CASE STUDY OF THE IMPLEMENTATION OF THE LEAN PROJECT DELIVERY SYSTEM (LPDS) USING VIRTUAL BUILDING TECHNOLOGIES ON A LARGE HEALTHCARE PROJECT

Atul Khanzode[1], Martin Fischer[2] and Dean Reed[3]

ABSTRACT

This case study presents the preliminary findings of implementing the Lean Project Delivery System (LPDS) using the Virtual Building Technologies on a 250,000 square-feet, $100M, Healthcare project in California, USA. This project is unique as it is the first time that Virtual Building technologies like 3D and 4D CAD are being used in conjunction with the LPDS on such a large Healthcare facility in the USA.

This study is part of an ongoing research project to study how Virtual Building Technologies can be applied on projects using the LPDS. In this paper we discuss how the project used Virtual Building Technologies, specifically 3D and 4D CAD and the LPDS during the *early design phase* of this project. We specifically discuss the following issues:

- Organization of the Project Team for the implementation of LPDS using 3D / 4D technologies
- Challenges & Benefits of using the 3D / 4D technology and LPDS on the project
- Development of new Metrics to track project performance using 3D / 4D tools
- A brief Guideline for implementing LPDS using 3D / 4D CAD technologies

This paper is part of ongoing research and should provide a summary to the practitioners in the industry of how Visualization technologies like 3D and 4D CAD can play an important role in applying the LPDS on complex construction projects.

KEY WORDS

Visualization, 3D / 4D CAD, Lean Project Delivery System

INTRODUCTION

The project under consideration is a $100M, 250,000 square feet Medical Office Building (**MOB**) for the Camino Medical Group, an affiliate of Sutter Health, in Mountain View, CA, USA. This project is part of Sutter Health's $5.5 Billion construction program over the next 10 years in Northern California, USA. Sutter Health, which is one of the largest Healthcare providers in Northern California, has adopted the Lean Project Delivery System (LPDS) to manage the construction of all projects in its portfolio (Lichtig 2004). This project is also the only project in the initiative that is using LPDS along with the Virtual Building Technologies (3D / 4D CAD).

The objectives of this case study are to document how this project utilized the Virtual Building Technologies and LPDS. More specifically we discuss:

1 Graduate Research Assistant, Department of Civil and Environmental Engineering, Stanford University, Stanford CA, USA and Business Analyst, DPR Construction, Inc, 1450 Veterans Blvd, Redwood City, CA USA 94063, atulk@stanford.edu OR atulk@dprinc.com

2 Associate Professor of Civil and Environmental Engineering and Director Center of Integrated Facilities Engineering (CIFE), Stanford University, Stanford CA 94305, fischer@stanford.edu

3 Chief Planner and Lean Construction Coordinator, DPR Construction, Inc. 1450 Veterans Blvd, Redwood City, CA 94063, deanr@dprinc.com

- Organization of the Project Team for the implementation of LPDS using 3D / 4D technologies
- Challenges and benefits of using the 3D / 4D technology and LPDS on the project
- Development of new metrics to track project performance using 3D / 4D tools
- A brief guideline for implementing LPDS using the 3D / 4D CAD technologies

The construction on the project has just started (December 2004). The project is expected to complete in March of 2007. Due to the early phase that the project is in, this case study addresses the use of Virtual Building Technologies only during the Lean design phase of the LPDS.

The paper is organized into the following sections:

- Background on Virtual Building Technologies
- Background on Lean Project Delivery System
- Background Research on Lean Design and application of Virtual Building Technologies during Lean Design
- Project case discussion of the use of Virtual Building technologies in Lean design phase using specific examples
- Discussion on Metrics to track project performance using Virtual Building Technologies and LPDS
- Brief guidelines on using virtual building technologies in the Lean Project Delivery system

BACKGROUUND ON VIRTUAL BUILDING TECHNOLOGIES AND VIRTUAL DESIGN AND CONSTRUCTION

Use of Virtual Building Technologies (sometimes also termed as Virtual Design and Construction or VDC) in the construction industry was pioneered by the research over the last decade at CIFE, Stanford University. CIFE defines, Virtual Design and Construction (VDC) as "the use of multi-disciplinary performance models of design-construction projects, including the Product (i.e., facilities), Work Processes and Organization of the design - construction - operation team in order to support business objectives". (Fischer and Kunz 2004). A variety of tools and techniques have been used for this purpose. Some of these tools are as follows:

