Building Information Modeling (BIM) - in Design Detailing with <u>Focus on Interior Wall Systems</u>

Master thesis from The Technical University of Denmark
conducted at University of California, Berkeley

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Title sheet

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Preface

This report is the result of my Master Thesis, which will complete my degree as a civil engineer from the Technical University of Denmark, DTU. The project is carried out in collaboration between DTU Management and the Institute of Civil and Environmental Engineering at the University of California, Berkeley. The project is granted 35 ECTS-points and conducted from September 1st, 2009 to April 22nd 2010.

My motivation for studying Building Information Modeling (BIM) is that I believe that BIM has great potential as a tool for building construction and management. My interest for BIM began when I attended two M.Sc. courses at DTU in the fall semesters of 2007 and 2008. I was intrigued by the potential, changes, and challenges which BIM induces.

January 1st, 2007 a compulsory rule regarding digital construction of government funded construction was established in Denmark. The first two years were considered to be an implementation period. At the end of 2008, a research project stated that the implementation of "Det Digitale Byggeri" (Digital Construction) had not happened at the pace expected. (Det Digitale Byggeri, 2009) The implementation period was therefore prolonged to the end of 2010.

The prolonged implementation period clearly indicates that implementation of BIM in Denmark has caused more challenges than expected. Based on that, I was curious to investigate how BIM is applied elsewhere in the world.

Based on an exploratory literature review on BIM I realized that the west coast of the US, more specifically the bay area around San Francisco (area known as Silicon Valley) would be an interesting place to go to study BIM. I therefore decided to conduct my thesis at U.C. Berkeley in collaboration with DTU. Before leaving Denmark, I conducted seven interviews with interviewees representing the various trade partners in the building industry such as architects, engineers, contractors, etc., to create an understanding of the current BIM situation in Denmark.

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It has been possible to write this report only because so many people have helped and contributed with information, advice, and support throughout the whole process.

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Larry Bailey. Larry is also working as an architect for the SmithGroup. I have come to know Larry through weekly cluster group meetings regarding the interior wall systems at CHH, Larry has conducted those meetings. I am very thankful to Larry for letting me participate in those weekly meetings, because attending them has been a great help for me to understand the design challenges regarding design of interior walls.

John Koga. John is a Value and Lean Process Manager, and responsible for Lean Implementation at CHH. In the beginning of my project, John helped me a lot with putting my research area into a broader industry perspective.
Later John and the Boldt Company gave me the opportunity to participate in a Choosing By Advantages CBA course which gave me a lot of valuable insight in how to make sound decisions. I cannot thank John and Boldt enough for given me this opportunity.

John Mack. John is the BIM Manager at CHH and is responsible for the overall BIM strategy applied at the CHH project. John has many years of experience in various sectors of the building industry and has therefore sound knowledge about what the industry needs, regarding application of BIM. John has been very interested in sharing his knowledge with me and I am deeply thankful for all insights that I have gained from discussing with him.

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Andrew Sparapani. Andrew is a part of the VDC group, and he has helped me in depth to understand how the deployment of BIM has developed at CHH, from the beginning of the project where the ambitions were to apply the full scope of BIM to where it is today and how and why it is applied as it is. I am very thankful for Andrew's help.

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David has been a great help in regard to help me understand the complexity of the interior wall systems.

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Professor Chuck Eastman. I met Chuck Eastman at the annual buildingSMART conference 2009. Chuck is Professor at the College of Architecture and Computer Science, at the Georgia Institute of Technology. I got the chance to talk to Chuck, he was very interested in my project and offered generous advisory for my further research. I am thankful to Chuck that he allocated all that time to speak with me at that conference.

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Abstract

This report is based on the thesis: Building Information Modeling (BIM) is a concept that promises to revolutionize the building industry in terms of better coordination and communication among the trades involved. This revolution will by no means happen automatically, even if software technology is able to facilitate such a change. Changes regarding management, processes, and contracting are needed to enable the building industry to embrace the concept and fully reap the benefits thereof.

This report argues that conventional project delivery is too fragmented to fully utilize the capabilities of BIM. To enable a better implementation of BIM, the project delivery approach has to be transparent and encourage collaboration, communication, coordination, and flow. The changes that have to happen in the building industry in order to create such an environment have to begin in the mind of those who are involved in the building industry of how to deliver projects. BIM itself cannot do that.

The reason why the conventional project delivery process is considered too fragmented is that there exist little or no communication, coordination and collaboration between designers and consultants engaged in preconstruction and contractors and subcontractors engaged in construction. The lack of collaboration, communication, and coordination among consultants and contractors implies that some of those errors occurring in construction can be related back to design errors. The idea behind BIM is to create a platform were a project can be virtually built before construction. The problem is how to get the right information into the model when the contractors who possess specific information about construction are not involved in the preconstruction phase? This report argues that contractors and subcontractors should be engaged at the end of schematic and beginning of design development in order to exploit their knowledge.

Earlier engagement of contractors and subcontractors in design requires new contractual setups as responsible areas, risk, economical incentives, etc. will change, but also management will have to change, as people from two very different cultures (preconstruction and construction) will be merged.

As for a change in the contractual setup, this report suggests a relational contract form called and Integrated Form of Agreement (IFOA), which is a new relational contractual setup in the US. The IFOA is based on the Lean philosophy in order to facilitate an Integrated Project Delivery (IPD). In brief the IPD is about collocating a design team in one location to create an environment where a high level of collaboration, communication, and coordination among trades can take place.

Abstract

For a change in the management, this report suggests Lean Management, as an approach that can enable better implementation of BIM. Lean can possibly create a higher utilization degree for BIM because besides sharing the values with BIM about reducing waste and creating value, it also focuses on flow.
The tools and methods that Lean can provide to create the flow are tools that encourage transparency, increase collaboration, communication, and coordination. An example is the TVD meetings. TVD is a acronym for Target Value Design which both represents the overall concept for Lean design as well as the name for a meeting which (depending on the project) takes place once or a number of times during each week of a design process. In a TVD meeting everyone in the design team is supposed to participate in order to share information and keep everyone updated on what is going on everywhere in the design process.

BIM and Lean are therefore complementing each other by Lean being able to create the right discussions at the right time in order to provide the best design, and BIM offering its capabilities of visualizing the ideas through 3D, 4D and 5D.

Besides theory this report also investigates a case study in order to analysis how theory fits with practice. The case study has been conducted on a hospital design project in San Francisco. The focus of this investigation has been on how the combination of BIM and Lean has been applied to create a better foundation for implementing BIM with a specific focus on interior wall systems. In this project contractors and subcontractors were engaged early in design and the design development happened through an iterative process. The study shows that the combination of Lean and BIM has had a positive effect as design errors are caught in design.

The potential of connecting the two concepts Lean and BIM appears to be promising, as both theory and practical experience confirm the synergy mellem the two concepts.

Key words:
BIM, Lean, Relational contract (Integrated Form of Agreement), Integrated Project Delivery (IPD), Collaboration, Communication, Coordination, Target Value Design, and interior wall systems.

Resume

Denne rapport er baseret på hypotesen: Bygnings Informations Modellering (BIM) er et koncept som kan revolutionere byggeindustrien i form af bedre koordinering og kommunikation mellem de involverede partnere. Denne revolution vil dog på ingen måde ske automatisk, selv ikke hvis software teknologien gør det muligt, at understøtte en sådan forandring. Forandringer i forhold til ledelse, processer og kontrakter er nødvendige for at gøre det muligt for byggeindustrien, at omfavne konceptet og udnytte det fuldt ud.

Denne rapport argumenterer for, at den traditionelle byggeproces er for fragmenteret til fuldt ud, at kunne udnytte kapaciteten af BIM. For at gøre det muligt at anvende BIM, skal byggeprocessen ændres til at være mere gennemskuelig samt lægge op til mere samarbejde, kommunikation, koordinering og ’flow’. De forandringer der skal ske i byggeindustrien for at opnå et sådant miljø, skal komme fra byggeindustrien selv. Dette betyder at det er dem som er involveret i byggeindustrien som skal ændre tilgang til selve byggeprocessen. BIM alene kan ikke gøre det.

Årsagen til at den traditionelle byggeproces er betragtet som værende for fragmenteret til at kunne danne grundlag for udnyttelsen af BIM er, at der stort set ikke forekommer noget samarbejde, kommunikation eller koordinering mellem projekterende og rådgivere involveret i projekteringsfasen/faserne op til udførelse og entreprenører involveret i (selve) udførelsesfasen. Manglen på samarbejde, kommunikation og koordinering mellem rådgivere og entreprenører forårsager, at der i selve udførelsesfasen opdages fejl der kan relateres tilbage til manglende design koordinering. Ideen med BIM er, at danne en platform hvor et projekt kan blive konstrueret virtuelt før selve udførelsesfasen. Problemstillingen består i hvordan den rigtige information skal komme ind i modellen når entreprenøren og underentreprenøren som har den specifikke viden, ikke er involveret i de tidligere faser. Denne rapport argumenterer for, at entreprenører og underentreprenør skal integreres tidligere, gerne et sted midt imellem den skematiske fase og begyndelsen af projekteringsfasen, for netop at udnytte deres viden.

Det at integrere entreprenør og underentreprenør i ’før konstruktionsfasen’ kræver nye kontraktformer da ansvarsområder, risiko fordeling og økonomiske initiativer mv. vil ændre sig, men også måden at lede et byggeprojekt på, vil ændre sig når mennesker fra to så vidt forskellige kulturer som ’før konstruktionsfasen’ og selve konstruktionsfasen bliver lagt sammen.

Til en forandring af den traditionelle kontrakt form, foreslår denne rapport en ’relations kontrakt’ kaldet Integreret Form for Aftale (Integrated Form of Agreement IFOA). Denne er

en relations kontrakt i USA der er baseret på filosofien bag Lean, for at kunne danne en ramme for brugen af Integreret Project Levering (Integrated Project Delivery IPD) hvilket kort fortalt handler om, at samle alle, som er involveret i et design projekt, det samme sted, for således at skabe de bedste betingelser for, at de involverede partnere nemt kan samarbejde, kommunikere og koordinere.

Til en forandring af ledelsesstrategi foreslår denne rapport Lean Management, som en mulighed for at skabe bedre udnyttelse af BIM. Lean kan muligvis skabe en større udnyttelse af BIM fordi Lean udover, at dele værdier med BIM i forhold til at reducere spild and skabe værdi, også fokuserer på ”flow”.

De værktøjer og metoder som Lean kan give til at skabe ”flow” er redskaber som fremskynder gennemskuelighed, mere samarbejde, kommunikation og koordinering. Et eksempel er TVD møder. TVD er en forkortelse for Target Value Design (Mål Værdi Design) som både repræsenterer det overordnede koncept for Lean i design og altså også navnet for en type møder som (afhængig af projektet) finder sted en eller flere gange i løbet af hver uge af design processen. Til et TVD møde skal alle som udgangspunkt møde op og deltage for at dele informationer således at alle er opdateret om hvad der foregår alle steder i projekteringsfasen.

BIM og Lean komplementerer derfor hinanden ved at Lean kan skabe betingelser for at den rigtige diskussion kan finde sted på det rigtige sted og tid, således at den bedste design løsning kan blive udarbejdet, og BIM kan tilbyde sin kapacitet i form af at kunne visualisere design ideer gennem 3D,4D og 5D.

Udover teori undersøger denne rapport også et case studie i forhold til at sammenligne teori og praksis. Case studiet er blevet udført på et hospitalsprojekt i San Francisco. Fokus har været at undersøge om kombinationen af Lean og BIM i praksis skaber bedre betingelser for at udnytte BIM i forhold til design af indervægge. I dette projekt blev entreprenør og under entreprenører ansat tidligt i design fasen og hele design forløbet foregik via en iterativ proces. Den foreliggende undersøgelse giver udtryk for at en kombination af Lean og BIM har en positiv effekt, da design relaterede fejl blev fanget i design fasen.

Potentialet ved at kombinere de to koncepter Lean og BIM fremstår derfor lovende, da både teori og praksis bekræfter synergien mellem de to koncepter.

Nøgle ord:
BIM, Lean, Relations kontrakt (Integrated Form of Agreement), Integrated Project Delivery (IPD), samarbejde, Kommunikation, koordinering, Target Value Design og indervægge.

Acronyms

AEC	Architect, Engineer, Contractor
BIM	Building Information Modeling
CBA	Choosing By Advantages
CHH	Cathedral Hill Hospital
CIFE	Center for Integrated Facility Engineering
CPM	Critical Path Manager
CPMC	California Pacific Medical Center
TFV	Transparency, Flow, and Value
IFC	Industrial Foundation Classes
IFOA	Integrate Form of Agreement
IPD	Integrated Product Delivery
LPDS	Lean Production Delivery System
LPS	Last Planner System
MEP	Mechanical, Electrical, Plumbing
PPP	Public Private Partnership
RFI	Request for Information
VDC	Virtual Design Construction

Index

1 Introduction

This chapter first introduces the thesis and the concept of Building Information Modeling (BIM) from both a historical perspective and today's perspective. The objective is to identify the capabilities of BIM and document some of the challenges that the building industry is facing in 2010 regarding implementation of BIM. Based on those challenges, this chapter then pursues the objective and research questions addressed in this report.

1.1 Thesis

Building Information Modeling (BIM) is a concept that promises to revolutionize the building industry in terms of better coordination and communication among the trades involved. This revolution will by no means happen automatically, even if software technology is able to facilitate such a change. Changes regarding management, processes, and contracting are needed to enable the industry to fully embrace the concept and to reap benefits thereof.

1.2 Concept of BIM

"*BIM represents a paradigm change that will have far-reaching benefits, not only for those in the building industry but for society at large, as better buildings are built that consume less energy and require less labour and capital resources*". (Eastman *et al.*, 2008) This is how the authors of the BIM handbook introduce BIM to its readers.

Figure 1. Illustration of the paradigm change.

Building **Information** Modeling (BIM) is basically a digital platform for creation of virtual buildings.(GSA, 2007) If BIM is applied, a model should be able to contain all the required information to collaborate, predict and make decisions regarding design, construction, operation, cost, and maintenance of a facility prior to construction. No project has yet fully realized the total scope of BIM.

