SOFTWARE DEVELOPMENT APPROACHES AND CHALLENGES OF 4D PRODUCT MODELS

Janne Porkka, Kalle Kähkönen
VTT Technical Research Centre of Finland

ABSTRACT: Experiences from projects utilizing 4D have been promising. Several companies together with researchers have seen 4D applications as potential products for lucrative business. The promising business prospects have resulted in numerous more and less intuitive attempts to develop such products. This paper draws commonalities from various approaches and reviews 4D applications from the viewpoint of product models. It is considered that now it is an appropriate time to look at the development strategies and achievements so far, and, based on lessons learned show the way forward.

First the principles for reaching 4D product models are covered. Various approaches in current commercial 4D applications are considered. One of the solutions used as ground information is Visual Product Chronology (VPC), developed by VTT.

Second the paper addresses the obvious challenges of 4D product models. There are obstacles waiting to be resolved before 4D is comprehensively harnessed for project management purposes. One of these obstacles is standardization, or more specifically the lack of it. One of the most potential formats for open BIM standard is Industry Foundation Classes (IFCs). The use of IFCs for scheduling and 4D purposes is discussed.

Finally new approaches from on-going research project 4DLive are addressed; preliminary results recognized are 1) open communication protocol for application integration, and 2) building site scenery linkage to product modelling. Possibilities and benefits exist on advanced designing and marketing solutions.

KEYWORDS: BIM, 4D, scheduling, data exchange.

1 INTRODUCTION

Over the past two decades building and construction industry has experienced significant changes. Project management applies knowledge, skills and techniques to project activities to meet project requirements (Project Management Institute 2004). In modern project environment these techniques are highlighting advanced IT systems and building information modelling (BIM), or product modelling, is a hot topic worldwide. Being successful involves that the scope of building construction is continuously scouted by representative body of stakeholders. Various tools are needed in modern project management and intelligent time management has great importance especially when conflicts arise. Traditional scheduling techniques, such as Gantt charts, have certain limitations and require coordination when clearly understood between stakeholders.

Combining building product model to corresponding construction schedule, 4D CAD concept, has been an interesting research theme for 30 years (e.g. McKinney and Fischer 1998, Koo and Fischer 2000, Bergsten 2001, Kamat and Martinez 2002, Kähkönen and Leinonen 2003, Heesom and Mahdjoubi 2004 and Jongeling 2006). Koo and Fischer (2000) revealed that 4D helps project stakeholders to identify potential problems and increases common understanding through visual communication even to stakeholders with insufficient knowledge. Making virtual prototypes before actual construction is in wider context an interesting topic in relation to building information models.

Great potential has been consolidated to 4D – it is suitable for solving conflicts and preventing problems pro-actively in an effective manner. Alan Kay stated in 1971 that "the best way to predict the future is to invent it". This paper considers first 4D software development approaches, then presents associated challenges and recognizes obstacles slowing down the take up of 4D applications. New approaches from Finnish 4DLive project are prescribed and conclusions are made in the end.

2 VARIOUS 4D APPROACHES

Several companies together with researchers have seen 4D applications as potential products for lucrative business. There have been more and less intuitive attempts to develop such products.

2.1 Commonalities in various 4D approaches

Software packages have commonalities in approaches. Jongeling (2006) noticed grouping possibilities based on detected common features. Following three 4D application types provide background for analysis of the individual 4D applications in the next section.

1. *Rapid prototyping applications.* Optimized to visual impressiveness and contain attributes for timing. Solutions are typically custom-made, e.g. for public relations or marketing purposes. Examples: 3D Studio Max, EON Reality, VirTools.
2. *4D CAD.* User-type specific approach on planning, widely recognized in literature. Solutions contain scheduling functionalities and/or support imported schedules. Latest efforts indicate that product modeling emerges 4D CAD to other simulations and analyses, such as costs. Examples: Graphisoft Virtual Construction, Enterprixe, and Tekla Structures.
3. *Integrative applications.* These applications facilitate geometry and schedule linking and are either focused on presentation and advanced collaboration possibilities amongst project stakeholders. Examples: Ceco4D, CommonPoint Project4D, Navisworks JetStream and Visual Product Chronology (VPC).

