Utilizing 4D Technology in Supply Chain Management

J. Porkka, J. Kojima, K. Rainio & K. Kähkönen
VTT Technical Research Centre of Finland, Espoo, Finland

ABSTRACT: During the last decade the role of technology in supporting the project execution and management has increased. However, the real impacts to supply chain have not been considered. This paper introduces a study utilising 4D technology for supply chain management. We explore how the interactive 4D application can be used for testing alternative supply chain scenarios. We describe experienced challenges when developing 4DLive Linker environment, which enables simulations of multiple scenarios in large construction projects. We demonstrate the research approach in a residential housing case that has two supply chain alterations. Our experiences show that decision making benefits from interactive environment. The end result enhances existing 4D applications to direction where alternative plans can be easily incorporated into applications, studied further interactively and presented in a communicative manner for decision making and construction site training.

1 INTRODUCTION

1.1 *Emerging role of the Information Technology in Construction*

During the last decade a role of technology in supporting the project execution and management has increased. Samuelson (2008) points out a clear increase in the information technology (IT) use in construction over last few years, and although longitudinal survey was implemented in Sweden similar results has been reported worldwide.

One of core technology drivers for this change and the emerging role of IT in construction is building information modelling (BIM). BIM is an integrative approach to manage building data over its lifecycle. The approach also combines multiple technologies. One of the technologies advocated in BIM is 4D CAD, that combines design to corresponding construction schedule (McKinney & Fischer 1998).

Together with the continuous development of IT technologies the construction technologies and construction processes have clearly changed. Management of increasingly complicated supplies, e.g. industrial building components, is getting essentially important for modern construction. Particularly the monitoring of supplies, the local optimisation by various partners and lacking communication system are seen as major problems of the current practice (Ristimäki & Stephens 2009). It is considered that most of the problems described above are related to producing, maintaining and sharing of project information.

1.2 *Growing use of 4D CAD in Construction*

The use of 4D CAD has increased in the industry and 4D simulations have been implemented in growing number of projects. Currently the projects utilise 4D as a planning review tool, rather than integral to the initial construction planning process (Zhou 2009). It appears that planning is done as earlier but the outcome in relation to schedule is presented also in 4D. Now that the technological maturity of applications has increased, the 4D technology is able to prepare the way to new project management tools.

The academia has investigated capabilities of the 4D technology. One of the studies revealed that 4D is applied to address the complex challenges of construction (Staub-French & Khanzode 2007). Previous research has also contributed to challenges with research initiatives targeted to e.g. collaborative working (Fischer 2001), logistics and site layout (Chau et al. 2005), work space (Akinci et al. 2003), alternative construction schedules (Vaugn 1996), and augmented reality (Kähkönen et al. 2007).

Research initiatives have also shown that 4D technology brings benefits when comprehensively implemented in the project. However, some we have also seen unsuccessful trials. Altogether, it has been recognised that 4D tools help project stakeholders to increase common understanding through the visual communication, especially when some of the stakeholders has insufficient knowledge (Koo & Fischer 2000). Koo & Fischer (2000) conclude that 4D helps project stakeholders to identify potential problems. Many studies have confirmed this and completed that it also helps to solve conflicts and pro-actively prevent problems in project execution (e.g. McKinney & Fischer 1998, Kamat & Martinez 2002, Heesom & Mahdjoubi 2004, Jongeling 2006, Porkka & Kähkönen 2007, Staub-French & Khanzode 2007).

We see that according to academic research and experiences from practice 4D has great potential. The challenge for the future is how well technology adopt to changing environment and is integrated to other technologies supporting project execution and management.

1.3 *Improving 4D with Supply Chain Management*

Over the past years construction industry has been criticised for slow productivity increase (Frijhoef & Koskela 2000). That is why a number of supply chain management (SCM) initiatives have been launched to increase productivity and achieve common objectives. To supplement 4D, SCM recognises the interdependency in the supply chain, and thereby improves its configuration and control based on such factors as integration of business processes (Frijhoef & Koskela 2000). However, it is difficult to reach these goals due to the complexity of supply chains, the conflicting interests of its participants and the interactions between chain participants through information flow (Fontarini et al. 2008).