Today, BIM is considered more than just a tool or a technology; it represents a whole new way of addressing the building process. BIM facilitates 3D, 4D, 5D, and 6D. Where 3D is object-based parametric modeling, 4D is sequencing and scheduling of material, people, floor

space, time, etc., 5D includes the part-lists and cost estimates, and 6D considers facilities management, the lifecycle cost, and environmental impacts. These concepts are profoundly depending on software technology in order to be implemented.

The crux of this new concept is that a BIM model can contain information. Not only is an object in the model defined geometrically but the model also contains information about materials, weight, cost, when and how products are installed, etc. The most important letter in B**I**M is therefore the **I for information**, as this is the revolutionary part of B**I**M (GSA, 2007).

1.3 BIM History

Traditionally, and to a high extent today, the building industry uses a linear process for project delivering where communication and information exchange happen consecutively from actor to actor (Ballard & Koskela, 1998). Each actor generates and adds information to all the drawings in a building project to fulfill their own obligations. This means that by the time an idea reaches construction it has typically been generated seven or even more times, see figure 14. (Building smart – 13, 2010). Those regenerations of data might explain why disputes and miscommunications are common problems in the building industry.

Regeneration of models and objects among more intrigued Professor Chuck Eastman when he, more than four decades ago, introduced a new concept to the building industry. He described a system where "*Any change of arrangement would have to be made only once for all future drawings to be updated. All drawings derived from the same arrangement of elements would automatically be consistent*" (Eastman, 1975) Back then, he called this concept for "Design Description System" and it is the foundation of what today is known as BIM. This and other definitions created by software developers to explain the concept (Bimwiki, 2010) are all focusing on the aspect of "embedded information" in the objects and how that can reduce waste in terms of automatic updates, etc. These definitions have however provoked a standing question in the industry whether or not BIM has to be one model or one database consisting of multiple models, to really be BIM. In this research it has not been possible to find any written documentation that claims BIM to be one or the other. Nevertheless, this is a problem for the implementation of BIM as this standing question is still standing, and therefore creates disputes and confusion about the concept. It is beyond the scope of this report to state one or the other, this report only states that this is subject which today is being discussed and in the case study for this report presented in chapter 5 the matter will be discussed again.

BIM is by many considered as a new technology profoundly based on software, which has directed the majority of research regarding BIM since it was defined towards software

development. Figure 2 display the software development of that era. This places Eastman's contribution into a broader perspective. Software was already in 1973 able to design 3D objects, which Eastman then in 1975 puts into words and predicts how this new technology will be able to make the building industry much more effective.

Also depicted are the years where the three companies AutoDesk, Graphisoft, and Bentley were founded. Those three software providers are today the biggest BIM providers in the world. Since then, they have concurrently with evolving demands from the building industry developed software to nourish new BIM technologies.

When the BIM concept was first launched, predictions were made of how this new approach would change the process in the building industry, but the extensiveness of the change was not and could not at the time be predicted (Eastman, 1975). It turns out that the changes that BIM technology is causing in the building industry are so extensive that it possibly can be considered as a paradigm change as suggested by Eastman (Eastman, 2008).

Software development

1957:	Dr. Patrick J. Hanratty is known as "the Father of CADD/CAM" for his pioneer contributions to the field of computer-aided design and manufacturing.
1968:	Donald Welbourn, now Director for the Industrial Co-Operation at Cambridge University, saw the possibilities in using computers to assist pattern makers to solve the problems of modeling difficult 3D shapes.
1973:	The easy creation and editing of arbitrary 3D solid shapes was developed
1979 :	Mike and Tom Lazear are developing the first PC CAD software.
	In the end of the 1970's a typical CAD system was a 16-bit minicomputer with maximum 512Kb memory and 20 to 300 Mb disk storage at a price of 125,000 USD.
1982:	Autodesk was founded in California. The goal was to create a CAD program for PC's for less than $1000 USD.
1984:	A Hungarian physicist, Gabor Bajor, smuggled two Macs into his country. At the time, ownership of personal computers was illegal under Communist rules. Using Pascal, he and a teenager, Tamas Hajas worked to write a 3D CAD program for the Mac which was the beginning of Graphsoft Company.
1985:	Keith Bentley founds Bentley Systems, Inc. MicroStation provides advanced computer-aided design for PC's. Originally named PseudoStation, the software developed by Bentley Systems allowed users to view IGDS drawings and files without needing Intergraph's software.
1986:	The first documented use of the concept Building Information Modeling

Figure 2. Historic review on the software development enabling the BIM technology. (MBdewign, 2010)

A paradigm change in this context means to fundamentally change the perception of how to design and construct buildings. This change of perception has to come from the people involved in the industry as they are the

ones who have to make the change. A tool alone cannot change anything as the output of a tool never gets better than the data than it is fed, the means by which it is put to use. "*Adopting BIM alone will not necessarily lead to project success. BIM is a set of technologies and evolving work processes that must be supported by the team, the management, and a cooperative owner. BIM will not replace excellent management, a good project team, or respectful work culture*" (Eastman *et al.*, 2008).

"Fundamentally, technology is not causing – in fact, it cannot cause – this change to happen. Rather, it creates the platform that makes it practical and efficient for architects and everyone else involved in the creation of a building to do business under this new set of rules" Philip G. Bernstein vice president of Building Solution for Autodesk. (Berntein, 2005)

A big challenge regarding BIM implementation right now is therefore to change the philosophy and perception that drives the building industry. The problem in doing that is that BIM is not logical, even though the technology appears to be. BIM relies on trust, collaboration and transparency they are all new in compared to the conventional approach (Eastman *et al.*, 2008).

Concurrently with the development of BIM technology in the 1990s, a new management philosophy developed, which at the time was not connected to BIM at all (Ballard, 2000; Koskela, 1992). This new management philosophy became known as Lean Construction, inspired by the thoughts from the Toyota car manufacturing company in Japan (Womack & Jones, 2003).

The reason why Lean is interesting regarding BIM implementation is that Lean is different from previous types of management. It integrates three types of management observations that traditionally have been applied independent from the others or pair wise. The three types of managements are transformation, flow and value. They have all been discussed and documented theoretically throughout the twentieth century, but never in a combined effort (Ballard *et al.*, 2002). In figure 3 the three types of management obervations are listed in a triangle to explain their connection.

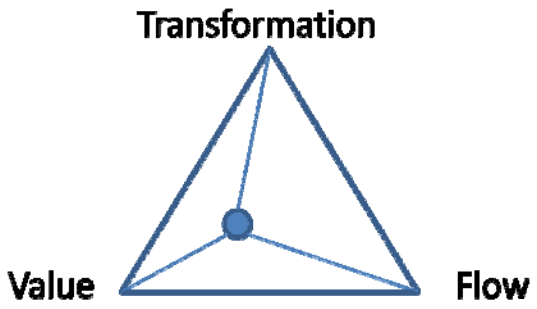


Figure 3. Transformation, Flow, Value (TFV).

Figure 3 illustrates that it is not possible to apply all three management types 100% at the same time. Figure 3 is supposed to be read like: if the dot in figure 3 would have been in the corner where it says transformation, then the applied management would solely depend on transformation management. If the dot would have been on the line opposite from the corner where it says transformation the applied management would only be about creating flow and value. This way of reading the diagram is equal for all three types of managements. This means that the type of management which is depicted in figure 3 is equally more depending on transformation and flow than value, but depending on all three. (Ballard *et al.*, 2002)

The reason why Lean possibly can enable a better or full implementation of BIM is that Lean can provide the "missing dimension" in terms of creating the flow that is "missing" to fully implement BIM. BIM is about designing and construction of a building which means to transform material into a building that brings value to the client, but it does not approach the aspect of flow such as how is this concepts going to be implemented or used most efficiently.

In the beginning of the new millennium various studies started to depict the synergy effects between BIM and Lean. A well documented case which shows synergy effects between Lean and BIM is the Camino hospital project in California 2005.

> "*It is our experience that detailers (BIM designers) must work side-by side in one "Big Room" (Lean concept) to model and coordinate their designs to meet the coordination schedule. Although we cannot precisely say by how much,* ***this shortens the overall time for modeling and coordination and is more economical in the end for all concerned parties*** *because the detailers won't need to wait for posting to see what others are doing which greatly reduces wasted detailing efforts…Detailers for the various specialty subcontractors sat in a*

> *single room, shared resources like servers, internet connections, printers and plotters, and coordinated the detail design with each other and design team in this room."* (Khazode *et al.*, 2008).

1.4 New tools and new processes.

Succesful BIM implementation depends on several aspects such as software, hardware, knowledge, education, motivation, etc. At the end of the day though, all those aspects can (possibly) be boiled down to the following two aspects:

1. Software.

2. A management philosophy.

As stated in the previous section the development of BIM technology has historically been focused on the software and only recently management has been taken into consideration. It is not fortuitous that the focus in the beginning primarily was on the software and to some extent still is today as without the software, BIM would not exist.

1.4.1 **New tools.**

The capabilities of BIM tools have developed during the past four decades and especially within the last ten years. This process of software development will continue as there will always be room for doing things better, faster, etc. At present in 2010 some of the major challenges that BIM vendors are facing are the following two areas: (Building smart, 2010)

- **User friendly interface.**
- **Interoperability.**

User friendly interface.
The interfaces in many of the software programs are still too cumbersome to use, even for people who have learned to operate a program. The operation of a program has to be more intuitive. This is a very difficult aspect to define as different things are intuitive to different people. The problem right now is that even people who have learned to operate a certain program are sometimes not able to design an object because the programs are either not able to create the object or able to create that particular type of object only by going through a

variety of menus. This problem causes people to find these programs very heavy and cumbersome to operate.

Interoperability.

The three big software vendors mentioned in section 1.3 are by far NOT the only ones on the BIM market. There are thousands of software providers serving various niches in the building industry. The problem with all those providers is that they work on different platforms and that their software programs are not able to interact flawlessly, which they have to be able to, in order to export and import files from one program to the other to prevent loosing information. Today these issues cause a lot of problems, as it is not yet universally possible to transfer an object containing information from one program to another. What is happening today is that objects are being consolidated in programs like NavisWorks or Jetstream, or other similar programs. Most of those programs are however solely consolidating objects in order to do clash detection, which means that a part of the information which is embedded in the objects is not transferred.

If no model or database exists that can contain all the objects and their attached information, then some of the benefits in the BIM concept are lost. There are many current attempts to solve these problems such as the IFC format and Solibri. (BuildingSmart, 2010) (Solibri, 2010) IFC format (Industry Foundation Classes) is an international format which is currently gaining worldwide footing. IFC is a file format that can contain objects and their attributes (information). The problem is that the file format is new and needs to be extensive, there are still some transformation problems, IFC is clearly a step in the direction of trying to solve the interoperability problem. Another attempt to address the interoperability problem is Solibi a model checker program similar to Navisworks and Jetstream, the difference is that Solibi is able to read IFC formats and therefore able to contain both objects and their attached information. Problems regarding interoperability are well known, and intensive research is taking place to solve those problems. (Interoperability in construction, 2007)

1.4.2 **New processes.**

Compared to the aspect about software development, the need for new processes does not get the imperative attention. This is interesting as independently on how powerful a tool is, or can get; it will possibly never reach its potential if no one knows how to operate it.
Without the acknowledgment of the need for new processes this new paradigm, BIM will never reach its potential. Therefore this aspect of BIM needs attention to reach the next level of implementation.

"Despite the extensive use of computer-aided drafting tools throughout the various phases of this process (at least, until building operation), this technology has failed to create needed continuity" Philip G. Bernstein vice president of Building Solution for Autodesk. (Bernstein, 2005)

One way of approaching this challenge is Lean, which is a management philosophy which builds upon TFV, which therefore possibly can enable a better implementation of BIM as described in section 1.3.

The first Lean thoughts or ideas were actually made by Henry Ford the American car manufacturer back in the beginning of the twentieth century, he was initially considering how to transform materials into cars, make a production line where materials could be turned into value, and where aspects could be changed (flow) according to clients wishes. However due to the societal circumstances Ford was heavily influenced by the manufacturing philosophy of General Motors, which at the time did not consider flow as an important aspect. The initial ideas of Ford were therefore dismissed (Rother, 2010).

It was not until after WWII (1948) similar thoughts began to germinate in Japan. After WWII, Japan was to a great extent secluded from the rest of the world and the car manufacturer Toyota was therefore limited to support only the Japanese market. That did not allow them to mass-produce anything as the market would not be able to consume the products. Toyota therefore designed a production system with a short changeover time, which means to be able to change the setup of the production line fast, which made them able to produce a specific car immediately after the car was ordered to support the needs of their customers (flow). The positive effect of this principle is that no waste is being produced, and no cars are being produced that are not requested (Liker, 2004).

In 1988 the father of the Toyota production system Ohno publishes a book called the " Toyota Production System Beyond Large – Scale Production" which opened up the doors for getting insight in the growing marked share that Toyota was gaining,, what was the key to their success (Ohno, 1988). The philosophy has since been translated to embrace several types of management disciplines in domains including construction and design

In 1990 James P. Womack, Daniel T. Jones and Daniel Roos published the book *"The Machine That Changed the World"* the "...objective was to send a wake-up call to organizations, managers, employees, and investors stuck in the world of mass production" (Womack & Jones, 2003).*"The Machine that Changed the World"* was among the first books to document the Lean philosophy in the US and Europe and it was sold in many copies. This book was what really marked the beginning of the Lean philosophy in both US and Europe.

In 1992 Lauri Koskela studied the philosophy of Lean production management as well as other types of production management to discussed Lean's application in construction in a report from CIFE at Stanford University (Koskela, 1992). This report is among the first reports to connect the Lean philosophy with the building industry and created the beginning of the concept Lean Production Deliver System (LPDS) (section 3.3.3) which also was the beginning of Lean Design.

Koskela indicates that insufficient design in a conventional project causes between 23-78% of rework(Koskela 1992). It is regarding these design errors that the integration of respectively BIM and Lean possibly can haven an eliminating effect.

In 1993 the first annual International Group of Lean Construction made their first annual conference.

In 1997 the Lean Construction Institute was founded in the US.

