect possible shortcomings. However, in 4D scheduling, the quality of a schedule is studied retrospectively, i.e., after the fact. Also, 4D scheduling does not produce optimal schedules. But these problems seem to have been resolved in model-based scheduling.

Model-based systems are increasingly being explored, developed and used for project management in construction. Integrating 4D modeling and model-based scheduling can be the pathway to future solutions for scheduling.

This paper includes (i) the review of the 4D scheduling paradigm, (ii) a description of model-based scheduling and its applications, and, (iii) a discussion of the hypothetical concept of combining these two paradigms.

2. 4D Modeling in the Literature

4D planning is a technique that integrates 3D CAD models with construction activities (schedule), which enables clear visualization of a construction program as an animated sequence (Dawood and Sikka, 2008). In the following sections, the concept of 4D modeling is reviewed with the help of a literature survey, and the relationship between 4D and Line of Balance (LoB) is briefly discussed.

2.1 The 4D CAD Concept

4D CAD is a concept that combines an object oriented 3D CAD model with time (Arditi, 2008). 4D CAD models are usually created by linking building components from 3D CAD models with activities that follow from CPM schedules, (e.g., Koo and Fischer, 2000) and LoB schedules, (e.g., Jongeling and Olofsson, 2007). McKinney and Fischer (1998) studied the effectiveness of a hybrid 4D application using the contemporary software, Primavera, AutoCAD, Jacobus Simulation toolkit, and Walkthru. Porkka and Kähkönen (2007) analyzed the currently available 4D applications, i.e., Visual Product Chronology (Kähkönen and Leinonen, 2003), Enterprixe, Tekla Structures, Common Point Project 4D, Ceco4d, and Navisworks JetStream (Software Links, 2009). There are several additional 4D CAD systems developed by researchers, e.g., Virtual Construction-VIRCON (Dawood *et al*., 2005), Progress Monitoring System with GIS; PMS-GIS (Poku and Arditi, 2006). An overview over the current state of 3D/4D models in the AEC industry and how they support the construction processes is given by Hartmann and Fischer (2007). There are also various applications of 4D including efforts to combine 4D with other technologies such as photogrammetry (Shih and Huang, 2006), video imaging technology (Abeid and Arditi, 2003), and 4DIVE (Doulis *et al*., 2007).

The benefits of using 4D CAD models include effectively allocating resource and work group assignment, easily training inexperienced planners (Heesom and Mahdjoubi, 2004), simulating and analyzing what-if scenarios before commencing work execution on site (McKinney and Fischer, 1998), checking the integrity of the master schedule, revealing potential time-space conflicts and logistical problems, supporting the communication of product and process knowledge, and efficiently tracking the work progress (Koo and Fischer, 2000). On the other hand, the limitations of 4D applications are recorded by Heesom and Mahdjoubi (2004). One may well say that CPM represents the first generation of model-based scheduling since it directs the planner to think carefully the dependencies between activities. 4D models are mostly built using CPM; however, with some of the later developments such as LoB (Line-of-

Balance), Last Planner and ALoB (Advanced Line-of-Balance) which directly address the characteristics of construction operations in addition to their logic, 4D models are being built to overcome the lack of information about resources and locations of crews in the activities linked to 3D CAD models.

2.2 4D Modeling and Line of Balance

The Line of Balance (LoB) method is a graphical scheduling technique and a location- and resource-based management system to plan and to manage continuous work flows in specified locations with balanced resource use (Firat *et al*., 2008a). Scheduling with LoB is oriented towards the required delivery of completed units and is based on knowledge of how many units must be completed on any day so that the programmed delivery of units can be achieved (Arditi *et al*., 2002). The main strength of the location-based scheduling such as LoB is the use of resources with paced and balanced activities. In other words, all activities are scheduled to continue from one location to another without any interruptions, resulting in the minimum project duration alongside a smooth and efficient use of resources.

Recent efforts to integrate 4D modeling and LoB have resulted in promising results (e.g., Staub-French *et al*., 2008; Norberg, 2008). Björnfort and Jongeling (2007) confirm that the application and integration of LoB and 4D CAD workspace simulations can support the set-up of a balanced and steady work flow in the construction process. Overall, this review reveals that despite promising developments about 4D modeling and LoB in use and being researched, there is still a need for extensive research to increase the usability of these developments. Integrating 4D modeling and model-based scheduling could be a novel approach that could facilitate this objective.