The practice has showed that construction projects are now even larger and more complicated than earlier. Therefore, the information flow in these modern construction projects gets easily even more scattered. It is apparent that a traditional approach on SCM is not adequate and new technologies, such as 4D technology, could be integrated to current approaches to enhance productivity.

This paper introduces an approach where supply chain management is applied in 4D technology in a construction project setting. First, we explore how an interactive application can be used for testing alternative supply chain scenarios. The application developed in this research is called 4DLive Linker. We explain briefly its core functions and demonstrate our research approach in a residential housing example. We also explain challenges when developing this interactive environment. Finally, we make conclusions based the experiences and consider development potential of this approach.

2 SUPPLY CHAIN MANAGEMENT

2.1 *Industrialised Construction Perspective*

This research draws from results at Open Building Manufacturing (ManuBuild) project, an industry-led collaborative research project on industrialised construction. ManuBuild project's vision was to transform the construction industry from resource-based industry into more value–driven one through the creation of an Open Building Manufacturing System, a new paradigm for building production by combining manufacturing in factories and construction sites, and open system for products and components offering diversity of supply in the open market.

Traditionally the supply chain management involves means to achieve the functionally best inputs at the lowest initial purchase prices while assuring supply by leveraging the supply chain (Spekman et al. 1998). The lowest price in economy of scale is challenged by increased need to customise and develop standardisation. According to Gann (1996), the trade-off between standardisation and flexibility in assembly is actually key issue in industrialised construction. In relation to earlier, 4D technology may be useful addition in balancing this trade-off.

2.2 *Contribution to the existing 4D research*

This work contributes existing 4D research by demonstrating the interactive environment developed for flexibly simulating various project execution alternatives. We focus on 4D perspective in the erection of the building, and supply chain management is considered as secondary matter. Therefore the SCM theories are not fully covered. We see that this work is valuable contribution to the existing 4D research as a road opener towards supply chain management and other systems.

3 IMPLEMENTING AN INTERACTIVE ENVIRONMENT FOR SUPPLY CHAIN MANAGEMENT

3.1 *Starting point of the development*

Our research approach requires flexible development environment. The dominant 4D software products have been criticised for being labour intensive Heesom & Mahdjoubi (2004), and lacking the interoperability with other solutions (Porkka & Kähkönen 2007). Further, dominant applications typically operate in a closed environment (Rönkkö & Markkanen 2007), that does not leave opportunity for third party to develop their solutions.

After carefully evaluating the possibility to develop solution on top of the existing 4D software, we decided to develop the interactive environment internally at VTT. In long this also allows us to continue development in following research projects.

3.2 *4DLive Linker Application*

Our research approach is targeted to help construction project managers to make a decision in selecting the most prominent design solution. Moreover, it is also a demonstration of interactive SCM simulation that provides versatile information for construction site training.

The application called 4DLive Linker has been developed internally at VTT Technical Research Centre of Finland. It is an end result of multiple research projects, and therefore it has been tested capable to run simulations also in large construction projects.

The application reads source files from 3D modelling and scheduling tools, has functionalities to create multiple supply chain scenarios, and store these scenarios as linkages. The core capability of the software is to assist decision makers with visual simulation (see Figure 1).

The application is a light-weight solution, and rendering of the model is based on an open source graphic engine OpenSceneGraph. In data exchange, we decided to support BIM model representation in IFC format in order to enhance interoperability with most architectural and structural design applications. In scheduling, we support Microsoft Project that other scheduling applications support as a kind of 'defacto' standard.

The current 4DLive Linker version has been written with Visual C++ 2005. MS MFC class libraries were used for user interface elements, and rendering is based on OpenSceneGraph open source graphics library. Both source file imports, IFC-BIM and MS-XML schedule, have been developed using in-house code based on open source code libraries.