In 2000 both Lauri Koskela and Glenn Ballard published their respective dissertations called "An Exploration Towards a Production Theory and its Application to Construction"(Koskela, 2000) and "The Last Planner System of Production Control" (Ballard, 2000) which both describes and documents how the Lean philosophy can be applied in the building industry. The title of Glenn Ballard's dissertation "The Last Planner System" (LPS) has to some extent become a synonym with Lean Construction in the building industry today on an international level.

Glenn Ballard will get the last word in this introduction section, as his description of the connection between Lean and BIM is very eloquent: "*Lean is the operating system, the fundamental management philosophy, so necessarily prior to any tools, no matter how powerful, Without Lean, BIM will not reach its potential*" (Personal communication with Glenn Ballard 2009).

Figure 4 summarizes key historical events regarding Lean development:

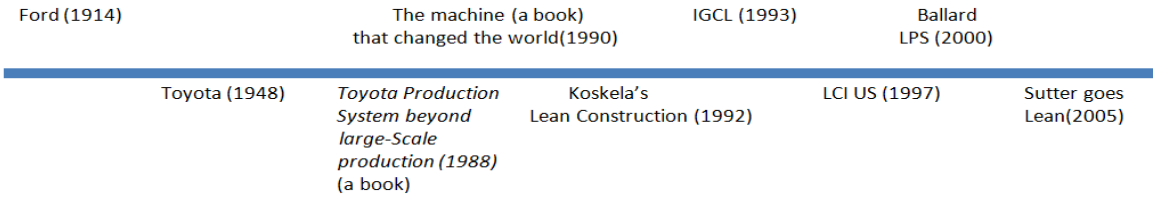


Figure 4. Time line of Lean development (Inspired by Glenn Ballard's class 268A at U.C. Berkeley 2009).

1.5 To whom is BIM an advantage and to whom is it a threat and how?

"*Perhaps the most important economic, driver for BIM systems and their adoption will be the intrinsic value that their quality of information will provide to the building clients. Improved information quality, building products, visualization tools, cost estimates, and analyses will lead to better decision-making during design. The value of building models for maintenance and operations is all likely to initiate a snowball effect, where clients demand the use of BIM on their projects*" (Eastman *et al.*, 2008).

There is no doubt that the money incentive is controlling the project delivery system and in general the building industry, and that the demand for BIM from the client side is essential. However, an interesting question is how BIM becomes an advantage for the trade partners involved in the industry itself, to also create a demand from the building industry itself to apply BIM

After having read the BIM handbook (Eastman *et al*, 2008) it becomes evident that the advantages of BIM can be described in six main categories, which are the following: time, economy, quality, reliability, safety, and trust for all the involved trade partners.

The application of BIM is however still limited today which possibly can have something to do with the fact that not everyone involved in the building industry understands the concept. Others might feel threatened that they will loose their job or responsibilities. For example the architects who possibly feel BIM as a threat, as this new process impose that they have to share their model with trade partners, and not provide the client with a model solely from them, as in the conventional project.

BIM is a tool to store and share information needed for design and construction of a building. This means that "this tool" needs to be fed with information to be able to provide others with the information that they need. For BIM to be an advantage there need to be concordance between what information the designers provide and what the contractors and clients need. If that happens, and the accuracy that BIM promises then prefabrication can become a more integrated part of the building industry. Prefabrication is a concept that for especially contractors and sub contractors can provide a lot of advantages that the building industry not yet have considered.

1.6 Objective.

The objective for this report is to:

- Document the theoretical synergy effects between Lean and BIM in design.
- Explain and analyze how Lean and BIM are applied in an ongoing hospital design project in San Francisco, California with focus of design detailing of interior wall systems.
- Discuss the difference between theory and practice, and what can be done to enable a higher degree of utilization of BIM.

1.7 Delimitation.

Due to the duration of this research, which is 6 months, it has not been possible to follow a building design project from the beginning to the end as a large building design project usually exceeds a 6 month period. To set a realistic and interesting scope for this project, it has been chosen to do only one case study. The case study selected is a mega project, where the complexity is high and the challenges and need for true BIM implementation are immense.

The scope has furthermore been limited to only focus on interior wall systems from a drywall contractor's point of view. Interior wall systems include a wide variety of installations such as plumbing, medical gas, electrical conduits, etc. The complexity of interior walls therefore provides a miniature of a full scale project. The challenges regarding interior wall systems are to organize the utilities in the walls and sequencing of the work of placing the utilities.

1.8 Research questions.

To elucidate the thesis, the following two research questions will be discussed in this report.

1.8.1 **Research question 1.**

How and why do BIM and Lean complement each other in building design?

- How, when, and where does communication and information flow?

1.8.2 **Research question 2.**

How do BIM and Lean impact coordination of interior wall systems among trades?

- Which trades are taking part in the coordination of interior wall systems?
- When is the right time to engage subcontractors?
- How does BIM impact design changes?

1.9 Structure and reading guidelines.

Figure 5 illustrates the central proposition of this report.

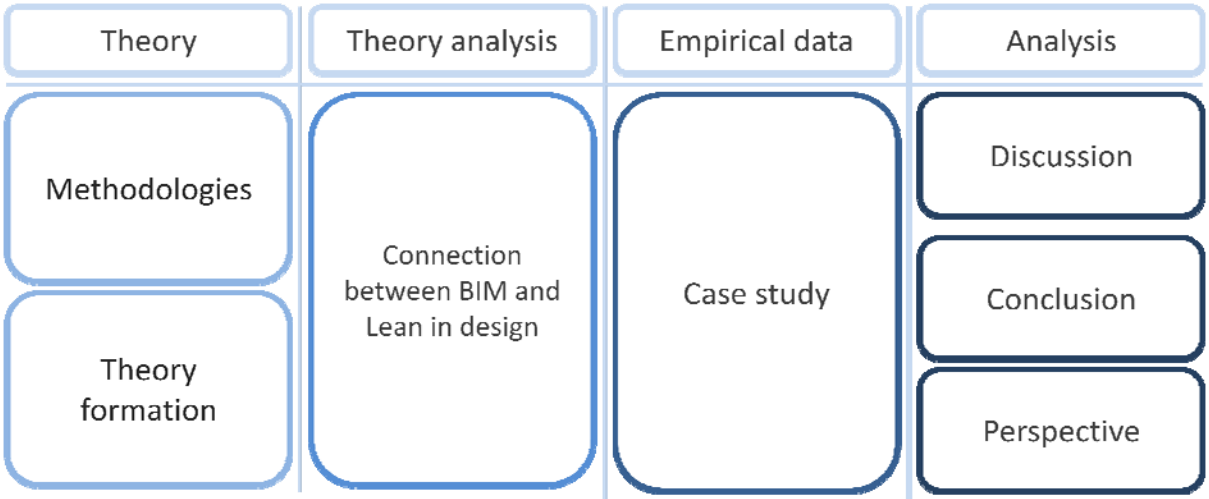


Figure 5. Proposition of this thesis.

Besides this introduction this report can be divided into the four sections as illustrated in figure 5, theory, theory analysis, empirical data, and an analysis. The theory section consist of 2 chapters, a chapter about methodologies and a chapter about theory formation, these are given to introduce the tools, methods, and theory that have been used for conducting this project. Section 2 consist of one chapter where the theory will be analyzed, the theory will be analyzed because this chapter wants to show the theoretical connection between BIM and Lean which were introduced in chapter 3 and use this as an additional theoretical foundation for this report. Section 3 also consists of one large chapter, this chapter is trying to broach the theory on a case study, and therefore this chapter embraces everything which has been documented in the previous chapters. The last section consist of 3 chapters, a chapter presenting the discussion, the conclusion and the perspective of the future challenges regarding BIM implementation.

Chapter 2 "*Methodologies*"

This chapter has three objectives. The first objective is to present the tools that are used to choose and analyze the literature and the empirical data. The second objective is to validate the process of literature review. Finally the third objective is to document the case study method as this is the method used in this project and explain how the case study method is applied.

Chapter 3 "*Theory formation"*

Based on a literature review, this chapter presents the following three types of contractual setups: Design-Bid-Build (DBB), Design-Build (DB) and Integrated Form of Agreement (IFOA). Followed by a presentation of BIM and Lean, which is done to enable a discussion later in this report about how the selected case study applies BIM and Lean in design.

Chapter 4 "*Connection between BIM and Lean in design*"

Based on a literature review and the theory presented in chapter 3 this chapter will describe how Lean can help the implementation of BIM

Chapter 5 *"Case study: Cathedral Hill Hospital"*

First this chapter documents how Lean and BIM have been applied, and to what extent they have complemented each other.

Secondly this chapter documents how BIM and Lean have affected the processes of designing and constructing interior wall systems.

Chapter 6 "*Discussion*"

First this chapter discusses why the industry has to change processes in order to reap the full potential of BIM, and why BIM itself cannot facilitate the needed transformation. Secondly this chapter discusses how Lean as the suggested catalyst in this report possibly can facilitate this transformation and how BIM and Lean complements each other.

Finally this chapter discusses the specific application of BIM and Lean regarding interior wall systems in the case study presented in this report and how this could be done better or differently in future projects.

Chapter 7 "*Conclusion*"

Based on theory and empirical data this chapter first concludes whether or not the thesis of this report can remain standing. Secondly this chapter discusses how BIM and Lean can complement each other, and whether or not it has had an effect that Lean and BIM both have been applied in the case study investigated in this report.

Chapter 8 "*Perspective*"

This chapter will provide a perspective of what it will require in the future to obtain successful implementation of BIM.

2 Methodologies.

This chapter has three objectives. The first objective is to present the tools that are used to choose and analyze the literature and the empirical data. The second objective is to validate the process of literature review. Finally the third objective is to document the case study method as this is the method used in this project and explain how the case study method is applied.

2.1 Choosing By Advantages.

Choosing By Advantages CBA is a decision making system, which in this report has been used in the process of deciding which case study to investigate. The CBA system consist of methods and processes to create a basis for making a sound decision.
The systems were described in 1981 by Jim Suhr, it "came to life when it was discovered and verified that, without exception, a disadvantage of one alternative is an advantage of another alternative".

In short a CBA system consists of five methods to analysis alternatives in order to make a sound decision. The five methods are in figure 6 ranked according to complexity.

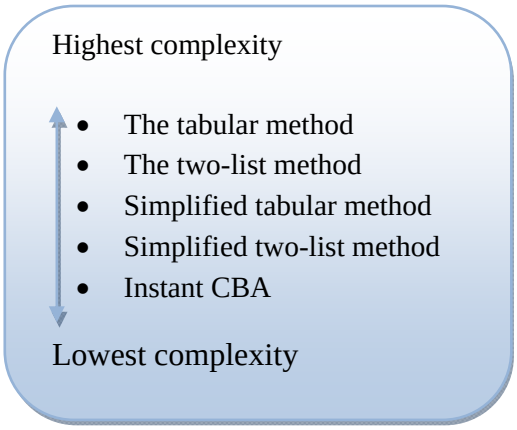


Figure 6. Choosing By Advantage. systems.

A CBA analysis consist of four elements which are: 1) Factors, 2)Criterias, 3)Attributes, and 4)Advantages. A **factor** is a fact, which means that it can be a criteria, an attribute or an alternative. A **criteria** is an aspect that a decisionmaker would like to have fulfilled by making a decision. When the criteria's are set, the different alternatives can be listed. Each alternative is different, which mean that they have different **attributes.** When all the attributes are listed, the different **advantages** of each alternative can be listed and based on that, a sound decision can be made.
"Decisions must be based on the importance of advantages" (Suhr, 1999).

It is beyond the scope of this report to explain all five methods and the theory of CBA. For an introduction to the CBA systems, the book "*The choosing by advantages decisionmaking system"* by Jim Suhr 1999 is highly recommended.

In short, in relation to this report, it has been the "*Simplified two-list method"* which was used to decide which case study to investigate.

"The simplified two-list method is the ideal method for many of our day to day decisions. This method is especially effective during decision meetings. It makes the decision process visible, and it bases decisions on the importance of advantages, while requiring only a minimum number of details…it requires only two central activities: List and Choose."(Suhr, 1999)

To illustrate the principals of the simplified two-list method it is necessary to explain the fundament of a CBA analysis as the Simplified Two-list method is a simplification of the full CBA analysis. A CBA analysis consists of five steps, which are best illustrated by following an example, see example 1.

The simplified two-list method is as written a simplified version and it therefore only consists of step 3 and 5 as they are listed in example 1.

Example 1.

1. Criteria:
   Peter wants a big fancy blue Volvo with stick shift and power steering, and he can choose among the following two cars and it is assumed that there are no differences in the cost of the two cars.

2. Attributes of two alternatives:
   Car 1: A small fancy yellow Volvo with stick shift and power steering.
   Car 2: A big simple blue Volvo with stick shift but without power steering.

3. Listing of advantages of the different alternatives:

Table 1. The Simplified Two-list method.

Advantages of car 1		Advantages of car 2	
➢ Power steering vs. no power steering ➢ Fancy vs. simple	100	➢ Blue vs. yellow ➢ Big vs. small	

   Stick shift is not mentioned in the table, as it is not and advantages for any of the two cars, because both cars have stick shift.

4. Importance:
   The attributes of the two alternatives have been listed and Peter now has to decide which of those advantages are most important to him. This is usually done on a 0 to 100 point scale, where the profound advantage is given 100 points. Assuming that the most important advantages for Peter is that the car has power steering, then that advantage gets a 100 point score and so on, as listed in table 1.

5. Total importance of advantages
   The total number of importance is the sum of the individual numbers of importance of advantages for each alternative.

Basically, CBA is a method to list attributes and advantages of different alternatives to make the basis for a decision more transparent. This process is useful for those who have to make the decision, but also for others when they have to understand why a decision was made.

By first acquaintance with CBA, it might seem as if CBA is trying to make a subjective decision objective, and this is to some extent true, but it is not done without the awareness that this is not fully possible. CBA is trying to anchor the relevant facts to a decision and make the decision more transparent to provide the opportunity to make a sound decision.