- Product visualization and modeling tools (3D Modeling Technology such as ArchiCAD, ADT, Revit, Triforma,CATIA)
- Product & Process modeling Tools (4D tools such as CommonPoint and NavisWorks)
- Organizational and Process modeling tools (such as VDT and SimVision)
- Online collaboration tools (iRoom, Project Based Learning Lab).

The Virtual Building Technologies used on this project include the following:

- 3D Product Visualization tools (AutoCAD Architectural Desktop, www.autodesk.com)
- 4D Product & Process modeling Tools (NavisWorks, www.navisworks.com)

On this project the project team used virtual building technologies, more specifically 3D and 4D CAD product and process modeling tools, so we limit our discussion to the applications of only these tools.

3D/4D CAD technologies have been used on a number of projects in the past. The 3D technology allows a team to visualize the product in three dimensions and 4D tools allow a team to visualize how the product will be built by connecting the process (schedule) with a product representation (3D model). A recent case study has identified the challenges and potential benefits of using 3D / 4D tools on a large construction project (Fischer and Haymaker 2001). Some of the benefits identified include:

- Photo-realistic representation of the built spaces for effective communication
- 3D modeling used for coordination of various disciplines
- Constructability analysis of various construction methods
- Evaluation of site logistics plans etc.
- Evaluation and analysis of various project sequences early on in the project
- Prediction of time-space conflicts or constraints (lay down areas etc.)during the entire project duration

BACKROUND ON THE LEAN PROJECT DELIVERY SYSTEM

The LPDS model consists of four (4) interconnecting phases that include Project Definition, Lean Design, Lean Supply and Lean Assembly. Figure 1 is an illustration of the LPDS. The LPDS also includes two modules of Production control and work structuring that extends through-out the lifecycle of the project (Ballard 2000). The 4 phases are a set of interconnecting triads. Each triad includes some downstream activity from the subsequent phase.

The Lean Design consists of Design concepts, Product Design and Process Design.

It is not the intent of this case study to explain the LPDS in detail. We assume that the reader is familiar with the LPDS. In this paper we limit our scope to address how the Virtual Building Technologies are used to specifically address the Process and Product Design elements of the Lean Design phase of the LPDS. As the project progresses it is our intent to document how the Virtual Building Technologies can be used in the Lean Supply and the Lean Assembly phases.

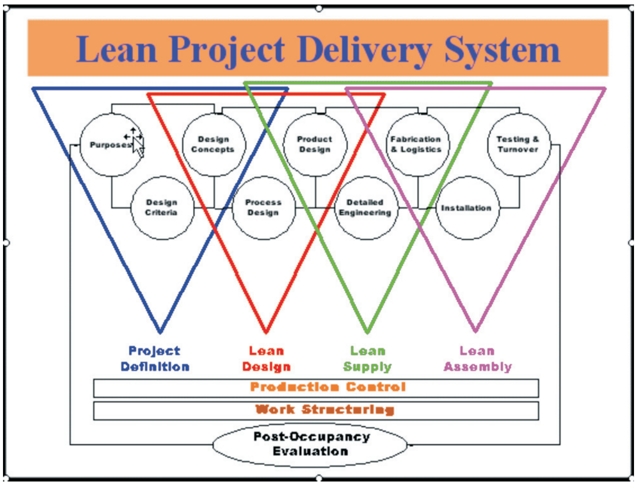

Figure 1: A conceptual representation of the Lean Project Delivery System (LPDS)

In the next section we discuss what are the specific challenges of Lean Design, what others have done to address this and how virtual building technologies have been used to address the challenges of Lean Design.