3.3 *Future considerations*

A next generation version from 4DLive Linker is currently under development in AR4BC (Augmented Reality for Building Construction) project. The system architecture for 4DStudio is described more thoroughly in other paper of this conference (Hakkarainen et al 2009). The new version enables users to see photorealistic augmented visualizations from plans, and make construction site follow-up. It also creates novel visualization for displaying virtual models accurately in real world locations.

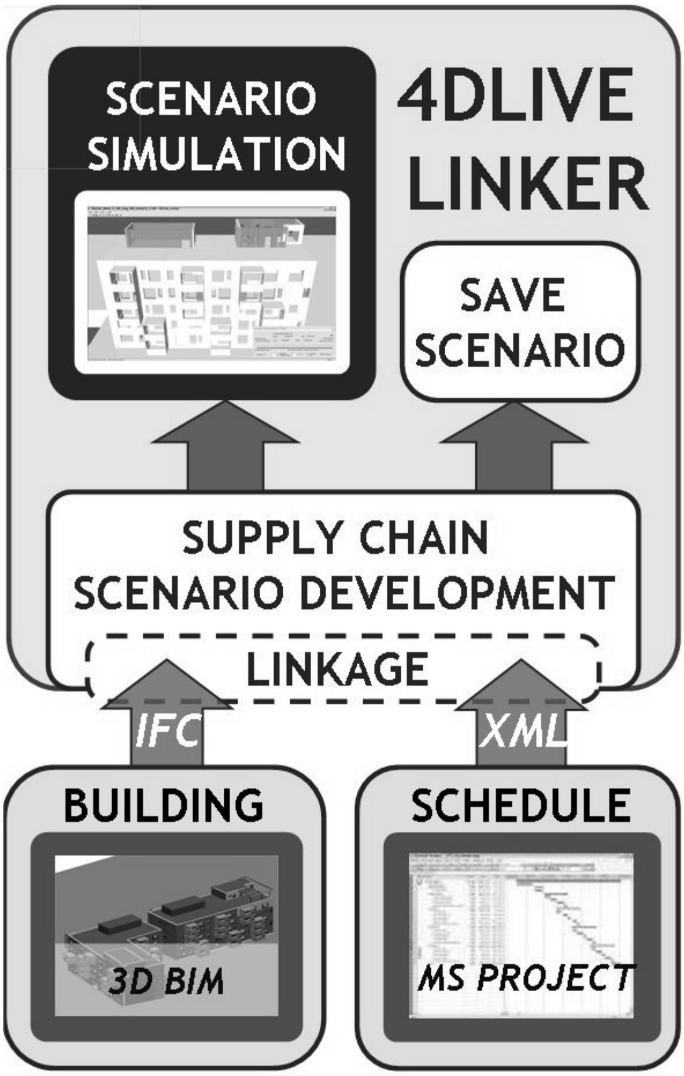

Figure 1. 4DLive Linker application

4 FUNCTIONALITIES OF THE 4DLIVE LINKER APPLICATION

4.1 *Core Functionalities*

4DLive Linker links building product model objects in IFC format with corresponding Microsoft Project schedule activities, so the progress of the building project can be animated. Compared to other 4D tools in the market, the user interface has been improved to reduce need of manual work. The concept for linking has taken to some extent also consideration the SCM perspective. It enables creation of many scenarios for project.

The normal use is very easy. First, user loads the building model and schedule files to system, and solution presents hierarchical tree views of the contents (i.e. building elements and project tasks, each in its own tree). The building model is visualised simultaneously to a separate sub window in 3D. The user can then link the building elements to schedule activities and needed supply chain information.

When developing the application, it became apparent that it has to be automated to some extent, and be flexible and fast in creating linkages. Defined linkages are saved to scenario files in a proprietary format. The application supports generation of multiple scenarios for the project, derived from different or same geometry and schedule files. Screenshot from 4DLive Linker is presented in the Figure 2, dark objects are already linked in the model. These elements are visualised with red colour.