2.2 Retrospective analysis of 4D applications

Retrospective analysis is based on literature review (Kähkönen and Leinonen 2003, Sheppard 2004, Heesom and Mahdjoubi 2004, Jongeling 2006), investigation of software packages (4D links 2007) and interviews committed. Applications were investigated in relation to product modelling especially how the information process is determined. It is an appropriate time to compare various 4D approaches since adequate time has passed from first 4D implementations. It could be helpful for showing the way ahead for next generation 4D applications.

Tentative results are presented in Table 1. This paragraph gives guidelines for readers and clarifies information in columns. The assessment of geometry (*3D*) and corresponding schedule (*4D*) have been evaluated separately. In 3D the functionalities for designing (*create geometry*) and/or importing 3D model from other applications (*import geometry*). According to 4D same functionalities were considered (*manual scheduling* and *import schedule*). Special interest in geometry and schedule was paid to streamlining process (*dynamic update*); is the manipulated information automatically updated to corresponding data.

Visual Product Chronology (VPC) was used as analysis baseline. It comprises IFC 2.0 compliant CAD package to MS Project compatible scheduling software in *integrative 4D application*. It has been developed by VTT in Divercity project (Divercity IST-1999-13365). The primary goal of the solution is the resultant IFC2.0-4D model that links 3D model and time together (Kähkönen and Leinonen 2003). Further discussions data exchange and IFC standard are carried out in following chapters. Tool has dynamic schedule update.

Table 1. Retrospective analysis of available 4D applications.

SOFTWARE	TYPE	3D: CREATE GEOMETRY	3D: IMPORT GEOMETRY	3D: DYNAMIC UPDATE	4D: IMPORT SCHEDULE	4D: MANUAL SCHEDULING	4D: DYNAMIC UPDATE	REMARKS	PURPOSE
Graphisoft Virtual Construction	4D CAD	yes	yes	yes	yes	yes	yes	Cost, work-flow, resources, collisions, cataloque, LOB scheduling	User-type spesific planning
Enterprixe	4D CAD	yes	yes	yes	yes	yes	yes	Work-flow, site, 2 user interfaces for modelling, server solution, shared model over internet	User-type spesific planning, one Autodesk based modelling client
Tekla Structures	4D CAD	yes	yes	yes	yes	yes	yes	Structural design, work-flow, production, procurement	User-type spesific planning
Common Point Project4D	Integrative	no	yes	yes	yes	yes	yes	Work-flow, visual comparisons	Standalone
Ceco4D	Integrative	no	yes	yes	yes	yes	yes	Work-flow, logistics	Standalone
Navisworks JetStream (Timeliner and ClashDetective)	Integrative	no	yes	yes	yes	yes	yes	Work-flow, collisions; extensive format support, management	Standalone, free viewer
Visual Product Chronology (VPC)	*Integrative, research*	*no*	*yes*	*no*	*yes*	*yes*	*yes*	*Work-flow, IFC2.0(3D+time)*	*Standalone*

Common Point with Project4D is forerunners of 4D. *Integrative 4D application* provides 4D playback for construction sequencing, movements and site management features, visual comparisons on status and planned progress, and communication for analyzing model with project stakeholders. Hence, both geometry and schedule are dynamically updated. It is also possible to add comments to schedule simulations. In data exchange Project4D supports IFC in geometry.

Graphisoft Virtual Construction operates shared model assembled from objects in catalogue including recipes, elements, methods, and resources amongst many others. It manages spatial aspects of a construction project in scheduling, facilitating Line-Of-Balance (LOB) method in Graphisoft Control, often neglected in Gant charts (Seppänen and Aalto 2005). Latest version 2007 enables 2-way-functionality between shared mode and scheduling. Catalogue provides content selection for visualization; e.g. actor's resource allocations can be simulated in 4D. Software package has dynamic update in geometry and schedule.