BACKGROUND RESEARCH

Considerable research has previously been done in documenting the challenges of Design management and how these challenges can be addressed using the principles of Lean Construction. The challenges of the current practice of Design management, especially in a fast track project environment, have previously been discussed at length (Ballard & Koskela 1998). These challenges include:

- Poor communication between Design team members and owners
- Lack of adequate documentation
- Deficient or missing information to make timely decisions
- Lack of coordination between various disciplines
- Negative iterations in Design that leads to waste in terms of non-value added activities

The paper points out that one of the major reasons for the challenges is the current conversion view of Design management. In this paper the authors propose that the Lean construction principles should be applied to Design management. The paper proposes that what is needed is management philosophy and tools that fully integrate all the three views of design i.e. the conversion, flow and value views. The paper points out that the current Design process is rooted in the conversion view and more attention should be paid to the value and flow view of Design.

Some research has also been done to explore the use of technologies in support of the Lean construction principles. This includes the application of 3D / 4D CAD to better understand the flow concept in Lean construction (Tan, Horman, Messner & Riley 2003). This study has identified that use of advanced visualization technologies like 4D can enable a project team to better understand the concepts of flow and value as compared with the traditional paper based tools.

A team of researchers has also studied the integration of workflow modeling and 3D modeling tools to track project performance (Songer, Subramanian & Diekmann 2000). A few researchers have documented the use of electronic document management systems in support of a Lean project delivery process (Giandon, Junior & Scheer 2002). There has also been research on using product-process modeling tools in support of the early involvement of contractors during the design process (Gil, Tommelein, Kirkendall & Ballard 2000).

Collectively, these research studies show that applying Lean principles along with the use of virtual building technologies in the design phase of a project has the potential to bring dramatic benefits to the project delivery process. In the following sections we illustrate some specific examples of how this was accomplished on the Camino Medical Group project.

RESEARCH METHOD

As mentioned before this paper is part of an ongoing research study on the application of virtual building technologies during the Lean Design phase of LPDS. Two of the authors in this study (Atul Khanzode and Dean Reed) are active members of the project team and are involved in the implementation of virtual building technologies on this project as well as acting as the Lean coordinators for the project. The research method we have adopted for this particular study is observation and analysis of the specific examples on how the virtual building technologies is helping the team deliver the project using LPDS during the Design phase of he project.

CASE STUDY DESCRIPTION AND DISCUSSION

In the following sections we discuss specific examples of how virtual building technologies were used in the Lean Design phase of this project. The examples discussed include the following:

- Creating continuous flow and value by utilizing the 3D / 4D tools during Design phase
- Incorporation of specialty sub-contractor knowledge during the design process using 3D / 4D tools
- Rapid iteration of Design solutions for efficient decision making using the 3D / 4D tools
- Incorporating the construction input during the Design phase

CREATING VALUE BY USING 3D / 4D TOOLS

LPDS advocates that major subcontractors (for systems like Mechanical, Electrical, Plumbing, Skin and Structural Steel) should be brought on board during the Lean design phase of the project so that the specialty subcontractor knowledge can be incorporated during the Design phase (Gil, Tommelein, Kirkendall & Ballard 2000). The prevalent contracting method, in the United States, under which subcontractors are brought on board early, is the Design-Build method. On this project the major sub-contractors were brought on board during the conceptual design or Lean Design phase in a Design-Assist role, which is much earlier than the traditional Design-Build contracting method. One of the big issues that the team discussed was how to organize themselves so that they can take advantage of using 3D / 4D CAD technologies and create the maximum value and continuous information flow during the Lean Design phase. The team came up with a process as outlined in the flow-chart (Figure 2).

In the figure CECI indicates Capitol Engineering Consultants, Inc., the Mechanical Design engineers for the project. SD indicates Schematic Design, DD indicates Detailed Design, CD indicates Construction Documents.

As the process indicates above the major subcontractors are already on board during the schematic design phase of the project. The team developed a protocol on how the 3D models will be created and utilized during the Lean Design phase. The solid lines in the flowchart above indicate how the 3D models have been developed and implemented during the Lean Design phase of the project. For example after the 50% DD phase the Architects / Engineers turned over the single line diagrams in 2D the subcontractors. The subcontractors then assumed the Design role to create a coordinated set of 3D models that could then be used further downstream in the Lean Supply and the Lean Assembly processes. The process illustrates a couple of key principles of Lean construction and how they were applied on this project using the Virtual Building technologies. This includes the concept of continuous flow in Design and also the concept of value generation through minimizing waste by early involvement of builders in the design phase and creation of design in 3D models.