When all linkages have been entered, any point of time of the building projects supply chain in can be visualised. Figure 3 demonstrates the visual simulation, where dark elements are reserved by ongoing activity workers. Software visualises ongoing activities with green and completed activities in white.

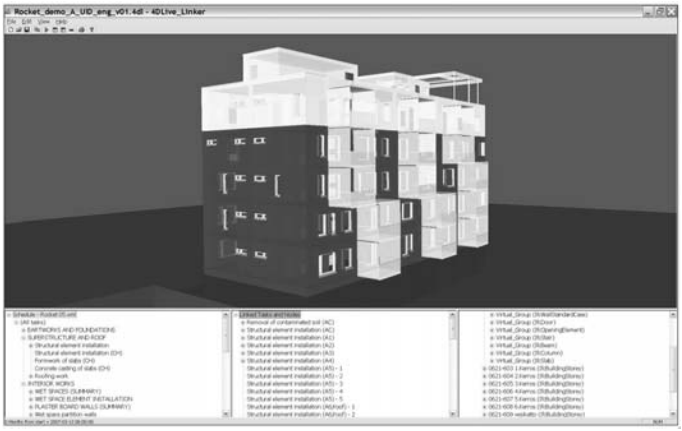

Figure 2. Linking product model and schedule in 4DLive Linker, dark objects are already linked.

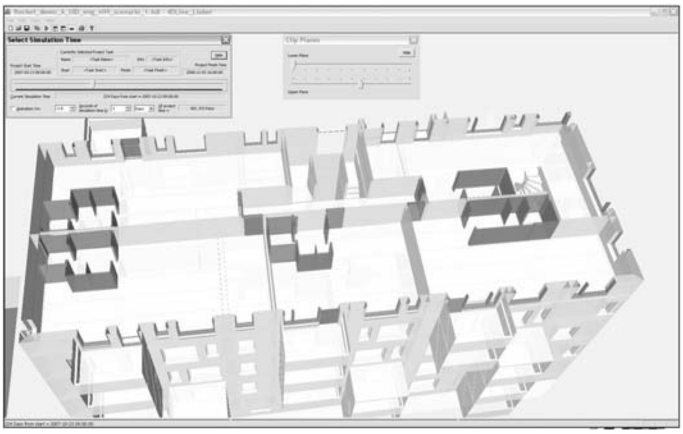

Figure 3. Performing supply chain simulation in 4DLive Linker, dark elements are under construction.

4.2 *Capabilities to Enable Communication*

The software has been developed in a way that it helps users to communicate supply chain scenarios visually. Therefore, the scenario viewer is also able to show e.g. only one floor of the building. Besides, the decisions makers may have also interest to run more detailed work flow simulations (see one from standard floor in Figure 3). In these simulations, user may change settings. One second of the simulation time may be adjusted to correspond for example one week of project time and when reaching the critical phase simulation may run slower.

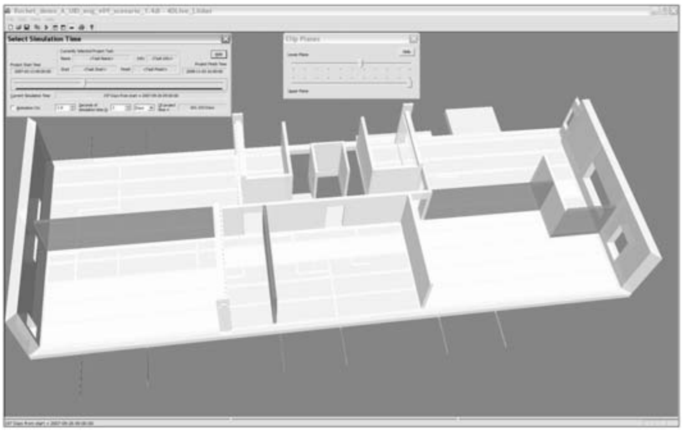

Figure 4. Standard floor in work flow simulation in 4DLive Linker.