Enterprixe is server solution facilitating shared model communication over the Internet. One of the modelling clients is Autodesk based. It has two user interfaces for 3D/4D; one for designer and planners and other for manufacturing (factories) and construction site through web browser. The latter commits restricted functions to shared model and has always the latest model revision for workflow planning and coordination. 4D capabilities are mainly used in work-flow simulations. Shared model follows the hierarchy set by main user and geometry and schedule updates are dynamically managed.

Tekla Structures is structural engineer's tool for managing concrete and steel structures. It enables functionality for design coordination, production planning and procurement. Solution facilitates integrated model; from engineers further to product manufacturing. In this substance 4D is rather new functionality; enabling virtual construction simulation of work-flow and assembly order. Geometry and schedule are dynamically updated, current 4D presentation functions are under development.

Swedish Ceco4D tool is used for communicating the work progress. Due to format selections (3D in VRML; schedule in XML) it has great interoperability; although made solution may complicate dynamic updating functions. Interesting aspect in CECO4D is simulation of spatial aspects (Jongeling 2006).

Navisworks JetStream (Timeliner and ClashDetective) is an *integrative product* for design reviewing and project management; mainly to understand design intent, construction plan and current project status. Animation of construction schedules contributes risk identification and reduction of waste as a result of better planning control. It has extensive format support and enhanced collaboration possibilities. Geometry and schedule are dynamically updated when changes occur in source. Timeliner uses Clash Detective to check time and space co-ordination and improve site and workflow planning. Solution can be tailored to stakeholders; user interfaces e.g. to data manipulation and viewing.

Analysis conducted *CAD* and *integrative 4D* applications, primarily targeted to work-flow simulations. Functionalities of various 4D software are at the moment increasingly automated and streamlined. The current capabilities do not provide so much support for the actual schedule preparation process and related reasoning. Typically tools are used in design phase where use scenario is balancing between competing demands for quality, scope, time and cost. Compared with this 4D is more focused on understanding the validity of the construction process and thus it focusing on understanding potential problem areas and decreasing the overall project risk to enhance project success.

Project management has 4D interest regarding status and progress control differing sometimes greatly from e.g. planners point-of-view. Currently project meetings can leverage 4D to design reviews, design alternatives and 'what-if' scenarios and verifying constructability. Navisworks provides support for cross-discipline design reviews (e.g. HVAC, Structural, architectural) and time-driven collision checks. According to Navisworks Finland the functionality has been very useful. From projects perspective the increased communication is needed in troublesome targets, whether this means checking main or work schedule, such as panel assembly.

Reporting from 4D application is currently strongly based on visual simulation. Two time management mechanisms have been adopted; 1) uniform time models (time runs in e.g. week, day, hour and minutes), and 2) activity-based models (navigate through tasks). Many of the solutions provide customization of visibility settings; it may be possible to change e.g. transparencies, colours and add text comments to simulation. This increases flexibility and adaptability to multiple purposes.

3 CHALLENGES OF 4D PRODUCT MODELS

The retrospective analysis of 4D applications revealed obstacles that need to be resolved during comprehensively harnessing 4D for projects. Challenges in IT systems are often in relation to adaptation strategies. Fox (2006) introduced levels for adaptation as *automational, informational* and *transformational* described in Figure 1. Analysis revealed that the 4D application main stream has reached *automational* and *informational* levels by offering automation reducing required manuel work and consolidating data to product models and new functionalities. Unfortunately the issues of complexity and labour intensive linking have not fully overcome (Heesom and Mahdjoubi 2004). Business forerunners are seeking lasting competitive advantage from *transformational* services; 4D solutions have e.g. better synchronization between stakeholders, increased support decision-making and integration to data management systems and other modelling packages improves.

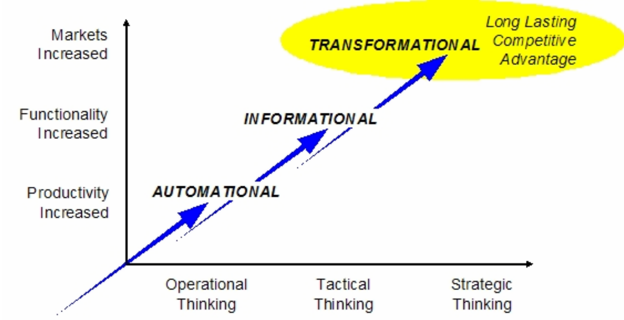

Figure 1. Adoptation strategy for industry regarding computer models of buildings and relating applications know also as Virtual Building Environments i.e. VBEs (Fox 2006).