2.2 Cross-functional diagrams.

Another tool applied in this research is cross-functional diagrams which is a process flow diagram, which makes it possible to visualize the flow of material, people, and information. In the building industry a cross functional diagram is normally oriented horizontally but it can also be oriented vertically. In a horizontally orientated cross-functional diagram the involved partners are listed in the left side of the diagram, in each their parallel “swim lane”, which is the reason why a cross functional diagram is also often referred to as a “swim lane” diagram.
The target of a cross-functional diagram is to create a fast conspectus for the reader of the depicted process. (Swimlaneflowcharts, 2010) (Figure 8,10,13,38)
There is as such no time duration connected to each task in a cross-functional process diagram. The only thing that this flow diagram shows is how the different tasks in the process are connected, and whom performs what, and in what sequence.

2.3 Selection of Literature.

Due to the time constrain of this project it has been necessary to set criteria’s for how to search for literature.
The foundation of this research is based on the BIM handbook (Eastman *et al.,* 2008), Lean Thinking (Womack and Jones, 2003), and The Toyota way (Liker, 2004). To support these three well recognized books, a literature search based on Google Scholar was limited to articles including the words BIM and Lean construction (or Last Planner System). The articles which were found on that basis were skimmed through and those with focus on processes or 4D modeling were read carefully. Also the ISI web of science was used to track the records of the authors of the selected articles. Articles cited in the selected articles were further investigated.
The books and articles that have been used related to this report are listed in the list of references.

2.4 Case study method.

Parts of this section has been submitted in a previous report by the author of this report (Tjell &Bak, 2009).

The case study method is an inductive research method which has been chosen as the preferred way to collect data regarding this project as the thesis takes its offspring in management or lack thereof regarding BIM implementation. (Eisenhardt,1989)
Questions related to management are often questions like "how was that done" or "why was that done". According to (Yin, 2009) "*..case study is one of several ways of doing science research …. In general case studies are preferred method when*

- ***"How"*** *and* ***"Why"*** *questions are being posed.*
- *The investigator has little control over the events.*
- *The focus is on a contemporary phenomenon within a real life context.*

This situation distinguishes case study research from other types of social science" Which is exactly the context in which the questions related to this report is asked such as "why" is implementation of BIM difficult and "how" can it be done better. "*In brief, the case study method allows investigators to retain the holistic and meaningful characteristics of real-life events – such as individual life cycle, small group behavior, organizational and managerial processes…and the maturation of industries.*"(Yin, 2009)

A case study is a research method just like any other method to discover and clarify a certain area of inquiring. The advantage of using case studies as a research method is that contemporary events can be investigated. The most significant feature for case studies is that the primary data collection is happening through interviews. The fact that a case study research is based on interviews is also the reason why some scholars' object case studies. E.g., the questions are not well prepared previous to the interview, a lack of rigor can occur.
A case study consists of 5 elements (Yin, 2003;Robson, 2002).

1. A design phase.
2. Preparation of data collection.
3. Data collection.
4. Data analysis.
5. Report writing.

Research projects begin with an interest for a certain topic and then questions evolve to get a better understanding. Case study is a method to organize how to approach and investigate a

certain area and how to publish the gained information in such a way that it is easily accessible to others.

Questions often emerge when something new is coming up within an area or if something changes. The questions which are interesting in relation to case studies are therefore often beginning with “why”, “what”, “who” and “how”.
The background knowledge an investigator possesses within a certain area will provide a spontaneous explanation when a “change” happens. If this explanation seems deficient, the basis for an investigation and questions has been made.

It could be “What a smart thing to do, how and where could this also be used” or “That sounds too good to be true – there must be something fiddling or “How could that happen, according to X that should not have happened”. (Yin, 2003)
It will make the job for the investigator easier if the strategy is clear from the beginning. The focus can then be put on elaborating the hypothesis to the greatest extent. It always has to be kept in mind though that something unexpected can happen and the strategy has to be changed.(Yin, 2003)
In general, case study research strategies can be divided into the following 3 categories.

1. Relying on theoretical propositions.
2. Thinking about rival explanations.
3. Developing a case description.

Independently of which one of the 3 strategies seem to be the most appropriate there are five common techniques for how to search for evidence. None of them are superior to any thus one and none of them can stand alone and fulfill the requirements for validity, which will be explained later in this section. Those five techniques are listed here:

1. Pattern matching.
2. Explanation building.
3. Time-series analysis.
4. Logic models.
5. Cross-case synthesis.

Pattern matching is showing the correspondence between the strategy and the evidences. Explanation building is about composing and making a statement probable in those cases where there are no obvious logical explanations. The time-series analysis is about proving a

possibility that the conclusion fits into both the time and environment. The logic model is about matching empirical events with theoretical predicted events. The cross-case synthesis is about checking that information from different sources are corresponding: “this analysis can start to probe whether different groups of cases appear to share some similarity and deserve to be considered instances of the same “type” of general case”(Yin, 2003) Page 135.

To make a successful case study, the most important aspect is to be able to document and verify the conclusion based on the evidence obtained. Theoretically validity of a case study is divided into three different types of validity which are c*onstruction*, *internal*, and *external* validity. The reason for this division is to help the investigator to be vigilant throughout the case study to obtain the necessary evidence. Construction validity is about proving that the selected case(s) is/are substantiating to cover the target for this research. Internal validity is about proving the comprehensiveness of the research, to preclude the possibility of surprises to arise. The external validity is about connecting the evidence and the conclusion. Reliability is also very important and this can be done by showing objectiveness.

The challenge with case studies is the collection of data. A challenge for the researcher is to collect the right material. It requires the right personal skills to remain objective and at the same time receive the trust and respect from the different interviewees engaged in a certain case. As a researcher, the awareness of this role is essential. Aspects which are important are the way to dress, the way to talk, be prepared and have patience.

2.5 Validation of selecting “hospitals in California” as research area.

Hospitals are among the most complex buildings to design and construct, which from the described perspective makes hospitals very interesting. Construction of hospitals is particularly interesting in California because of a law regarding seismic performance that was inaugurated in 1994 (SB1953), demands that every hospital in California has to fulfill certain standards between 2008 and 2030. (CHCF, 2010) Those requirements made it necessary that the majority of all hospitals in California have to be either replaced or retrofitted.

It is a very ambitious project to require all most all hospitals in California to meet certain standards within a 36 year time frame. The project is estimated to cost more than $110B USD (CHCF, 2010) (Equals to a bit more than 15 Great Belt Bridges, a big bridge connecting two islands in Denmark)

In California, many hospitals are run by non-profit organizations. For example Sutter Health and Kaiser Permanente are the two major healthcare providers in Northern California. The

selected case study in this report is a Sutter Health project called Cathedral Hill Hospital (CHH). (Lichtig, 2005)

Justification for selecting the Cathedral Hill Hospital as the case study

Based on a simplified two-list CBA analysis (chapter 2.2) the CHH project was selected as the preferred case study based on the following aspects:

- At present the largest hospital design project in the Bay area.
- Is an IPD project. (IPD is a project delivering method heavily influenced by the Lean principles – which mean a higher degree of integration).
- Using CBA analysis's for design and value decisions. Which means a better decision foundation
- The project team was more welcoming and interested in participating in this project than any other project considered.

The following aspects were also evaluated, they were not pivotal for the decision because several cases could fulfill those requirements.

- Using both Lean and BIM.
- Geographically easily accessible.

CHH is the largest hospital design project in the Bay area at present. It is a $1.7B USD project which is using the IPD concept. IPD stands for Integrated Project Delivery and the core of this concept is that everyone in a project is being collocated to one location to integrate trade partners in the design development of a project to encourage better collaboration, communication, coordination, etc. The concept is described in chapter 4.2. The IPD concept is furthermore supported by a new contractual setup called an Integrated Form of Agreement (IFOA), which is a relational contract developed by Sutter health. (Section 3.1.3). Furthermore CHH is using the sound decision making process called CBA, which is introduced earlier in this chapter, as this tool also is used by the author of this report to for example select this particular case study. When CHH as a Billion dollar project is trying out new concepts like IPD and IFOA, it really tells something about the ambitions and drive this project team has. The positive attitude towards innovation is transmitted to every part of the organization, and creates a very positive and welcoming atmosphere.

2.6 Application of the case study method.

This report is based on a "single case" case study. It would have been desirable to have studied several case studies as indications based on several case studies would have been more reliable. The limitation of only using one case study is recognized and it is therefore "*suggested that the framework* (of this report) *is treated as a proposition, for further rigorous testing and refinement on multiple case studies and surveys of megaprojects*" (Davles, 2009)

To investigate the CHH project, the project has throughout the research period from September 2009 to April 2010 been visited almost on a weekly basis, to get familiar with the project, and to be able to select those interviewees who will be most interesting to make interviews with in regard to this project. According to the case study theory this was part of the design phase of a case study, where background information and a general understanding of the project were collected. During this investigation period the questions for the interviews developed.

A detailed question frame was made previous to each of four interviews which have been held regarding this case study. The questions can be found in appendix A to D. Each question frame was categorized into four topics, where the "easiest" questions were asked first and the most difficult last to make the interviewee more comfortable. All question frames were send to the different interviewees a week before the individual interviews, to inform the interviewees about what type of question they could expect, and for them to be able to prepare themselves and possibly to make a little research on certain topics if necessary to be able to discuss all the questions. All interviews have been conducted in the "home" environment of the interviewees, to optimize the outcome of the interviews according to Yin (Yin, 2003). Each interview was furthermore recorded in concordance with each of the four interviewees previous to each interview.

After each interview, the interview was based on the recorded material transcribed and send back to the interviewee to let the interviewee know the outcome of the interview and to provide the interviewee with the opportunity to correct something in case of a misunderstanding or to add something in case that there would be something they would like to be more specific about.

In this case where the collected data is collected in order to compare with the theory presented in chapter 3 and 4 and build up an explanation of how BIM and Lean complement each other, the method of "Explanation building" (Yin, 2003) that have been used to analyze the collected data.

Selection of interviewees

Table 2. Interviewees from CHH.

Interviewee	Position	Company
Arlee Monson	Project Architect	SmithGroup
John Koga	Value and Lean process manager	HerreroBoldt
John Mack	BIM Manager	HerreroBoldt
David Lim	Interior partition	KHS&S

Table 2 list the persons who have been selected as interviewees.

Arlee Monson:
He was selected because he is the project architect and therefore represents the aesthetic part of the design process versus the trades which have to coordinate and construct the building.

John Koga:
He was selected because he is the Value and Lean Process Manager, and therefore responsible for Lean Implementation at CHH, and therefore could provide knowledge about the lean strategy applied at CHH.

John Mack:
He was selected because he is the BIM Manager at CHH and therefore is responsible for the overall BIM strategy applied at the CHH project. John Mack has many years of experiences in various sectors of the building industry and has therefore a sound knowledge about what the industry needs, when it comes to application of BIM.

David Lim:
He was selected because he represents the sub-contractor KHS&S who is responsible for the interior walls. In his daily work, David designs interior walls in Strucsoft, a complementary program to Revit. David has therefore both experience with designing interior walls in Revit and working in a Lean environment.

3 Theory formation

Based on a literature review this chapter will present:

- Three different contractual setups for building projects, namely Design-Bid-Build (DBB), Design-Build (DB) and the Integrated Form of Agreement (IFOA).
- The BIM concept
- The Lean concept.

This is done to enable a discussion later in this report about how the selected case study has applied BIM and Lean in design.

3.1 Contractual setups

This section is about contractual setups because the contractual setup has an impact on how people can, do, and will work together. As introduced in chapter 1 people's way of behave and approach towards the process of project delivery is what has to change in order to implement BIM successfully.

The two first contract forms which this section describes are Design-Bid-Build (DBB) and Design-Build (DB). Those two are the most frequently applied conventional approaches in the building industry today. The third approach this section documents is a relational contract called an Integrated Form of Agreement. Relational contract should enable a higher utilization degree of the BIM compared to conventional contracts.

Hereby not said that BIM cannot be applied in some projects were certain contract forms are applied, only that the full potential of BIM is more likely to be utilized in relational contract opposed to for example conventional contracts.

3.1.1 **Design–Bid–Build (DBB)**

DBB is the most traditional approach in the building industry and it has probably been around since before anyone began to keep track on contractual aspects like this. (Decker, 2009) A DBB project can be divided into 7 stages as depicted in figure 7

Figure 7. A conventional building project can traditionally be divided into 7 stages.

Each of these stages represents a delimit part of a building process, where the communication and information is being shared consecutively among the different stages. The DBB is at present the most used contractual setup regarding public construction projects in the US. "A significant percentage of buildings are being built using the DBB approach (almost 90% of public buildings and about 40 % of private buildings in 2002) in the US. (Eastman *et al.*, 2008)

Figure 8 depicts a cross-functional diagram showing the first five design stages of a DBB project, to show which trades are involved in the preconstruction of a DBB project and how the communication and information flows among them respectively.

The cross-functional diagram (figure 8) illustrates how the architect is typically involved in the programming, schematic design, and design. After design, consultants regarding plumbing, electricity etc. are engaged to do the detail development in order to do the contractual documents. The consultants have to be engaged to make sure that the project holds the necessary amount of detail for contractors to be able to prepare their bids.