5 SUPPLY CHAIN MANAGEMENT IN RESIDENTIAL HOUSING CASE

5.1 *Case Introduction and Experiences*

This chapter demonstrated the application in residential housing setting and explains preliminary results from utilising 4D technology for supply chain management. The building is located to Finland, and the project is carried out by one of the largest domestic construction companies. The extent of case is five thousand square meters, consisting from two apartment buildings. Those include 53 apartments; sizes vary from 2 room to 6 room apartments. The building skeleton is erected from 2D concrete elements. Car park is build underground next to buildings, and common spaces have direct connection to parking from the basement.

Data was collected from project documents, models and interviews with company representatives. The project delivery was in November 2008. Picture from actual building is in Figure 5. The interest in supply chain was targeted to selection whether to use 3D elements in the bathrooms. Tested supply chain alterations are: 1) Scenario 1: On-site bathrooms, and 2) Scenario 2: Factory-made 3D bathroom elements.

Figure 5. Pictures from the residential housing case in Finland.

Simulation model helps the decision makers to outline differences between alternatives. Based on simulations and supporting other supply chain material, using such tools leads to more justified decisions. In the demonstration project the selection criteria of alternatives was cost-efficiency. Because of this, the scenarios considered 4D representation with supply chain and estimated the financial significance of changes. As an outcome of the simulation, the 3D element bathrooms were considered more expensive solution. Screenshots from simulation in on-site bathrooms are presented in Figure 6. Detailed results of the simulation are confidential.

As a whole, the application has potential and it helps to consider various alternatives visually. Decision making in projects needs more support from existing IT tools, because the trade-off between standardisation and customisation is often a very case sensitive matter. In the future standardisation may also lead to rather customised solutions.

Figure 6. Residential housing simulation in on-site bathrooms scenario, dark elements are under construction.

5.2 *Challenges and Outcome of the SCM demonstration*

The development of the interactive environment was challenging. Mostly the challenges were related to the concept, and in practice meant balancing between automation and manual work. It is also demanding to integrate supply chain perspective to 4D and support information flows from external applications. User interface should be as automated as possible. This also increases the suitability of using tool for construction site training and visualise consequences of selections in practice.

Other group of challenges is related to source material. The architectural model is not explicit for the use in supply chain management. Hence, we used a hybrid model from various design disciples in the simulation. However, the design disciplines are rather independent from each other. Therefore, exploiting the interdependencies is what more likely leads to better productivity. In other words, it is the interplay of design solutions that enhances the likelihood of project being successful and running to time and budget.

6 CONCLUSIONS

This paper has presented the results of demonstration utilising 4D technology for supply chain management in construction project setting, in order to find the prominent supply chain through simulation of supply chain scenarios. The end result called 4DLive Linker application enhances 4D applications to the direction where the alternative plan can be easily incorporated into application, studied further interactively and presented in the communicative manner.

We have considered the technical aspects and discussed the challenges in 4D technologies and their application in construction project setting. Mostly challenges are related to the concept development and shortcomings in source material.

To conclude, we see that such an interactive environment could be used for testing and simulations purposes in order to find the prominent supply chain. We base this statement to experiences from residential housing case. This new solution contribution is in an insufficient manner considered in existing 4D tools, and has potential to support more thoroughly BIM and other related technologies in construction IT. The message from client side also tells that tools that enhance decision making are needed. Viewing and studying the alternative plans is also very lucrative for construction site training, and therefore, pros and cons of the various supply chain scenarios can be understood better. At the moment the information on best practices is in “project leaders” and “site managers head”, but this kind of initiatives may visually illustrate to other project participants how these experts actually make decisions.