INCORPORATION OF SPECIALTY SUBCONTRACTOR KNOWLEDGE DURING THE DESIGN PROCESS USING 3D / 4D MODELS

As illustrated above the subcontractors were involved in this project in a Design-Assist role at the Schematic Design stage. The team incorpo-

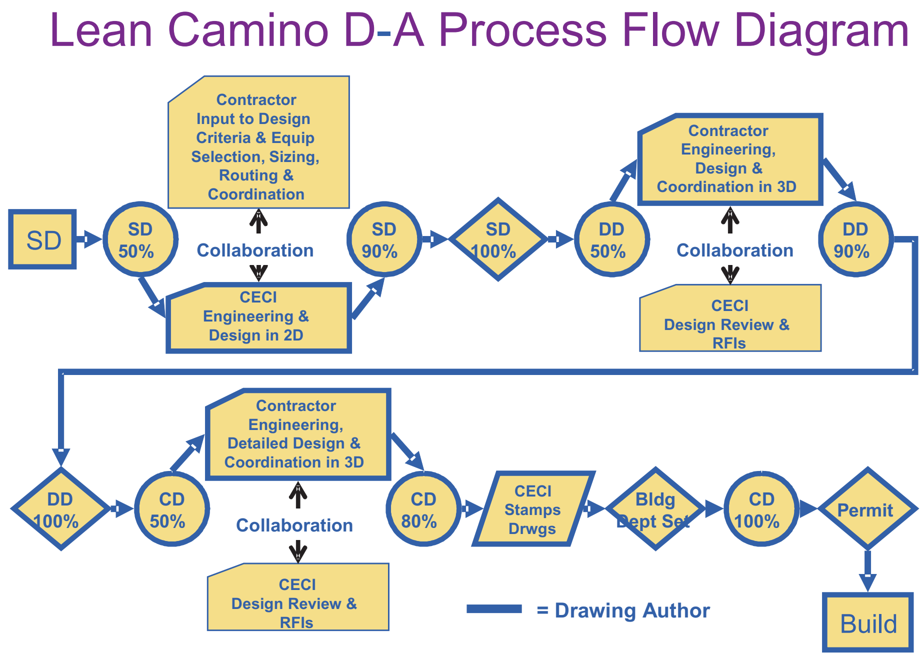

Figure 2: The Lean Design Assist flowchart that indicates how the Camino Medical Group project team organized itself to take advantage of using the 3D CAD models during the Lean Design phase of the project

rated the specialty knowledge that the subcontractors provided to make some key design decisions. An example of this is as follows.

The Lobby Area of the Medical Office Building was important to the client. During the development of the Design concept a few alternatives of the Lobby Area were generated in 3D and discussed with the client. The client was specifically interested in understanding how the skin glazing system will work and how the lobby area would accomplish the goal of being an open connector to the two wings of the building as well as make a significant architectural statement. The Design team developed a few 3D design alternatives with the input from the skin contractor on the feasibility of the glazing system and its connection to the two wings of the building. This allowed the client to visualize and communicate with their stakeholders the Design of the lobby area. A screenshot of the final Design is as shown in the figure below (Figure 3). This is a clear example of how the Virtual Building technology enabled the Design team to incorporate the specialty contractor knowledge in the early design phase therefore generate value for the client which otherwise would not have been possible.