Based on these contractual documents, contractors can bid on the project and with almost no exceptions the lowest responsible bid always gets the contract. This approach implies that contractors are competing against price ahead of product; it also implies that no political pressure can be put on someone to select a certain contractor. (Eastman *et al*, 2008) page 4

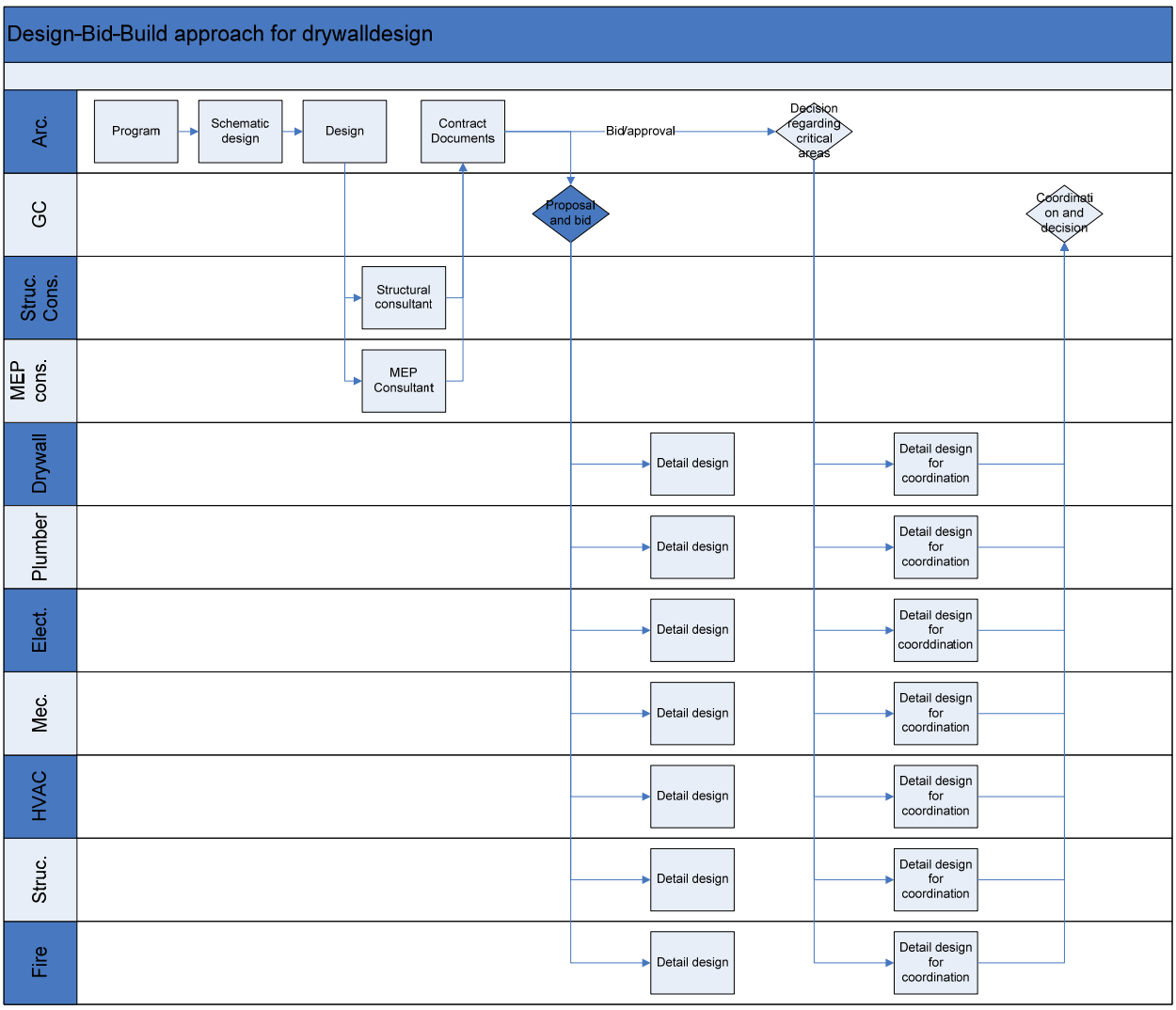


Figure 8. Cross functional diagram of the conventional Design Bid Build approach of interior wall systems.

The contractor's bid has to include a list of sub-contractors to make their bid probable in terms of prices and capabilities in carrying out the job. When a contractor and subcontractor have won a project they start the detail design without any interaction or communication with the consultants which have been engaged earlier. The detailed coordination which will take place will only include those areas which have been listed as critical areas regarding constructability by the architect. The ratio between interior walls e.g. which are listed as critical areas and none critical areas is normally around 30/70% according to the drywall company KHS&S at CHH. This indicates that the majority of coordination is done on site.

"*Often during the construction phase, numerous changes are made to the design as a result of previous unknown errors and omissions, unanticipated site conditions, changes in the*

material availabilities, questions about design, new client requirements, and new technologies. These need to be resolved by the project team. For each change, a procedure is required to determine the cause, assign responsibility, evaluate time and cost implications, and address how the issue will be resolved. This procedure, whether initiated in writing or with the use of a web-based tool, involves a Request for Information (RFI), which must then be answered by the architect or other relevant party."(Eastman *et al.*, 2008).
As a consequence, there is a lot of rework in the conventional approach, and this rework is integrated in the process to an extent where that it has become a natural part of the pricing. This furthermore means that various actors in the process take a lot of risk. The issue regarding risk allocation is a very interesting topic but beyond the scope of this report.

"*As a result of these problems, the DBB approach is probably not the most expeditious or cost efficient approach to design and construct*" (Eastman *et al.*, 2008).

A number of efforts have been made, to address the issues regarding the gap between design and construction that DBB causes. One of these efforts is the Design – Build (DB) approach.

3.1.2 **Design – Build (DB)**

The DB concept was developed to consolidate the responsibilities for design and construction. The most essential difference between the two concepts DBB and DB is therefore that no contractual document has to be developed in the middle of the process as depicted in figure 9 and that consultants and subcontractors have to work together (Decker, 2009).

The "DB" concept is depicted in a cross-functional diagram in figure 10 to show how the flow of communication and information among the consultants and trade partners is, and how it is different from the DBB concept.

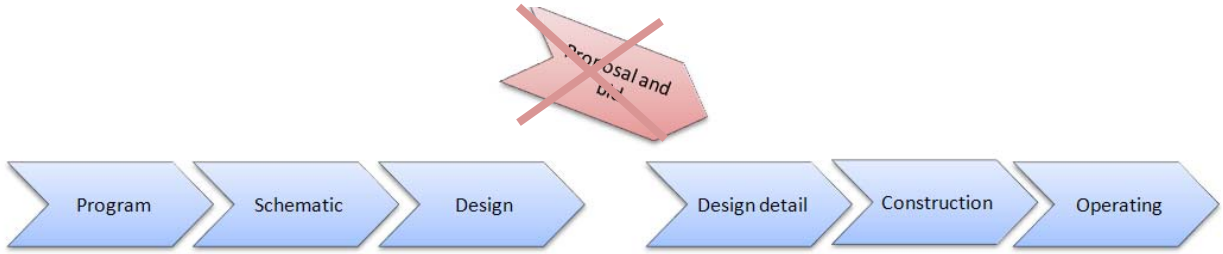


Figure 9. Conventional Design - Build project.

In a DB project both the general contractor and the architect are hired early on in the project to encourage collaboration among trades in design.

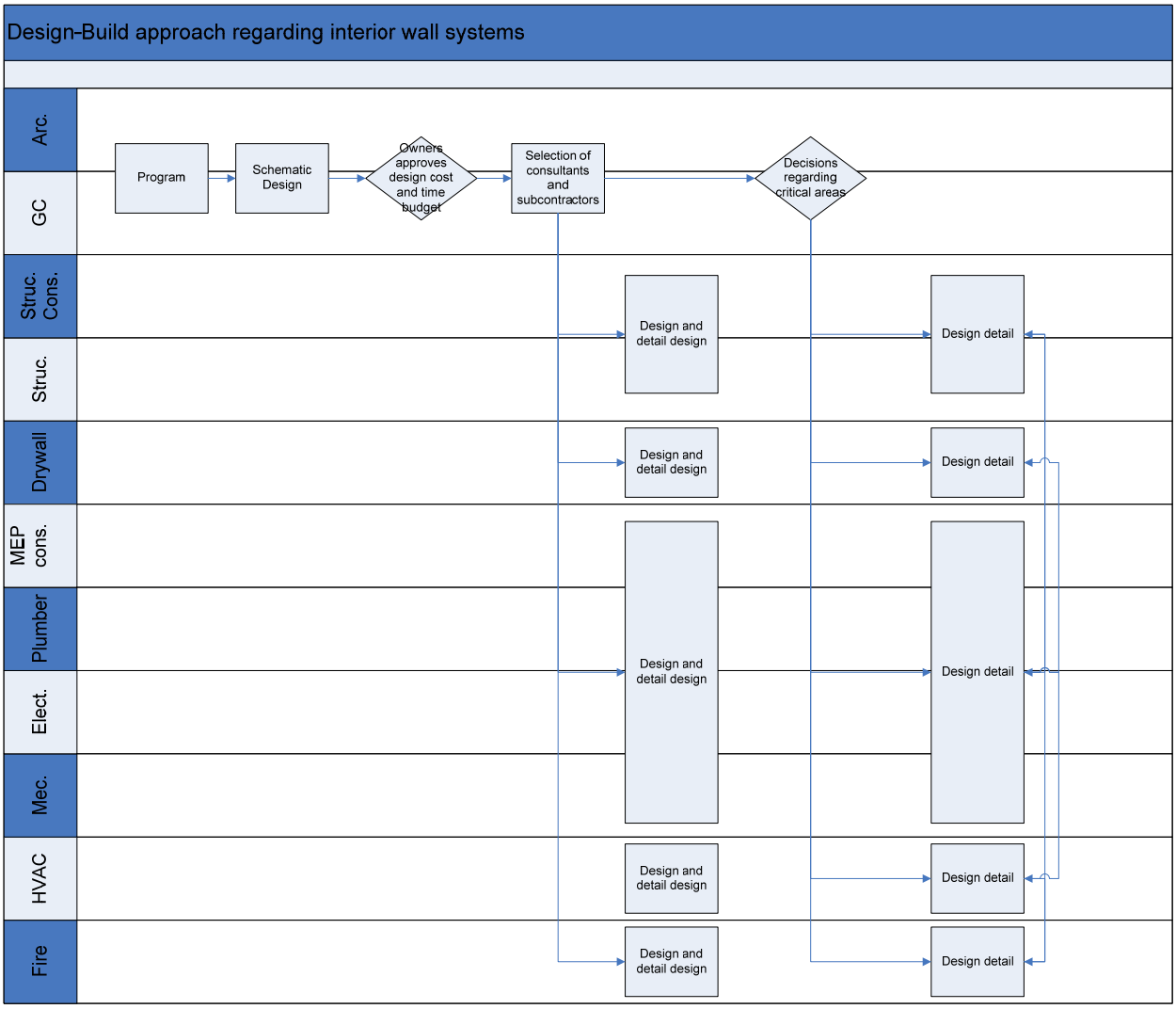


Figure 10. Cross functional diagram of the DB of interior wall systems.

This creates a more consolidated approach within the field related trades, but the coordination among different trades has not normally been effected by the contractual changes. (Ballard & Koskela, 1998)

The DB approach is reducing some of the issues regarding the DBB approach (Matthews & Howel, 2005) but it clearly does not solve them (Decker, 2009).

3.1.3 **Relational Contract.**

A relational contract is a contractual setup where the good relation among tradepartners are in focus. In a relational contract the involved partners are encouraged through an economical incentive to collaborate, and through that eliminate waste and improve value within a certain budget. (Tradelineinc, 2010)

Relational contracts have been known for at least two decades, but it is not until recently, in 2005, that the US has hid the ground running regarding relational contracts. The concept 'relational contracts' has for example been applied in the UK since the mid 1990' at the time known as Private Financial Initiative PFI, which later has changed to Public Private Partnership PPP. (Tjell&Bak, 2008) (Tradelineinc, 2010). In Australia 'relational contracts' are known as "alliance contracts", which is a concept where the financial interest of the different involved partners are being aligned, to encourage collaboration. (Lean-in-Public, 2010) This project is carried out in California, US and will therefore explain how relational contracts are used in the US.

The development of relational contracts in the US was first initiated in 2004 by the non-profit health care provider Sutter Health in Northern California when they decided to develop a contract structure to support the Lean principles. In 2005 (ENR.Construction, 2010) Sutter Health hired, lawyer William A. Lichtig to help them develop a relational contract that could support the Lean Production Delivery System (LPDS) and the concept of Integrated Project Delivery for their future hospital projects (section 3.3).(Decker, 2009:Lichtig, 2005) In brief, the Integrated Project Delivery (IPD) concept is about collocation of a design team to one location, to enable a high level of collaboration among trades. The contract that Sutter health and William A. Lichtig developed is called an Integrated Form of Agreement IFOA.

The case study in this report (chapter 5) is the second project in the US to apply the IFOA agreement, even though the contract was not completed prior to the beginning of the project, this will be explained in chapter 5.2. This section explains how the IFOA is structured including a description of the principle behind the economical incentive, which probably is the most significant part of this concept.

The IFOA is a contract between the owner, the architect, and the general contractor as represented in figure 10. The parties, who signed the IFOA agreement, initially have two things they must do. First they have to create a core group to represent the interest of the parties signing the IFOA. Secondly they have to engage consultants and trade partners with whom they will form the IPD team. It is the architect's responsibility to engage design consultants and the general contractor's responsibility to engage trade partners as depicted in figure 10. The consultants and trade partners also need to sign an amendment called the

"Trade partners and consultants IFOA agreement" (figure 10) which is based on the same elements as the main IFOA.

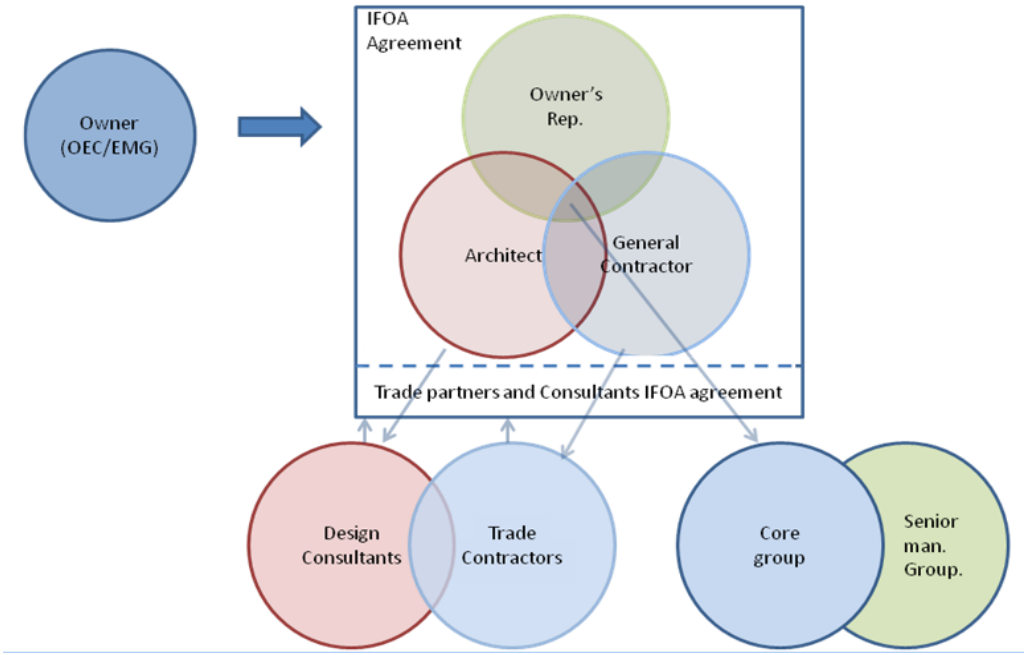


Figure 11. The contractual connection between Integrated Project Delivery team.