7 ACKNOWLEDGEMENTS

This work has been conducted as part ManuBuild - "Open Building Manufacturing" EU NMP project 515825-2. ManuBuild was an industry-led collaborative research project on Industrialised Construction, part-funded by the European Commission. This project was started in April 2005 and completed in March 2009, thus it was a 4-year project and involved 22 partners from 8 countries across Europe. Since completion of ManBuild the development of interactive environment has been supported by other ongoing projects. Currently development continues in AR4BC project (2008-2010), with VTT as the main developer, companies Skanska, Tekla, Pöyry, Buildercom, Deskartes and Sensetrix as industrial partners, and main funding provided by Tekes (Finnish Funding Agency for Technology and Innovation).

8 REFERENCES

Akinci, B., Tantisevi, K. & Ergen, E. (2003). Assessment Of The Capabilities Of A Commercial 4D CAD System To Visualize Equipment Space Requirements On Construction Sites. ASCE Construction Research Congress, Winds of Change: Integration and Innovation of Construction. Eds Molenaar, K. and Chinowsky, P. Honolulu, Hawaii. March 19-21 2003. ISBN: 0-7844-0671-5

Chau, K., W., Anson, M., & Zhang, J., P. (2005). 4D dynamic construction management and visualization software: 1. Development, Automation in Construction, Volume 14, Issue 4, August 2005, pp 512-524

Fontanini, P., Picchi, F., Loureiro, S., Lima, O. & Folch, A. (2008). Simulating a Construction Supply Chain– Preliminary Case Study of Pre-Cast Elements. In proceedings of 16th annual conference of the International Group for Lean Construction (IGLC), Manchester, UK. 371-380.

Gann, D. (1996). Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. Construction Management and Economics, 14, 437-450.

Hakkarainen, M., Woodward, C. & Rainio, K. (2009). Software Architecture for Mobile Mixed Reality and 4D BIM Interaction. In proceedings of CIB W78 2009 Conference, Istambul, Turkey.

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

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., Hyväkkä, J., Porkka, J., Siltanen, S. & Woodward, C. (2007). Integrating Building Product Models with Live Video Stream. 7th international conference on construction applications of Virtual Reality. Pennsyvania State University, October 22-23, 2007

Kamat, V. R., & Martinez, J. C. (2002). Comparison of Simulation-driven Construction Operations Visualization and 4D CAD. In proceedings of the 2002 Winter Simulation Conference.

Koo, B., & Fischer, M. (2000) “Feasibility Study of 4D CAD in Commercial Construction”. Journal of Construction Engineering and Management, 126 (4), July/August 2000, 251-260.

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

Porkka, J. & Kähkönen, K. (2007) ”Software development approaches and challenges of 4D product models”. In proceedings of CIB W78 2007, Maribor, Slovenia. 85-90.

Ristimäki, T. and Stephens, J. (2009) Logistics management, assembly planning and monitoring tool, Internal ManuBuild deliverable, ManuBuild consortium.

Rönkkö, J. & Markkanen, J. (2007) ”Lightweight 3D IFC visualization client”. In proceedings of CIB W78 2007, Maribor, Slovenia. 461-466.

Samuelson, O. (2008) “The IT-barometer – a decade's development of IT use in the Swedish construction sector”, ITcon, Vol. 13, pg. 1-19

Spekman, R., Kamauff J. & Myhr, N. (1998) “An empirical investigation into supply chain management: a perspective on partnerships,” Supply Chain Management, 3 (2), 53-67.

Staub-French, S., & Khanzode, A. (2007) “3D and 4D modeling for design and construction coordination issues and lessons learned”. Journal of Information Technology in Construction, ITcon, Vol. 12, 381-407.

Vaugn, F. (1996) 3D and 4D CAD Modelling on Commercial Design-Build Projects. Computing in Civil engineering Congress 3. Anaheim, California. June 1996. Eds Vanegas, J and Chinowsky, P. pp 390-396

Vrijhoef, R. & Koskela, L. (2000) “The four roles of supply chain management in construction”, European Journal of Purchasing & Supply Management, 6 (3-4), 169-178.

Zhou W, Heesom D, Georgakis P, Nwagboso C & Feng A (2009) An interactive approach to collaborative 4D construction planning, ITcon Vol. 14, 30-47.