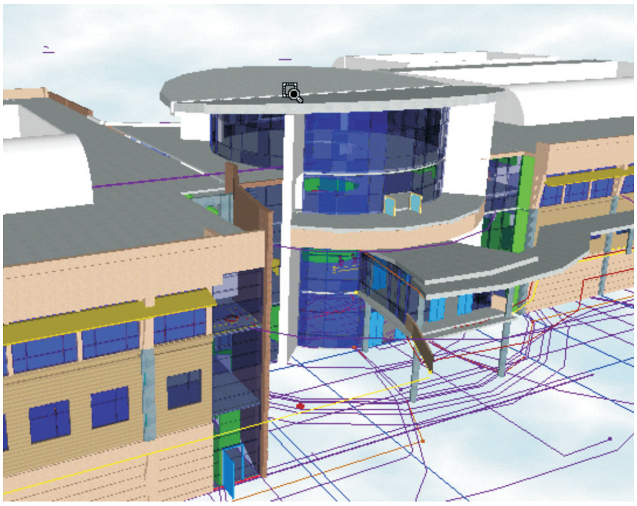

Figure 3: Figure shows the 3D model of the Camino Medical Group Mountain View project. The model shows the Lobby Area and how it is connected to the North and South wings of the Building

RAPID ITERATION OF DESIGN SOLUTIONS USING 3D / 4D TOOLS

The project consists of a Medical Office Building and an underground Parking structure that occupies the whole site area. At the conceptual Design stage it was determined that the client would prefer a natural stone exterior skin for the Building to match with other buildings in their portfolio. It was important for the client to find out the feasibility of having a precast or stone exterior for the building given the tight constraints on the site. At the conceptual Design stage the Team developed a 3D model of the Parking structure and MOB and also developed multiple construction sequencing scenarios using a 4D model simulation. It was determined that the laydown area available for rigging of the crane and lifting of heavy precast stone panels was considerably larger than what would be available on the site and either a smaller crane would be needed or alternative to the heavy precast or stone panels should be explored. The Design team with the input of the skin contractor chose GFRC (Glass Fiber Reinforced concrete) panels as an alternate. These panels are much lighter and would require a smaller crane which fit the laydown area available during construction. The look and feel of these panels also matched what the client was expecting.

This is an example which illustrates how the use of 3D / 4D helped the Design team rapidly generate Design solutions for the client and also demonstrate the viability of the solution based on construction methods. An example of the MOB and Parking structure is shown in the Figure 4.

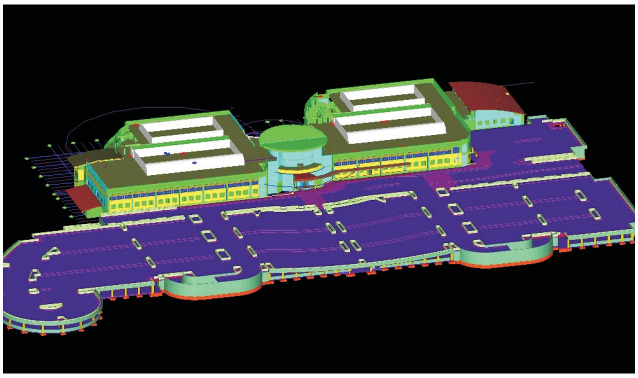

Figure 4: The Figure shows a 3D Aerial view of the Parking structure and MOB together. This was used to convey the Design concept of the underground parking structure and its connection to the MOB to the client.

INCORPORATING THE CONSTRUCTION SEQUENCING INPUT DURING THE DESIGN PHASE

The Lean Design phase also includes the process design. The 3D models were used in the conceptual stage to analyze various construction sequencing options for the project to:

- Determine the availability of lay down areas during the various phases of construction
- Determine the location of trailers and other site offices
- Determine location and movement of cranes required for the construction etc.
- Communicate the overall construction sequence to the owner and other stakeholders.

This was accomplished using the 3D (Product) model developed during Schematic Design of the project and connecting it to a high level schedule (Process model). Examples of this 4D sequence are shown in figures below.

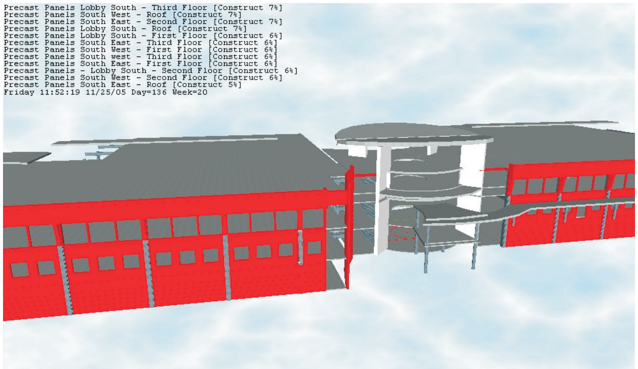

Figure 5: Figure shows a screen-shot of the construction sequencing of the Camino Medical Group project. The panels on the West side of the Building (in Red) are being constructed at the moment.