3. Model-Based Scheduling

“Model-based” scheduling refers to a process where the user/planner builds a model-based schedule by structuring it according to a well-established methodology or, in some cases, using/modifying a template schedule. Because effective planning is one of the most important aspects of a construction project (Heesom, and Mahdjoubi, 2004), model-based scheduling systems have been researched by academicians and software developers who hold the view that it can improve the quality and efficiency of scheduling. However, due to the complexity and uniqueness of construction projects, it is difficult to automate construction processes. On the other hand, since there are many repeating and/or similar activities in different building projects, it is easier to use a model-based approach. As verified by test results (Firat *et al*., 2008a), model-based scheduling can be achieved by integrating Building Information Model (BIM) technology and Advanced Line of Balance (ALoB) with the input of an interactive planner (Firat *et al*., 2008b).

3.1 Advanced Line of Balance

“Advanced Line of Balance (ALoB)” is not only a modified location- and resource-based scheduling method, but also a graphic device and a project management tool that enables a manager/planner to see at a glance which of the many activities in a complex operation are "balanced”, i.e., have similar production rates and are “paced”, i.e., the workflow and the flow of resources are not interrupted as operations move from location to location. On the basic principles of LoB were modified and further developed into ALoB at Helsinki University of Technology in efforts that started back in 1985 by Kiiras and Kankainen (Kiiras. 1989). The recent outcomes of these efforts are software such as DynaProject™, which has evolved today into Vico Control (previously Graphisoft Control) (Software Links, 2009).

The effective use of sections is the main difference between ALoB and LOB. Locations must be identified so small that activities form a chain without overlapping. A location is defined as a physical part of a building in which activities are completed in their entirety. The locations need not be equal in size or even in content (Firat *et al*., 2008a). The sectioning feature increases the controllability of construction projects. These sections are further divided into working spaces. Another key point in ALoB is reserving one location for one work at a time. In other words, only one critical activity can take place at a time; it sets the pace, and all activities are scheduled to continue from one location to another without any interruptions, i.e., Location Breakdown Structure (LBS) is formed. After phasing the activities that are dependent on each other, dimensioning and sequencing of the activities are performed. Dimension and sequence information is retrieved from the Building Construction Information Model (see next chapter). Proper phasing of activities and clearly assigning the dependencies between activities results in a list of generic model activities that in turn opens the way to model-based scheduling (Firat *et al*., 2007). An optimum process is a balanced production where all activities have similar production rates (i.e., are synchronized).

In Figure 1, an example of ALoB is given. This technique is successfully used in ship building. When same resource groups have been increased in three different sections (locations) the project completion time can be shortened. Figure 1 show this gain in time; however managers must make the feasibility study in order to understand the ratio between the gain and extra resource input.

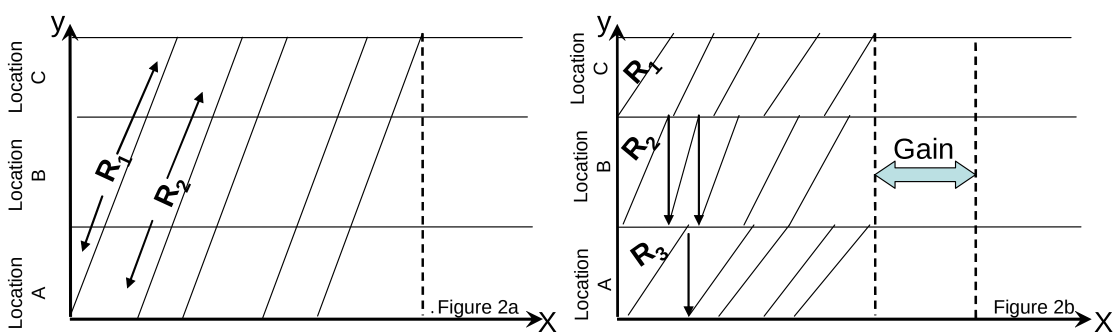

Figure 1: a) Linear Production with 2 Different Resource Groups in Three Different Locations