3.1 *Obstacles restraining utilization*

There are issues explaining relatively slow take up of 4D technology, although benefits and cost savings have been reported (e.g. Fischer and Kam 2002). A recent industrial practice study in Finland revealed that BIM utilization has clearly increased (Kiviniemi 2007). Unfortunately major share of building construction projects is not utilizing latest BIM tools. However, over eighty percent of Autodesk BIM authoring software clients sees the need for re-evaluating ways of working (Sullivan 2006). Currently the bulk of design time is spent for producing construction documents that have earlier fixed costs. Clear indications for the need to develop adaptable process exists and possibilities to utilize intelligent technologies, such as 4D, improved. Roadmaps for ICT in construction concluded trends for enhancing after design life-cycle phases, such as use and maintenance (Hannus et al. 2003, Kazi and Hannus 2006). Stakeholders could also get long lasting competitive advantage from virtual design teams operating in integrated data management systems.

Methodological development should concentrate better on 4D model creation and manipulation automation towards non-labor intensiveness and integration to product model content (Tanyer and Aouad 2005). Analysis concluded that main outcome of 4D is the visual representation. Therefore it is justified to argue that new, appropriate ways for reporting should be developed in order to support decision making. Heterogeneous application field raises also data exchange problems and range of vendor specific formats possibly reduces interoperability.

Current 4D applications have enhanced automational and informational functionalities. Development of transformational functionalities requires more user-orientation. Currently the modeller makes the decision how much in detail he is willing go in 4D simulation. Possibly next generation products can provide adjustable level-of-detail – tailored to user needs in various project meetings.

3.2 Standardization

One of the most potential vendor neutral formats is Industry Foundation Classes (IFCs) (IAI 2007). Building owners and clients have taken active role in BIM development; e.g. in year 2005 China adopted IFC2x to official national standard, next year GSA in the United States required IFC BIMs in conceptual design and latest BIM request is coming from Senate Properties in Finland. All proposals highlight vendor neutral formats. In relation to earlier Navisworks is overcoming the paradigm by supporting multiple formats.

The first set of IFC was published in 1998 as Release 1.5; followed by IFC2.0 in 1999. According to 4D, first implementations were made to IFC2.0 for project management (Froese and Yu 1999). Results described process and work plan model for scheduling; although inconsistency was discovered in core elements. Early tests led to trial implementation (Froese et all. 1999). Seren and Karstila (2001) described how task scheduling information and associations to building elements are managed in IFC1.5.1, IFC2.0 and IFC2x. This mapping specification was used in Visual Product Chronology, VPC (Kähkönen and Leinonen 2003). IFC2x2 was released in 2003 and task planning and 4D have been considered further nationally in Finland (ProIT 2005). Aspect card *ProIT-140* describes general descriptions, partial EXPRESS-G schemas and inherited instance diagrams. High level object for work plan *(IfcWorkPlan)* may contain number of work schedules *(IfcWorkSchedule)*. Tasks *(IfcTask)* are related to work schedule through *IfcRelAssignsTasks*, and connected to timing by *IfcRelAssignsTasks*. Hierarchy between tasks includes nesting *(IfcRelNests)* and dependencies *(IfcRelSequence)*. Target objects of tasks are *IfcRelAssignsToProcess* instances.

The information that is used in 4D modelling originates from scheduling and design disciplines. Therefore there are varied implementation methods for data exchange between various 4D applications. Most integrative 4D applications define the linkage information to separate geometry and schedule files. Certain solutions use merged file. Efficient product modelling utilization and better interoperability between applications require that some uniform 4D standard is agreed. Vendor specific defacto standards have resistance; current IFC version, IFC2x3, has more potential. Currently many applications support IFC in geometries. IFC already includes the capabilities to exchange 4D data, but detailed structure (model view) must be agreed before software implementers can start to utilize IFC standard. According to IFC, Model View Definition (MVD) defines which subset and how IFC specification is applied in the data exchange between different applications, according to exchange requirements (IAI 2007).