The economical incentive aspect of the relational contract shall encourage a high degree of collaboration within the IPD team by putting everyone at risk. Before any prospective IPD team member can become a part of the project, the company has to present a transparent budget that shows how much the company is allocating for design cost, construction cost, profit etc. The reason for this is that a percentage of the amount that a company is expecting as profit will be held back from the company in an "added risk pool". (Decker, 2009) The "added risk pool" is a pool where each trade involved in the project is "depositing" a certain percentage of their profit that they will get back if the construction cost is less than or equal to the Estimated Max Price (EMP), which is a price that are estimated at the end of the design phase (figure 11).

When the owner, the architect and the general contractor is forming the IFOA agreement, the agreement is among more consisting of a "target cost", which is the price that the owner is willing to pay for the project (Section 4.5). That price is set before anything is designed, so the "target cost" is a price that the owner together with the architect and general contracts have estimated based on the owners requirements. If the owner finds the estimate reasonable, the architect and the general contractor can begin to form the IPD team, and the design process can begin. At the end of design, just before construction, the IPD team should be able to predict a more reliable "construction cost" which is the EMP. Ideally, the EMP should to be equal or below the "target cost", as indicated in figure 12. The right column shows that the

EMP is below the target cost (left column), which has been the price that everyone have worked to meet throughout the design process.

If the EMP is not met and the reason for that can be related back to either design errors or "irresponsible" behavior in construction by one of the trade partners, the money to cover that additional cost will be taken from the "added risk pool", and in that way every IPD team member will get less back from the "added risk pool" if one company is not performing as expected. Because they get the same percentage back from the added risk pool, as they have contributed with independent of what is left in the added risk pool. The IPD team is not eligible for any cost increasing the "added risk pool" (Nguyen, 2010)

If the project on the contrary is getting in below the EMP, then the owner will share the money that they save with the IPD team, which means that IPD Team member will get more profit. The four gradually darker colored blue boxes below the EMP line indicate the incentive rate, which can vary from project to project. At the case study presented in chapter 5, the incentive goes like this: if the project gets in $10M USD below the EMP the owner will share 10% of those $10M USD with the IPD team, If the project gets in $20M USD below then 20%, $30M USD below then 30% and finally a flat rate of 40% if the projects gets in more than $40M USD below EMP.

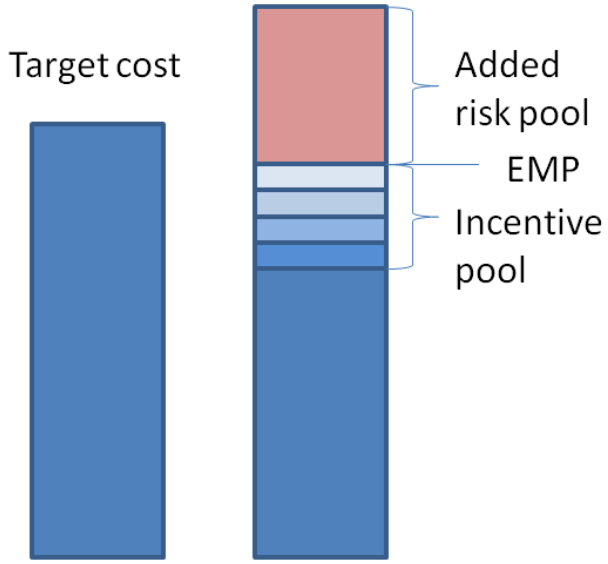


Figure 12. Depiction of the economical incentive in an IFOA agreement.

The IFOA agreement and working in an IPD team creates new work flows and handovers among trades. Figure 13 depicts the IFOA process in a cross functional diagram.

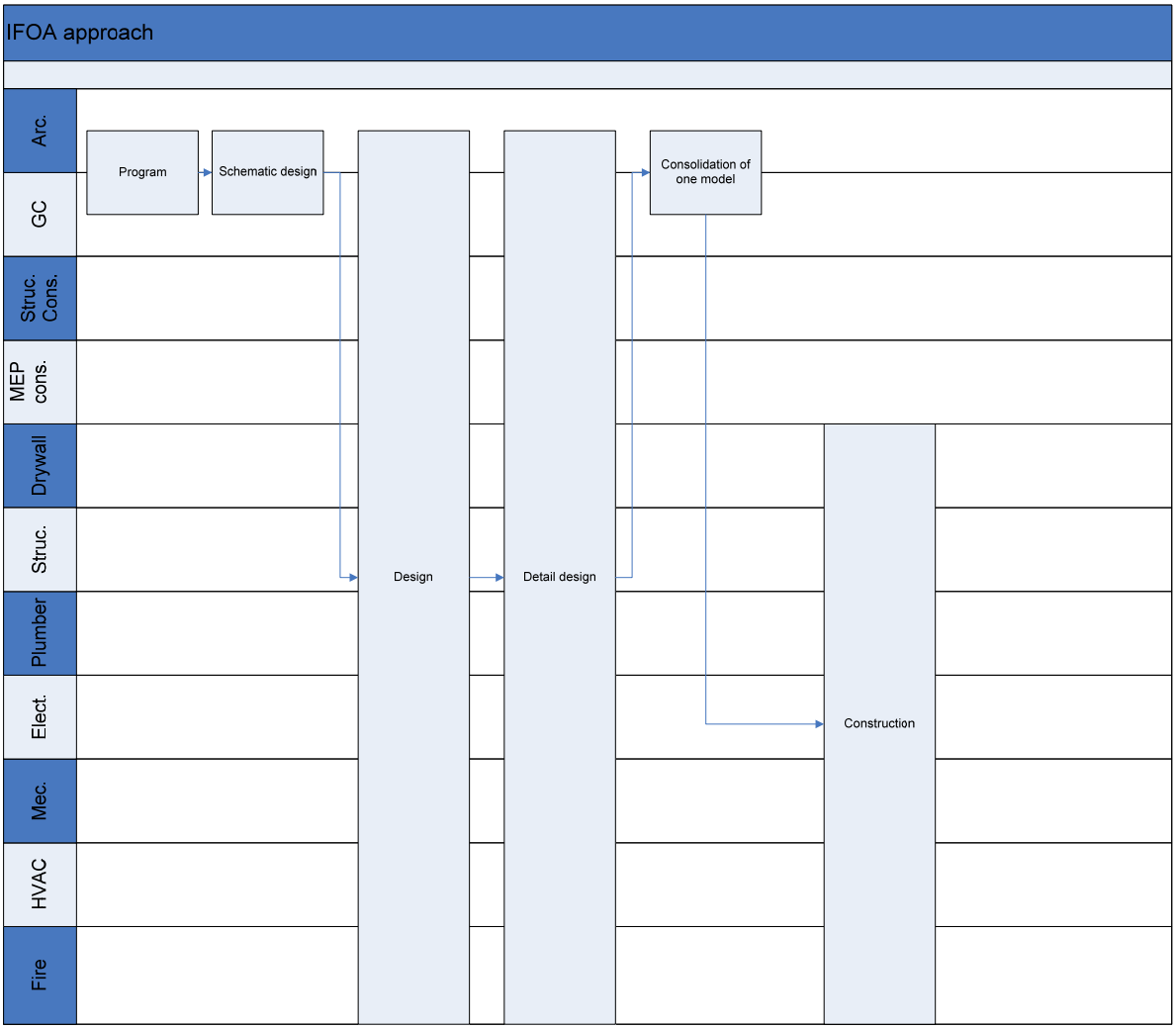


Figure 13. Cross functional diagram depicting the IFOA concept.

When comparing figure 9,10, and 13 some very eye catching differences appears. An obvious graphical change is that the number of “boxes” has decreased and the size of boxes have increased. This simple fact indicates that more trades are engaged early and that there are significant less handovers and more collaboration and integration happening between trades, which is important in the aspect of implementing BIM successfully.

3.2 Building information modeling (BIM).

This section consist of five parts:

- A description of how information and data is flowing and generated in a conventional project.

Then it describes the following four components, which BIM can be divided into:

- 3D modeling.
- 4D modeling.
- 5D modeling.
- 6D modeling.

It is deliberate that this section describes the objectives for BIM and not any software product or particular tool. All the tools which are available today are relentlessly developing to facilitate the industry better; therefore a study of those will provide a picture of what is possible today and less about where the industry is aiming to go.

This section also explains why BIM cannot automatically be incorporated in the "conventional approach", and how BIM if it would be applied in a conventional project most likely would be reduced to a 3D modeling tool. (Eastman *et al*, 2008)

"It is the building industry itself that has to change, there is no such tool that can do that. BIM tools can be magnificent which in the future will significantly improve the building industry, but only if the philosophy and perception of how to design and construct buildings changes" John Messner Associate Professor of Architectural Engineering, Director, CIC Research Program The Pennsylvania State University (Personal conversation at the annual BuildingSmart conference in US 2009.)

*"The most important factor behind the evolutionary change is not technology, as some speculate, but business reality. Technology is just a catalyst to effect a needed change that addresses failures that have long been recognized in the building industry."*Phillip G. Bernstein vice president of Building solutions for Autodesk (Bernstein, 2005)

"…people are unlikely to jettison an unworkable paradigm, despite many indications that the paradigm is not functioning properly, until a better paradigm can be presented" Thomas Kuhn. (Kuhn, 1962)

3.2.1 **Information generation in a conventional project.**

The coordination and communication in a conventional project can cause misunderstanding and through that potential errors and rework. Each time information is being handed over from one trade to another in a conventional project; information will be reinterpreted and regenerated.

A research project from Norway[1] some years ago indicates that from the time an idea is born to the time it is actual built; it will on average be generated seven times. (Building smart – 13, 2010) In each of these regenerations, changes or new interpretations might happen. In other words, if the owner has an idea for the building, then that idea has to pass through a minimum of 7 generations. The question is then, how much of that original idea, will make it into construction. Through that perspective it becomes easier to understand why mistakes happen in the building industry. In figure 14, possible levels or generations are illustrated.

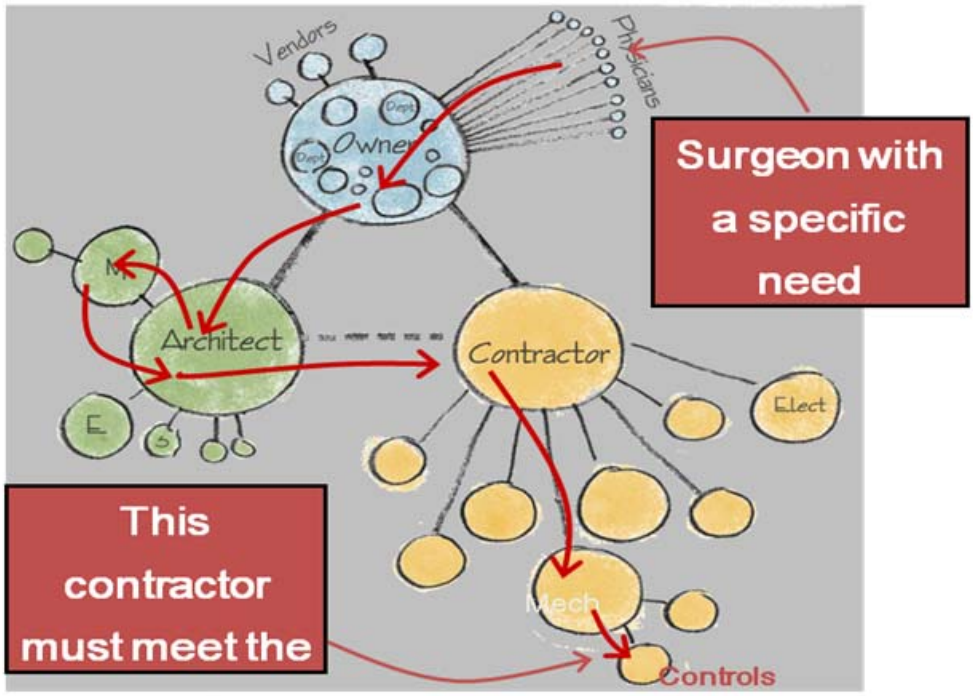


Figure 14. Seven generations (William A Lichtig).

[1] It has not been possible to find that particular report. A Research including correspondence with Eilif Hjelseth professor at the Technical University of Norway confirms the existence of this report, but also that he is not able to find it. He explained that this statement in Norway is as accepted as the law of gravity, which made the need for that report no longer present. (Building smart – 13, 2010)

3.2.2 **3D modeling in a BIM environment**

Traditionally and today, building documentations are and have been paper based, relying on 2D representation. (Eastman *et al.*, 2008) Figure 8 and 10 show how coordination and clash detection have played a modest role in the conventional approach, as the trades have not been working together. Traditionally, cavities in buildings were divided into zones for different trades to fit their installations, if one trade was not able to remain within its dedicated area, coordination with other trades would take place (called the gentlemen's agreement) or if an area would have been pointed out as a critical zone by the architect. In general, coordination is assumed to be taken care of on the job site.
With the development of 3D geometry in the beginning of the 1970s, those critical areas could be more effectively coordination, as more clashes could be detected. It was especially for the MEP(Mechanical, Electrical, Plumbing) trades that the 3D modeling was a huge advantage, which explains why the MEP trades regarding 3D modeling are ahead of other trades today (Appendix C). 3D geometrical representation does however not solve the problem with the many drawing regenerations or the missing collaboration among trades which are happening in the conventional approach, and does therefore not accommodate Eastman's 1975 vision alone.