b) Linear Production with 3 Similar Resource Groups in Three Different Locations

3.2 Building Construction Information Model

In line with Eastman *et al*.,'s (2008) definitions, the BIM concept adopted in this paper involves not only a virtual model of a building, nor only the information modeling activity, but a whole information modeling process with interactive human users storing data in libraries and updating them periodically. The Building Construction Information Model (BCIM) is a dynamic, changeable library-based information model using commercial software to allow the semi-automatic, partly interactive generation of design and production information such as drawings, specifications, bills of quantities, estimates, budgets, schedules, and procurement plans and status reports.

Figure 2 shows the ideal BCIM with its consistent models and also with its updating mechanism. These project models use information stored in their respective libraries (highlighted in grayscale). A building product model (BPM) targets the finished building as a set of interdependent design objects, i.e. spaces, building elements, and their product structures at a minimum. Generic building element structures are stored and updated and reused via their library by the leading party such as the contractor (Alsakini *et al*., 2007). There is much commercial software available for enabling the realization of a viable library system. A building resource and cost model (BRCM) targets the building project as a set of interdependent resource objects, i.e., the amounts of building products (retrieved from the BPM) and their resource structures or receipts, with current prices, planned to be exploited for the manufacturing and installation of these building products. Generic resource structures and prices are stored, updated, and reused via a resource structures library. A building process model (BPrM) targets the building project as a set of interdependent activity objects, i.e., tasks that are coupled with their resource structures (retrieved from the BRCM) and resource based rules for calculating activity durations. Generic building project activities, their planning rules, and interdependencies are stored, updated, and reused via an activity structure library (Firat *et al*., 2008b).