4 NEW APPROACHES ON 4D PRODUCT MODELING

New research issues have been investigated in a national 4DLive research project targeted to integrating augment and camera systems to 4D product modelling. Mobile solutions, such as Augmented Reality (AR) are increasing convergence of virtual model and real environment in model viewer solution. 4DLive project capitalizes multidomain knowledge at VTT in building construction, virtual reality and video processing. Figure 2 illustrates process comprising 1) integrative 4D application, and 2) building site scenery sub processes.

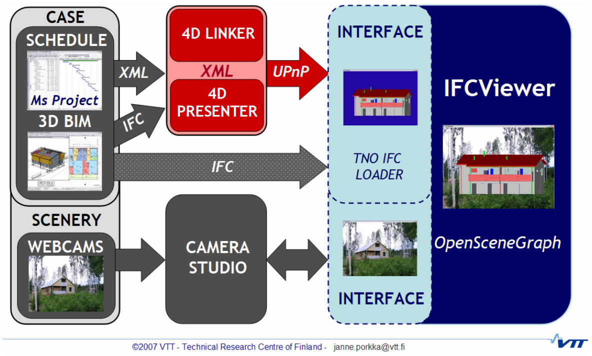

Figure 2. The 4DLive process outline for putting together live camera streaming with 4D building models.

Model viewer solution *(IFCViewer)* is based on OpenSceneGraph (OpenSceneGraph 2007) and free IFC Engine component (Bonsma 2007). Supported formats are MsProject XML and IFC BIM (IAI 2007). Visual representation manages objects by global unification ids (GUIDs), intending to simulate order of erection instead of realistic visualization.

4.1 Open communication protocol for application integration

Universal Plug and Play standard (*UPnP*) provides possibility for managing communications in a standardized way. Practically multiple applications can access same building model and 4D application transmits visualization commands to *IFCViewer*. *UPnP* protocol allows devices to automatically configure network by XML handshaking. These applications can 1) provide services to others (announce presence) and 2) use services from other applications (control point). *UPnP* protocol specification was developed in VBE2 project; visualization service access methods; including individual and object group controls for hiding/showing, highlighting and setting transparency (Hietanen 2006). The advantage of selected approach is flexible applications integration. Early implementation experiences are positive. It is adaptable for various purposes, like analyses or simulations. It has also capability to increase interoperability and provide platform neutral innovative services.

4.2 Linking building site scenery to product models

Typically product model backgrounds are one-colored or shaded. The research emphasis has been covering mostly one-camera systems (Behzadan and Kamat 2005); 4DLive project addresses domain by utilizing multicamera system. Technological novelty value creates also market potential. Recognized challenges include procedural management of angles of view for smooth operations, and most of the sceneries are created from "virtual angles" computed from multiple pictures. Feasible use scenarios might be early design and marketing.

5 DISCUSSION

Adoptation of 4D in companies has proceeded rather slowly. Recent experiences from pilot projects utilizing 4D in Finland have been positive. Tekla Structures software package was utilized in the second phase of a major shopping centre construction project (Jumbo shopping centre, Finland, Vantaa) to simulate building skeleton from steel and concrete. The main contractor in this project, Lemcon, reported very promising results on Christmas 2005. Skanska has used Enterprixe's 4D solution in many projects. One of these, the Reimarintorni (tower of Reimar, residential building of 18 floors in Espoo), utilized 4D in demanding wall panel assemblies. Project took lately 'Finnish construction site of the year 2006' prize.

This paper has reviewed capabilities of 4D applications. Product modelling was recognized as an emerging technology. Therefore it is probable that process will be developed to support new tools and 4D concept that has great potential in the future. So far, the experiences from projects Finland have been mainly positive. *4D CAD* tools provide functionalities for multiple disciplines. Some indications for integration, such as intelligent cataloguing and server based solutions, have already been detected. *Integrative 4D applications* provide extensive format support, optimized visualizations and enhanced algorithms to link geometry and corresponding schedule. Some of these approaches should be leveraged to future 4D development from these tools.