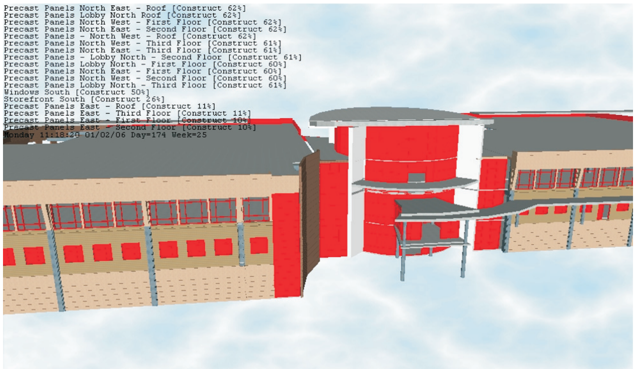

Figure 6: The Figure shows a screenshot of the construction sequencing of the Camino Medical Group project. The storefront panels (in Red) are being constructed.

Figure 7: The Figure shows a screenshot of the construction sequencing of the Camino Medical Group project. The exterior construction is completed and interior construction is now in progress

The examples above are only a few of the examples of how virtual building technology was used during the Lean Design phase of the project and to specifically address the challenges of Design. In the next section we discuss some of the metrics that the project team is currently in the process of implementing on the project to track the project performance and document benefits of using the virtual building technologies during the LPDS.

METRICS TO TRACK PROJECT PERFORMANCE DURING DESIGN PHASE

The project team is using the Last planner system to track the reliability of the planning process during the Design phase using the Percent Plan Complete Metric. In addition to tracking this metric the team is also tracking the potential savings due to the use of 3D / 4D modeling tools along with LPDS. This is done using a Virtual RFI process. The team is already using the 3D / 4D tools to identify and resolve coordination issues, conflicts etc. The potential benefit of identifying and resolving the conflict in the Lean Design phase is currently being documented using the Virtual RFI process. Virtual RFI is a document that was developed by the project team to understand specifically how many potential construction coordination issues are resolved during the Design process and the potential value of resolving that issue earlier during the Design process with the help of the knowledge and experience of the builders. An example of the Virtual RFI is shown in the following figure.

This will provide an understanding of how valuable it is to use Virtual Building Technologies during the Lean Design phase. At the time of writing we did not have much data to provide a specific value for this metric on this project. The project team continues to gather data on this project and it is our intent to publish this data once it is available and can be analyzed.

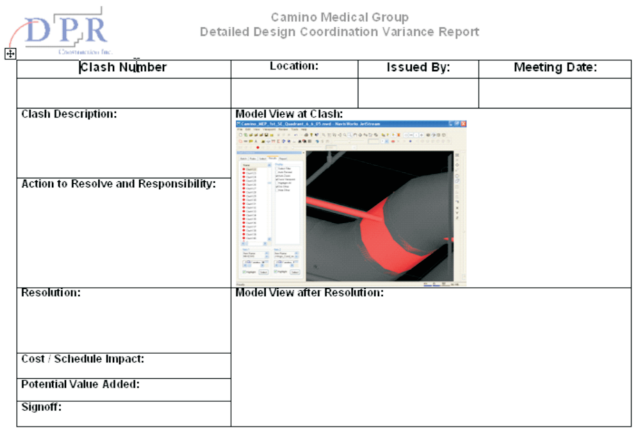

Figure 8: Figure shows the Virtual RFI form that the team is using to document savings due to the conflicts resolved in Design phase.