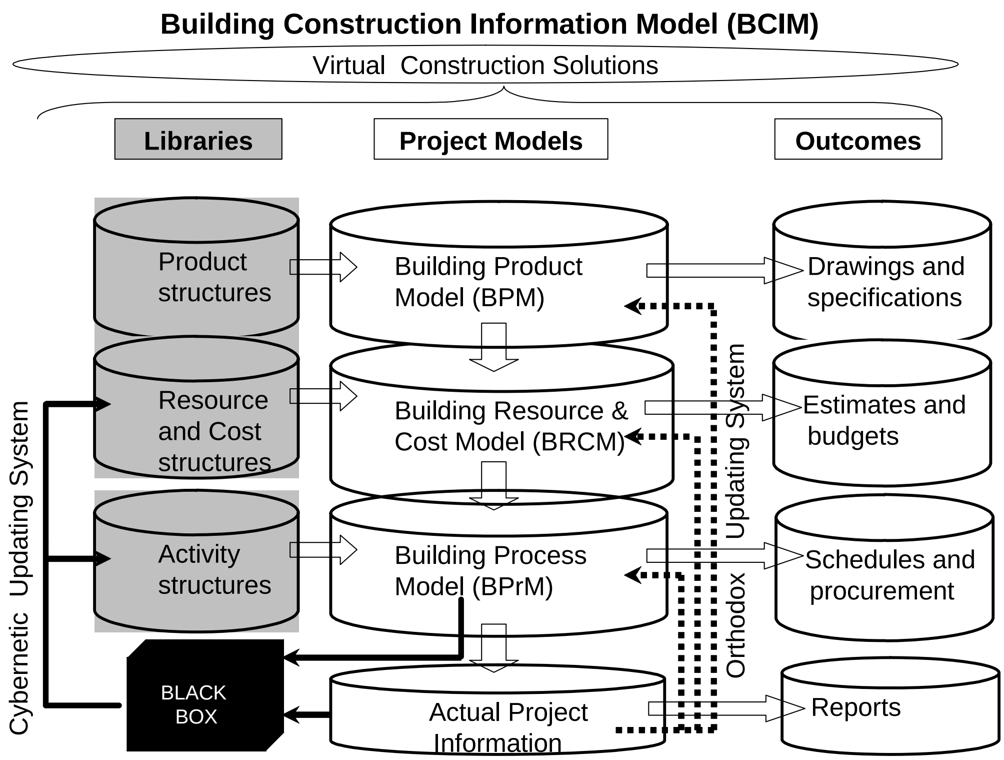

Figure 2: Suggested Ideal BCIM and its Updating Mechanism

In addition, actual project information is fed back into the model. A two-pronged updating approach is recommended; cybernetic and orthodox updating principles are used together. The project models should be updated based on change orders, and changes in methods or resources, or schedule. The dotted arrows on the right side of Figure 2 show simple and straight updating using orthodox methods. On the other hand, the resource, cost, and process libraries are updated by using Beer's (1966) cybernetic methods (solid arrows on the left side of Figure 2). The actual project information to be gathered from among the outcomes of the BCRM and the BPrM is processed in a black box. This cybernetic black box is feeding the necessary information back in the libraries. Thus, costs, resources, and schedules are fully updated by these feedback loops. The updating of the model (dotted arrows) is common project practice, but the cybernetic updating (solid arrows) is novel and not commonly known.

4. Discussion: Integrating 4D Modeling and Model-based Scheduling

The common order of constructing a 4D model first and thereafter proceeding with scheduling does not meet the requirements of producing effective project plans. Hence 4D models are still not project management tools but visualization, inspection and animation tools. However model-based scheduling can be the new way of 4D scheduling. Since a production schedule is created by information retrieved from the Building Construction Information Model (BCIM) combined with automatically linking objects, the conversion of building components into activities, and the formation of the sequence models can be performed as 4D models. Hence using ALoB as the underlying scheduling method and BCIM as the main information database, 4D models can be generated. For example, a new feature of Tekla Structures allows a step in this direction (Software Links, 2009). Tekla Structures' task manager feature in Construction Management (TS-CM) allows one to assign time to an activity, retrieving the building component directly from the 3D CAD model.

More generally, one can consider model-based scheduling to be a means to incorporate elaborate schedule preparation principles that can guide a planner to produce good quality schedules. These solutions are naturally dependent upon the context of the schedule, i.e., the type of the project and the type of the schedule. In this paper the focus has been on building construction and on the preparation of master schedules for such projects. The overall preparation process is a somewhat different in more detailed schedules, such as phase and weekly schedules and in updating these schedule. These aspects must be taken into account when the model-based scheduling approach is expanded into these directions.

Current developments, the fast adoption of 4D scheduling, and trends towards model-based scheduling present new and promising directions in the field of construction project management. One can now use model-based scheduling to prepare a master schedule and one can integrate 4D scheduling into it in order to have the sequencing of activities and to generate more detailed plans. Integrating these two modern scheduling paradigms could be an important step to future ways of scheduling.

5. Concluding Remarks

A brief literature review on 4D modeling revealed that there is not much research on integrating 4D scheduling and model-based scheduling. Advanced Line of Balance (ALoB) and Building Construction Information Model (BCIM) are suggested as a key information repository and information flow platform, and are proposed as scheduling viable combination. These two different elements of scheduling, i.e., 4D and model-based scheduling need both full attention: the schedule can be created by using a model-based approach that generates a master schedule that can later be broken down into detailed weekly and/or phase schedules by using the 4D concept. Integrating 4D scheduling and model-based scheduling can have a significant impact on construction project management. Further research and software development are needed to create new and more efficient ways of scheduling.

6. References

Abeid, J., and Arditi, D. (2003). "PHOTO-NET: An integrated system for controlling construction progress". *Engineering, Construction and Architectural Management*, Vol. 10, No.3, pp. 162-171.

Alsakini, W., Kiiras, J., and Huovinen, P. (2007). "Management of a virtual construction management services company". *Encyclopedia of networked and virtual organizations, Information Science Reference*, December 2007.

Arditi, D. (2008). "Innovative 4D management of construction projects", *Proceedings of 5th International Conference on Innovation in Architecture, Engineering and Construction (AEC)*, June 23-25, 2008 Antalya, Turkey.

Arditi, D., Tokdemir, O., and Suh, K. (2002). "Challenges in line-of-balance scheduling". *Construction Engineering and Management*, Vol. 128, No. 6.

Björnfort, A., and Jongeling, R. (2007). "Application of line-of-balance and 4D CAD for lean planning". *Construction Innovation*, Vol. 7, No. 2, pp. 200-211.