6 CONCLUSIONS

Development of the 4D applications since their introduction has evolved towards automated and streamlined solutions. There are high-level challenges that should be solved to follow-on path towards large-scale use. These issues are mainly related to the development of *methodologies*, *process* and *user orientation*. Current construction process has deficiencies and 4D solution should possibly be leveraged better for decision-making support. The new process, differing greatly from current one, should be developed from starting point of re-evaluating ways of working. To some stakeholders enhanced and adaptable process potentially means long lasting competitive advantage.

Retrospective analysis revealed shortcomings in the methodology. 4D model creation and manipulation in many cases lead to buildings not verified against the requirements set by the clients in the beginning. Therefore it is proposed that integration to other systems is improved. According to simulation outcomes, there is potential to create new advanced reporting features facilitating information in multiple Level-of-Detail. These appropriate ways for reporting should be developed in order to support decision making. Due to relatively slow new ICT solution adoptation in building and construction industry, the competitive advantage in software development might also be a result of user friendliness.

For ensuring the seamless data exchange between scheduling and 4D models some uniform standard should be agreed. Currently wide range of software packages lacks interoperability and one of most promising candidates for open BIM standard is Industry Foundation Classes (IFC). IFC2x3 can be taken to a technological starting point; to be further equipped with 4D case definition. This case definition needs to present the new process taking advantage of the holistic IT infrastructure within construction process.

It is possible that the 4D applications shall be integrated with other digitalised services in near future. New approaches from 4DLive project described open communication protocol for application integration, and building site scenery linkage to product modelling. Both approaches have been disclosed promising and implementation to e.g. design and marketing might be reality in the future. It is considered that new dimensions such as combining live video streaming with interactive 4D building model can result in a communication vehicle that meets well with the needs of continuously changing project conditions and relating managerial challenges.

ACKNOWLEDGEMENTS

Main author is doctoral candidate in Helsinki University of Technology. 4DLive project is part of the national Finnish Kitara research programme. Acknowledgements are raised to professor Juhani Kiiras and colleagues at VTT, especially Stephen Fox, Sami Kazi and Juha Hyvärinen.

REFERENCES

4D links, (2007). http://www.graphisoft.com; http://www.enterprixe.com; http:www.tekla.com; http://www.ceco.se; http://www.commonpointinc.com; http://www.navisworks.com; (Accessed March 15th, 2007)

Akinci, B., Fischer, M., and Kunz, J. (2002). Automated Generation of Work Spaces Required by Construction Activities. Journal of Construction Engineering and Management, 128(4), 10.

Behzadan, A., and Kamat, V. (2005). Visualization of Construction Graphics in Outdoor Augmented Reality. Department of Civil and Environmental Engineering, University of Michigan U.S.A.. in Proceedings of the 2005 Winter Simulation Conference. M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

Bonsma, P. (2007). IFC Engine Viewer web site available at: http://www.ifcbrowser.com/ (Accessed March 15th, 2007)

Fischer, M. and Kam, C. (2002). PM4D Final Report. CIFE Technical Report Number 143, October 2002.

Fox, S. (2006). VBE2 public report: Building Information Models Inter-organizational Use in Finland 2006. VBE2 R & D Project Work Package 1.4. Public Report.

Froese, T., and Yu, K. (1999). Industry Foundation Class Modeling for Estimating and Scheduling. Published in CIB W78 1999 in Ottawa. Edited by M.A. Lacasse and D.J. Vanier. pp. 2825-2835.