BRIEF GUIDELINES FOR USING VIRTUAL BUILDING TOOLS FOR A LEAN PROJECT

As this was the first time for the project team to be using virtual building technologies in conjunction with the LPDS on this project, the team had to collectively develop guidelines for how this process would be managed. Most of the guideline developed was about the responsibility to create models but some of it also revolved around how the Lean construction principles of using pull scheduling, limiting batch sizes, rapid iteration, were also incorporated in the guidelines. The following are only some of the points from this guideline:

- Determine the authors of the architectural and structural models at the beginning of the project and with the whole team
- Pre-qualify all the team members for their capability to produce 3D drawings an work in 3D
- Determine specific collaboration and modeling responsibilities
- Agree on protocol on sharing models
- Agree on coordination and conflict resolution process
- Pull design in small batches using the construction schedule
- Determine the batch size for MEP coordination to meet the pull driven schedule
- Sequence trades through interactive construction of 4D models

SCOPE FOR FURTHER STUDIES ON THIS PROJECT

The construction on the project has just started. The project team intends to use the 3D / 4D models during the Lean Supply and the Lean Assembly phases of the project. The project has provided an opportunity to explore how the concepts of Virtual Design and Construction could be applied during the Lean Project Delivery process. We are currently developing Guidelines that other projects could follow to implement the Virtual Building Technologies during the LPDS. As mentioned above we are also documenting the benefits of using 3D / 4D during LPDS and will share it with the Lean Research community.

CONCLUSIONS

This project demonstrates that Virtual Building technologies, more specifically the product and process modeling tools of 3D / 4D CAD can be used effectively to address the conceptual design, product and process design elements of the Lean Design phase of the LPDS. This paper outlined some specific examples that demonstrate real benefits of using virtual building technologies during the Lean Design phase. The paper also outlined a new metric in the form of Virtual RFI that the team is trying to follow to document the benefits of using virtual building technologies in the Lean Design phase. The paper provides a brief guideline on how to apply Virtual Building Technologies, specifically 3D / 4D CAD during the Lean Design phase of LPDS.

ACKNOWLEDGEMENTS

We would like to thank the Camino Medical Group Project Team which includes Sutter Health, DPR Construction, Inc. and Hawley Petersen & Snyder Architects for the access they provided to this project as well as allowing us to use the 3D and 4D images from the project.

REFERENCES

Ballard, Glenn (2000). "Lean Project Delivery System." *White Paper* 8, Lean Construction Institute

Ballard, Glenn and Koskela, Lauri (1998). "On the Agenda of Design Management Research". *Proceedings of the 8th conference of the International Group of Lean Construction*, Guaruja, Brazil

Fischer, Martin and Haymaker, John (2001). "Challenges and Benefits of 4D Modeling on the Walt Disney Concert Hall project." *Working Pager* 64, Center for Integrated Facilities Engineering (CIFE), Stanford University, Stanford CA

Fischer, Martin and Kunz, John (2004). "The scope and role of Information Technology in Construction." *Technical Report* 156, Center for Integrated Facilities Engineering (CIFE), Stanford University, Stanford CA.

Giandon, Andre, Junior, Ricardo and Scheer, Sergio (2002). "Implementing electronic document management system for the Lean design process.", *Proceedings of the 10th Congress of the International Group of Lean Construction*, Gramado, Brazil, August.

Gil, Nino, Tommelein Iris, Kirkendall. B, and Ballard, Glenn (2000). " Lean product-process development process to support contractor involvement during design", *Computing in Civil and Building Engineering*.

Gil, Nino, Tommelein Iris, Kirkendall. B, and Ballard, Glenn (2000). " Contribution of Specialty Contractor Knowledge to early Design", *Proceedings of the 8th Congress of the International Group of Lean Construction*, Brighton, UK.

Lichtig, William (2004). "The Decision to Go Lean", *Presentation* to The 6th Annual Congress of the Lean Construction Institute, Park City, UT, USA

Songer, Anthony, Subramnian, Prasad and Diekmann, James (2000). "Integrating workflow modeling and 3D CAD for visualizing project performance.", *CIB W78*.

Tan, Bo, Horman, Michael, Messner, John, and Riley, David (2003). "Increasing the understanding of Lean principles with advanced visualization technologies.", Proceedings of 11th Congress of the International Group of Lean Construction, July 22–24. Virginia Tech, Blacksburg, VA, USA.