Beer, S. (1966). *Decision and Control*, Wiley, Chichester, UK.

Doulis, M., Vogel, M., Pfluger, J., Rietmann, M., and Raps, M. (2007). "4DIVE - A 4D interface for the visualization of construction processes in a virtual environment". *Proceedings of 7th International Conference on Construction Applications of Virtual Reality*, October 22-23, 2007

Dawood, N., Scott, D., Sriprasert, E., and Zaki, M. (2005). "The virtual construction site (VIRCON) tools: An industrial evaluation". *ITcon*, Vol. 10, pp. 43-54.

Dawood, N., and Sikka, S. (2008). "Measuring the effectiveness of 4D planning as a valuable communication tool". ITcon., Vol 13, pp. 620-636 (www.itcon.org).

Eastman, C., Teicholz, P., Sacks R., and Liston, K. (2008). *BIM Handbook: A Guide to Building Information Modeling.* John Wiley & Sons, Inc.

Firat, C.E., Kiiras, J., and Huovinen, P. (2008a). "Solving fundamental problems in model based, semi-automated building project scheduling", *The 5th International Conference on Cybernetics and Information Technologies, Systems and Applications: CITSA 2008*, Orlando, Florida, USA, June, 2008.

Firat, C.E., Kiiras, J.,and Huovinen, P. (2008b). "A building construction information model for managing projects virtually", *Innovation in Architecture, Engineering and Construction (AEC)*, June 23-25, 2008, Antalya, Turkey.

Firat, C.E., Kiiras, J., Kähkönen, K., and Huovinen, P. (2007). "Model based scheduling in building projects; Is it oxymoron", *24th CIB W78 Conference*, Maribor, Slovenia, June, 2007.

Hartmann, T., and Fischer, M. (2007). "Supporting the constructability review with 3D/4D models". *Building Research & Information*, Vol. 35, No.1, pp. 70-80.

Heesom, D., and Mahdjoubi, L. (2004). "Trends of 4D CAD applications for construction planning". *Construction Management and Economics*, Vol. 22, No. 2, pp. 171-182(12).

Jongeling, R., and Olofsson, O. (2007). "A method for planning of work-flow by combined use of location-based scheduling and 4D CAD". *Automation in Construction*, Vol. 16, No. 2, pp. 189-98.

Kähkönen, K., and Leinonen, J. (2003). "Visual product chronology as a solution for accessing building product model data". *Proceedings of CIB W78 2003*, Auckland, New Zealand.

Kiiras, J. (1989). "OPAS ja TURVA, Erityiskohteiden työnaikaista ohjausta palveleva aikataulu- ja resurssisuunnittelu", (A schedule and resource planning system for the implementation phase control of special projects). *HUT/CME Publications*, Espoo, Finland.

Koo, B., and Fischer, M. (2000). "Feasibility study of 4D CAD in commercial construction". *Construction Engineering. and Management.*, Vol. 126, No. 4, pp. 251-260

McKinney, K., and Fischer, M. (1998). "Generating, evaluating and visualizing construction with 4D-CAD". *Automation in Construction*, Vol. 7, pp. 433-447.

Norberg, H. (2008). "On-site production synchronization: improving the resources-flow in construction projects". Licentiate Thesis, Lulea University of Technology.

Poku, S., and Arditi, D. (2006). "Construction scheduling and progress control using geographical information systems". *Journal of Computing in Civil Engineering, ASCE*, Vol. 20, No. 5, pp. 351-360.

Porkka, J., and Kähkönen, K. (2007). "Software development approaches and challenges of 4D product models", *24th CIB W78 Conference*, Maribor, Slovenia, June, 2007.

Shih, N.-J., and Huang, S.-T. (2006). "3D scan information management system for construction management". *Construction Engineering and Management*, Vol. 132, No. 2.

Software Links. (2009). online at; www.tekla.com; www.graphisoft.com; www.commonpointinc.com; www.navisworks.com; www.vicosoftware.com; www.ceco.se (accessed 15 January 2009).

Staub-French, S., Russell, A., and Tran, N. (2008). "Linear scheduling and 4D visualization". *Journal of Computing in Civil Engineering*, Vol. 22, No. 3, pp. 192-205.