The core difference between a 3D geometrical representations and 3D BIM model is that BIM consists of intelligent objects which are able to hold information which automatically can be updated and modified with the progress of a project. (GSA, 2007).
No one has to make their own model for the benefit of their own trade, everyone will work on the same platform and everyone will be able to identify who has done what and when. In that way, a particular idea will not be forgotten or reinterpreted in one of the many traditional regenerations.

BIM is using parametric modeling to transform "geometric design" into an object based knowledge embedding tool (Eastman *et al.*, 2008). This means that "*it represents objects by parameters and rules that determine the geometry as well as some non geometric properties and features. The parameters and rules allow the objects to automatically update according to user control or changing context*." (Eastman *et al.*, 2008) that means that objects that will be affected by a particular change will update automatically to facilitate that particular change. An example of that could be the movement of a wall, where the attached objects, such as a door opening, utilities in the wall, other walls, will adjust to that change. In that way, a model is incrementally refined throughout the process.

One way that the BIM model is able to do that is because all "Objects are defined using parameters involving distances, angles, and rules like 'attached to', 'parallel to', and

‘distances from’. These relations allow each instance of an element class to vary according to its own parameter settings and contextual relations” (Eastman *et al.*, 2008).

The capabilities regarding being able to adjust are no doubt a major change from the conventional approach to BIM, but the most essential change that BIM implies is the capabilities of embedding information in the individual object, the intelligence that is being incorporated in the model.

Every object in a model can contain information about weight, cost, constructability, and everything which is needed for the people in the field to physically construct the building. This means that an understanding of what the contractors need, is essential because BIM is not a magic wand: It cannot invent information it was never given.

The interesting aspect regarding this way of designing buildings is therefore how to get the right information which is needed to construct the building into the program.

The ‘I’ for information in BIM is therefore the most important letter, the letter that distinguishes BIM from previous construction documentation process such as simple 2D and 3D drawings. BIM can present a virtual representation of a building, to minimize surprises on the job site.
This means that many if not all coordination issues that designers in the conventional approach have left for the construction workers to solve on site, now can to be solved in design. This approach offhand sounds good, but also almost impossible to carry out, as designers typically do not have sufficient knowledge about constructability because they do not have the same experience as the construction workers. Construction workers have been in the field for many years and through their experience, they do have the knowledge about construction solutions that designers typically do not have. To exploit that knowledge particularly in a BIM setting, constructions workers have to be engaged in design.

This means that the linear structure where communication is happening consecutively as depicted in figure 7 and 9 has to change. Successful implementation of BIM requires that every trade from the whole process is being incorporated somewhere in the design stage, which is a huge change, and not something that will happen automatically.
“*Perhaps the most important point is that contractors must push for early involvement in construction projects, or seek out owners that require early participation. Contractors and owners should also include subcontractors and fabricators in their BIM efforts.*
The traditional DBB approach limits the contractor’s ability to contribute their knowledge to the project during the design phase” (Eastman *et al.*, 2008)

To utilize the full potential of BIM, the design process has to be one cooperative process among all trades, otherwise BIM is likely to become just another 3D modeling tool. This sets a new agenda for how to design and construct buildings and requires a new kind of both contractual setup, but also management. There are trades that have to work together, which have never worked together before. They therefore do not really know what they need from each other, and most critically they do not know how to communicate with each other. (Emmitt, 2004)
The historical gap between designers and contractors is so immense that a new management approach has to be considered.(Bernstein, 2005) In section 3.3 Lean is suggested as a possible management approach to address these challenges and in chapter 5 a case study where BIM and Lean is applied is presented, to broach the effect thereof.

3.2.3 **4D in a BIM environment**

4D modeling is the fourth dimension, which means that it connects place and **time**. In 3D, an object can be determined by place, size and shape (x,y,z) but it cannot tell anything about *when* an object will be in a particular place. Therefore the time is added, the fourth dimension, to be able to determine *when* an object will be in a particular place (x,y,z,t) (GSA, 2009; Koo & Fischer, 2000).

4D models will enable a contractor or sub contractor to determine where people, workers, material, equipment, space requirements etc. (Akinci, 2002) will be at different times and for how long. 4D modeling implies full construction coordination in design. In a conventional project, the coordination of people, workers, material, equipment etc. is done by the project manager on site who does not necessary have the full understanding of the different subcontractors tasks in a particular project: This often leads to poor material, worker and space allocations. (Koo & Fischer, 2000) Manual assessment of connecting drawings and time schedules for a whole building project and sequencing of the workflow on site is almost impossible without causing delays in some areas.

"*First interpreting of the schedule can sometimes be cumbersome as typical schedules have hundreds or thousands of activities, and the assumptions for the preceding relationships are not represented in the CPM (Critical Path Management) schedule, this can make identifying mistakes…in the CPM schedule difficult. Second, different project members may develop inconsistent interpretations of the schedule when viewing the CPM schedule. This in turn makes effective communication among project participants difficult*" (Koo & Fischer, 2000).
Therefore, if coordination of construction could be done virtually during the design stage, many of those aspects which cause delays in construction could be detected and avoided. (Koo & Fischer, 2000)

To upgrade from 3D modeling to 4D modeling is not a big upheaval as stated by the GSA. ” *The majority of time to create a 4D model is spent on creating the 3D model itself…If projects are already going through the spatial BIM validation process, a 3D model will already be created; thus, already contributing towards the cost of creating the 4D model*”(GSA, 2009).

This means, if a project is designed with 3D dimensional objects, then the upgrade to create a 4D model is not big. The upgrade primarily implies that all the objects have to be assigned more information such as time duration for transportation and installation. Also information about the equipment which are needed for transporting and installing the object, plus how much room they need for maneuvering and whether the equipment is available at the specific time and specific place has to go into the system. A 4D model is therefore a 3D model with extra elements in terms of installing equipment and more information embedded to each object about how and when what object will be installed, not here by said that it is easy, butit does not requiring extra software it is about adding and changing the current procedure of how to develop a model.

When every object is connected to an installation task, coordination becomes more reliable, because fewer surprises can possibly happen.
In a case study done by CIFE (Center for Integrated Facility Engineering), similar observations were made. They tried to detect coordination issues from drawings and schedule materials from an already completed project where they did not find any issues. Thereafter they tried to combine the drawings and schedule into task related units, here they did detect objects that were not connected to any specific installation task. “*We could not determine whether the schedule was complete, by model we could immediately see which components did not have related activities in the schedule*.”(Koo & Fischer, 2000) The project was build before this analysis. The construction team on the project was therefore contacted to hear what type of issues had arisen during construction and it became obvious that many of those construction issues could have been detected, if 4D modeling would had been carried out in advance of construction.

Not only can 4D modeling simulate the construction process, it can also to a great extent prevent that more people will be working in the same place and through that create hazard areas during construction. Furthermore if something unexpected happens such as delivery problems with a certain element, then such a change can easy be incorporated in the program and the schedule can be updated and changed, and other tasks can be pushed forward, etc. (GSA, 2009)
4D modeling also enables the project manager to visually document the amount of completed work and through that explain and understand the coming tasks. (Chau *et al.*, 2004).

In the previous section it is described how 3D modeling implies that solutions for construction details are solved during design. In this section it is described how the construction sequencing, 4D modeling, has a desirable effect if it is done prior to construction which means in the design stage. The unsurpassed challenge regarding bringing more and more of those tasks which were previously done in construction into the design stage of a project is that the people with the knowledge on how to solve those constructability issues are no longer those who will be solving the problems unless the contractors and subcontractors are engaged earlier. To engage contractors and subcontractors in the design stage will as earlier stated require both another contractual setup and a new management approach. A possible management alternative is described later on in this chapter (section 3.3).

3.2.4 **5D in a BIM environment**

5D modeling is the fifth dimension, which means that it connects place, time and (total) **cost**. In 4D, an object can be determined by shape, size, place and time (x,y,z,t), but this does not tell anything about how much it will cost to get a certain object to be at a certain place at a certain time. Therefore the cost is added, the fifth dimension, to be able to determine the (total) cost of getting a certain object to be present at a certain place at a certain time (x,y,z,t,$).

The benefit of the fifth dimension is that the total cost of a project can be determined based on material cost, labor cost, transportation cost, etc. all information which can be embedded in the objects. If all that information would be attached to the objects it would be easy to extract the numbers and based on these, make a final cost calculation for the entire project.

One thing is that the software is recently caching up with the 5D concept, but the most important parameter for the lack of 5D implementations today is the standardization on how to determine the cost attributes.
In contradiction to 4D simulation, which could more or less be done with the software already available today, 5D requires more specialized software for economical calculations. The difference between implementing 4D and 5D is that 4D can be done right here right now, what it takes is a change in the mindset of the designers and their drawing behaviors in how to design, opposed to 5D that is also depending on software (Nguyen, 2010).

3.2.5 **6D in a BIM environment**

The sixth dimension is still under dispute whether it exists or not. For those that believe that the sixth dimension exists it is about lifecycle cost, facilities management, and environmental impact. So actually the sixth dimension is about aspects which have an impact on the building and how the building has an impact on its surroundings. It is a very interesting topic that certainly deserves attention and no doubt will get attention in the next couple of years. (BIMandIPD, 2010)

3.3 Lean

Chapter 1 describes how the Lean possibly can be a management approach to create an environment where BIM can be implemented successfully. It also explains how Lean was developed at Toyota in Japan as a production management approach and later in the 1990s how the Lean construction concept emerged. Neither of these two management approaches can be directly applied in the design stage of a building project, but according to Schmenners Matrix (Schmenner, 1986) every management concept consists of some of the same elements, which means that different management genres can learn from each other.

As Lean design is maturing only limited material is available on the topic (Ballard & Koskela, 1998; Emmitt, 2004). This section is therefore focused on explaining the core values of Lean in manufacturing and construction to show where the concept comes from. The following chapter, chapter 4, will then present some of the tools and methods from Lean manufacturing and construction which have been modified to accommodate design purposes, to document what Lean possibly can do for BIM and the other way around. First however is the need for at management theory discussed.

3.3.1 **Why management theory**

Management theory is by some people considered to be useless and sophisticated nonsense, which possibly reflects the lack of connection between practice and theory. Theory is needed to be able to discuss a certain topic, independently of whether or not it is about management or the law of gravity.

Management theory is an intertwining of theory and practice meaning that observations are being connected to predict the outcome of similar situations in the future. *"Practice is ahead of theory, but the lack of theory limits the further development of practice" (Alex Laufer) (as quoted by Glenn Ballard 2009)* This means that observations are needed to create a common reference frame, to allow more in-depth and specialized research to either confine the theory

or leave it standing. Essentially theory allows people to talk in the same language about a certain topic (Koskela, 1999).

BIM needs to be accompanied by a management theory, because at present no common understanding exist about what it exactly implies to use BIM and what outcome can be expected. At present BIM is a technology and a bunch of tools which are being developed simultaneously with the building industry. This possibly has to do with the uncertainties of transforming from one paradigm to another. BIM therefore needs a management philosophy that can create a reference frame and a common set of expectations; expectations for both what it requires to use BIM and what outcome can be expected when using BIM. One management philosophy in line with the same values of BIM, namely to reduce waste, rework, and create more value for the end user, is Lean. The following two sections introduce the Lean philosophy as it originally began at Toyota in Japan and in Lean construction as it merged in the 1990's. The following chapter, chapter 4, will explain the concept of Lean design and how it complements BIM implementation.

3.3.2 **Toyota**

It happens to be at Toyota in Japan just after WWII that the thoughts about minimizing waste, creating transparency, creating flow, increasing value, and producing products fast and reliable were first connected into a management system and turned into words and principles. One explanation to why it developed at Toyota is that the economical situation in Japan after WWII was challenging and forced Toyota to reconsider the structure of their company in order to remain in business.
An engineer named Ohno was therefore given the task to save Toyota, so he had to develop a system to eliminate waste and rework and through that create more value for the client.
In order to develop such a system Ohno visited the US to investigate the Ford assembly line, which at the time was famous for production efficiency. Ohno soon realized that the assembly line contained too much overproduction to be the solution for Toyotas survival. On the same trip to the US, Ohno also saw the American supermarkets, which really fascinated him. He saw a system which could provide customers with fresh products, everyday, immediately as the customer wanted it. That was what Toyota needed, a reliable production system that could produce custom-made cars immediately when the client ordered it.
In order to reorganize the production system at Toyota, Ohno developed different tools and strategies, to facilitate the change; the biggest challenge was according to Ohno himself to change the mindset of the workers. (Womack & Jones, 2003; Liker, 2004)

3.3.3 **Lean construction**

Lean construction merged during the 1990s, the first real evidence that the Lean philosophy was connected to the building industry was in 1992 were Lauri Koskela in a report from Stanford is connecting the two. Up through the 1990 the concept of Lean construction gained footing especially in the US, and in 1997 Lean Construction Institute was founded in the US.