Froese, T., Fischer, M., Grobler, F., Ritzenthaler, J., Yu, K., Sutherland, S., Staub, S., Akinci, B., Akbas, R., Koo, B., Barron, A., and Kunz, J. (1999). Industry Foundation Classes for Project Management - A Trial Implementation. ITcon, Vol 4, 17-36. Available at: http://www.itcon.org/1999/2 (Accessed March 15th, 2007)

Hannus, M., Blasco, M., Bourdeau, M., Böhms, M., Cooper, G., Garas, F., Hassan, T., Kazi, A., Leinonen, J., Rezgui, Y., Soubra, S. and Zarli, A. (2003). Construction ICT Roadmap. Public report of ROADCON project IST-2001-37278, Deliverable WP5/D52, 30 September 2003. Web page available at: http://cic.vtt.fi/projects/roadcon/docs/roadcon_d52.pdf (Accessed March 15th, 2007)

Heesom, D. and Mahdjoubi, L. (2004). Trends of 4D CAD applications for construction planning. Construction Management and Economics, Volume 22, Number 2, February 2004, pp. 171-182(12).

Hietanen, J., Rönkkö, J., Markkanen, J., Lehtinen, S., and Ylä-Mella, T.(2006). Interactive 3D visualization UPnP methods specification. UPnP implementation guidelines from VBE2, project report, November 9th ,2006.

IAI (2007). The documentation of the IFC data exchange standard for architecture, engineering, construction and facilities management is administrated by International Alliance of Interoperability (IAI). 1) IAI web page: http://www.iai- international.org/2) Latest IFC standard specification: http://www.iai- international.org/Model/IFC(ifcXML)Specs.html . (Accessed March 15th, 2007)

Jongeling, R. (2006). A Process Model for Work-Flow - Combined Use of Location-based Scheduling and 4D CAD. Doctoral thesis, Luleå University of Technology, Sweden. Publication 2006:47, ISBN 978-91-85685- 02-8.

Kähkönen, K., and Leinonen, J. (2003). Visual product Chronology as a Solution for Accessing Building Product Model Data. Published in CIB W78 2003 in Auckland, New Zealand.

Kamat, V. R., and Martinez, J. C. (2002). Comparison of Simulation-driven Construction Operations Visualization and 4D CAD. Proceedings of the 2002 Winter Simulation Conference E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds.

Kazi, A. and Hannus, M. (2006). Strat-CON Roadmap - Strategic Actions for Realising the Vision of ICT in Construction. Draft version from 24 Nov. 2006. Web page available at: http://cic.vtt.fi/projects/stratcon/ (Accessed March 15th, 2007)

Kiviniemi, A. (2007). ICT-barometri 2007 – ICT:n käyttö Suomen rakennusalalla. ICT barometer 2007 - The use of ICT in Finnish Building and Construction Sector. Preliminary public report to published. In Finnish.

Koo, B., and Fischer, M. (2000). Feasibility Study of 4D CAD in Commercial Construction. Journal of Construction Engineering and Management, Vol. 126, No. 4, July/August 2000, pp. 251-260.

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

OpenSceneGraph (2007). Web page available at: http://www.openscenegraph.com (Accessed March 15th, 2007)

ProIT (2005). The aspect card for Task Planning and 4D. Aspect card: ProIT-140 describes general description, partial EXPRESS-G Schema inherited Instance Diagrams. Eurostepsys, 20th of January, 2005.

Project Management Institute (2003). A Guide To The Project Management Body Of Knowledge, 3rd ed., Project Management Institute. ISBN 1-930699-45-X

Seppänen, O., and Aalto, E. (2004). A Case Study of Line-Of-Balance Based Schedule Planning and Control System. Proceedings IGLC-13, July 2005, Sydney, Australia.

Seren, K., and Karstila, K. (2001). MS Project – IFC Mapping Specification. Divercity project report. Published by Eurostepsys and VTT.

Sheppard, L. (2004). Virtual Building for Construction Projects. IEEE Computer Graphics and Applications, Vol. 24, No. 1, 6-12.

Sullivan, J. (2006). Transition to Building Information Modeling (BIM): A Federal Perspective. Paper from Autodesk at buildingSMART week Washington, October 31 2006, Washington.

Tanyer, A.M and Aouad, G. (2005). Moving beyond the fourth dimension with an IFC-based single project database. Automation in Construction, 14 (2005), 15-32.