Lean Construction is a concept that wants to embrace the whole life span of the building, this concept is called Lean Project Delivery System and is depicted in figure 15.
The overlap of the triangles shows how the different stages that a building project goes through are connected and how they depend on each other. The arrow that goes from demolition to purpose indicates the backflow of information which is one of the core elements in the Lean philosophy namely to learn from previous experience and continually improve the system. The vertical bars Production Control and Work structuring represent the management approach which has to be a continuous effort through of the lifetime of a building. (Ballard *et al.*, 2002)

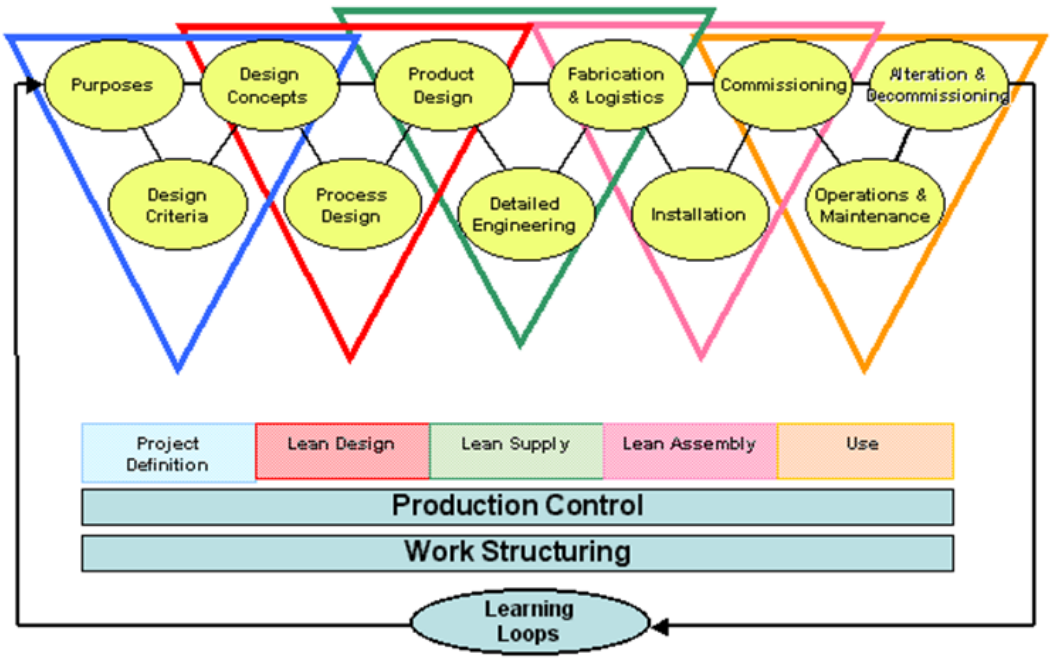


Figure 15. Lean Project Deliver System (LPDS). (Ballard *et al, 2002)*

In the beginning of Lean constructions separation from Lean manufacturing the focus in the LPDS was on the vertical bars in terms of creating at Lean environment for the whole building process followed by the construction aspects which are depicted in the pink triangle

in figure 15. Within the past five years the focus has begun to include the remaining triangles in the LPDS diagram, such as the triangle which, in part is the objective of this report..

That Lean construction is rooted in the same philosophy as Lean manufacturing has caused skeptics in the building industry to question whether or not Lean can be applied in the building industry or not. (Ballard *et al., 2002)*
The objection regarding adopting the Lean concept into the building industry is that building industry is very different from, for example, car manufacturing. In car manufacturing the same product is being produced over and over again whereas a building is a unique, a one-off product. (Howell, 1999)

Independent of how different businesses are, such as manufacturing, construction and design, they can still learn from each other according to the Schmenner Matrix (Schmenner, 1986). Lean is about creating transparency, flow, minimizing waste, creating most value (for the client) and provide the client immediately with what he or she wants. (Ballard & Koskela, 1998) These elements are fundamental in Lean manufacturing, construction and design and therefore they can learn from one another.
"Lean is not a state of being, but a way of acting in the world; a way of managing how we design and make things that includes pursuit of an ideal, in accordance with principles, using the best available methods"(Ballard and Kim, 2007)

In the building industry trades have traditionally worked in "silos" (Mosey, 2009; Bernstein, 2005) which means that each trade has protected their own interest area, which is the opposite of what the Lean philosophy seeks. The Lean philosophy seeks transparency and collaboration, therefore one of the challenging aspects of changing from at traditional management system to a Lean Project Delivery System (LPDS) (figure 15) is clearly the willingness among the trades and employees to try out new concepts. Lean is a fundamental change in how to manage a project, in terms of how to structure and organize a company and is therefore truly depending on that everyone is on board. (Womack & Jones, 2003)

The engineer Ohno who developed the Lean concept at Toyota also developed some tangible tools for people to initiate their endeavor to become Lean[2]. Many of those tools were developed for manufacturing systems and can therefore not without modification be applied in the building industry. Lauri Koskela and Glenn Ballard are possibly the two persons that have had the greatest impact in analyzing the tools from the Lean manufacturing system and modifying them and put them into a construction perspective. (Koskela, 1992: Ballard, 2000). During the 1990's Glenn Ballard developed the Last Planner System, which in the construction industry has almost become a synonym to Lean. In the following section the Last Planner System is first described to explain some of the ground pillars of the Lean

[2] The tools also have the function that it visually illustrates that something has change in how things are done.

construction theory and secondly to lead to the next chapter where the application of Lean design will be analyzed.

3.3.4 Last Planner System LPS™

The "Last Planner system" (LPS™) is aiming to create a flow in construction based on reliability and commitment; reliability in terms of only planning things which can possibly happen, and commitment in terms of making personal agreements that people can commit to.

The fundament of LPS™ is to embrace dynamic projects which includes a lot of changes and at the same time be reliable and construct the building within the given time frame. Today the complexity of projects is increasing because the technology such as various CAD programs and BIM allows more and more advanced geometries and constructions. The more complex projects are, the more dynamic design teams are required to be. The management strategy therefore has to change when the project scope is changing. In figure 16, the topmost line indicates the incremental steps going from a studgy project to a dynamic project, the middle line indicates which type of management should be applied according to how dynamic a project is, and the lower line indicates which contractual setup that best facilitates a project according to how dynamic it is.

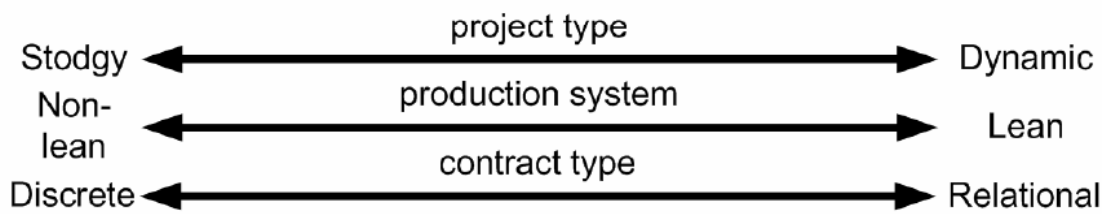


Figure 16. The spectrum of contracts correlated with types of production systems and projects . (Ballard & Howel, 2005)

LPS™ has accepted that detailed planning far out in the future is unreliable because in a complex construction project there are too many unknown factors. "*All plans are forecasts and all forecasts are wrong. The longer the forecast, the more wrong it is. The more detailed the forecast, the more wrong it is*" (Used by Glenn Ballard, however source unknown). To create reliability, only those things are planned, where all the information which is needed are known to make sure that a certain plan can be carried out, nothing more.

In construction there are seven types of information's which are required in order to be sure that a certain task can be carried out. These are: Manpower, space, weather conditions,

materials, pre activities, equipment and information, (Koskela,1999) (FAFO, 2010) (see figure 17)

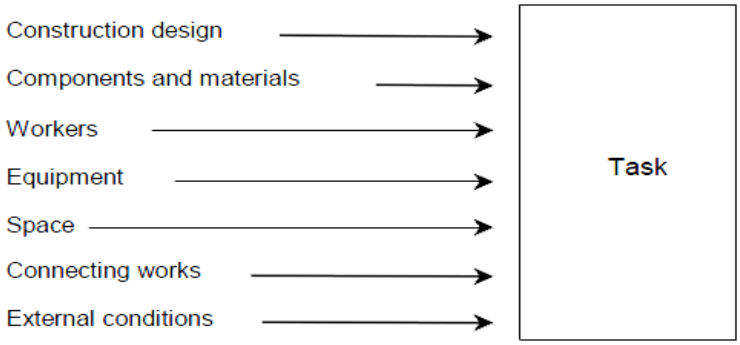


Figure 17. The seven flows. (Koskela, 1999)

When these aspects are known, then a personal agreement between those who have to carry out the job can be made, with this type of planning; only those things which can be carried out will be planned. Furthermore the people, who have to carry out the job, are personally committed to the job.

To make this apparently unstructured system structured a certain overall system has to be applied. This overall system consists of a five step planning process: 1) Master and Pull Schedule, 2) Phase sequencing, 3) Lookahead planning, 4) Weekly Planning, and 5) Learning from failures. This system is depicted in figure 18.

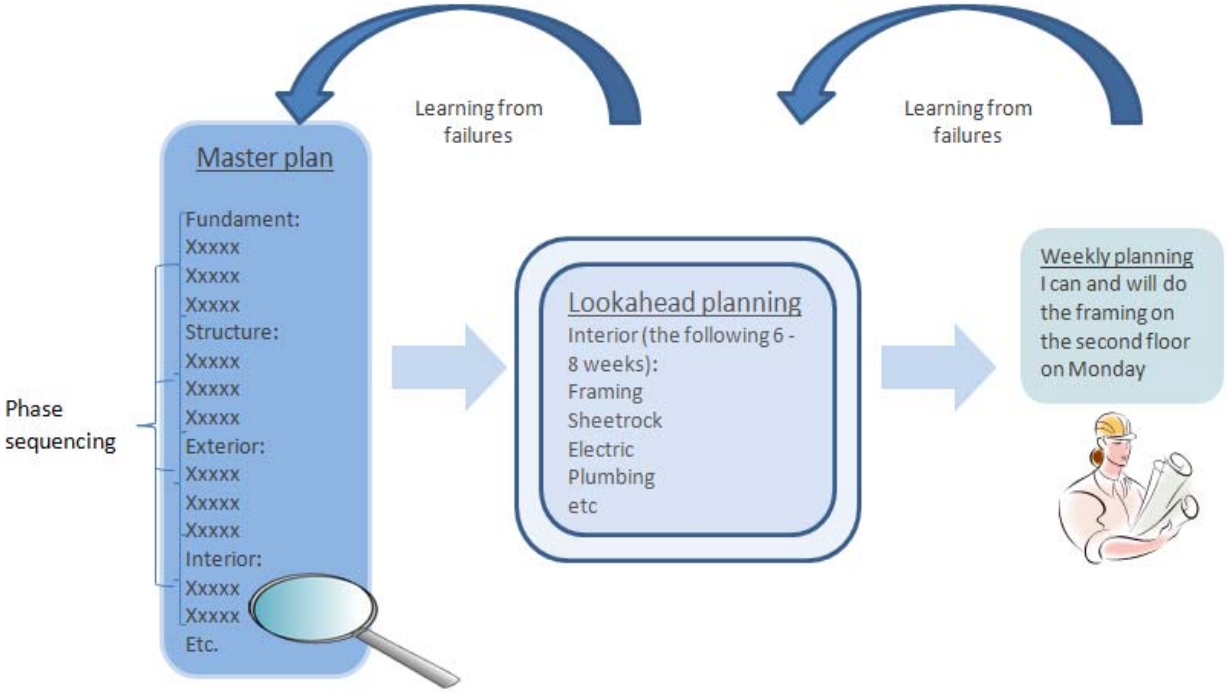


Figure 18. A depiction of the four steps in the Last Planner System.

The master plan has to be developed, similar to a conventional project. The difference is that the master plan in a LPS environment only consists of major milestones and not a fixed plan. The phase scheduling is about breaking the master plan into phases such as fundament, structure, exterior etc. The lookahead planning is a process where the different tasks which are about to come up according to the master plan or the phase plan are being screened for the likeliness that they will be able to be carried out within the next 6 to 8 weeks. When a task is transferred to the lookahead plan it is ready to be pulled into the weekly planning when all seven prerequisite elements depicted in figure 17 can be confirmed. This usually not until a week before as the necessary information about weather conditions, equipment accessibility etc. cannot be known much more than a week in advance. (Ballard, 2000)

Through this system the reliability increases, since a task is only being planned when all the involved actors have agreed that it is possible to carry out a particular task in the coming week and who is responsible for carrying out the task. When people make an agreement face to face with someone, they commit to the task, and therefore feel a certain personal responsibility for carrying out the job. Personal commitment and responsibility are factors that are very important for having things done as planned. (Ballard, 2000)

When a task is carried out, the final step is to check whether the way that a particular job was done was the best way to do it or whether it is possible to do better in the future.

In the Lean terminology the aspect about not making a plan before all relevant factors are known is called "*the last responsible moment*". The last responsible moment, the concept of flow, commitment and reliability are the key words in the LPS system.

4 The connection between BIM and Lean design.

This chapter describes how Lean can be applied in design and how Lean processes and methods possibly can create an environment where the capabilities of BIM can be utilized. This chapter is purely relying on theory, therefore what is presented in this chapter are theoretical synergies between BIM and Lean.

Figure 19 illustrates how the relation between BIM and Lean in the building industry can be understood. The figure depicts two overlaid circles, a big circle representing the Lean concept and a small circle representing the BIM concept. The two concepts are independent and either can or shall they replace one or another. The two circles are depicted on top of each other because the two concepts are approaching some of the same areas from different perspectives. The idea is that Lean creates an overall transparent structure for how information regarding the whole building project and BIM facilitates the part regarding model related documentation.

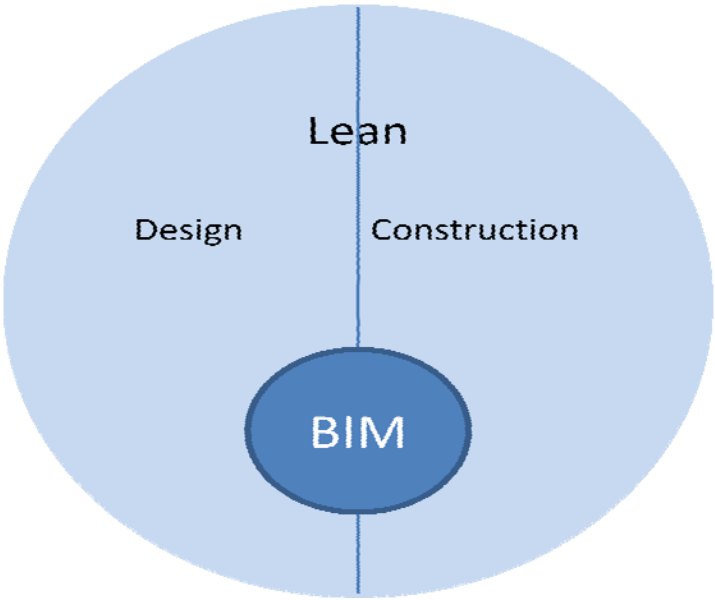


Figure 19. Depiction of a considered connection between BIM, Lean Design and Lean Construction.

The overall concept of Lean design is called Target Value Design (TVD) which can be divided into 5 subgroups as depicted in figure 20. 1) Production System Design, 2) Collocation, 3) Collaboration, 4) Set-based design, and 5) Target costing. They are all elements in configuring the value in a project and maintain the focus of creating the most value within the budget. (Nguyen *et al.*, 2009)

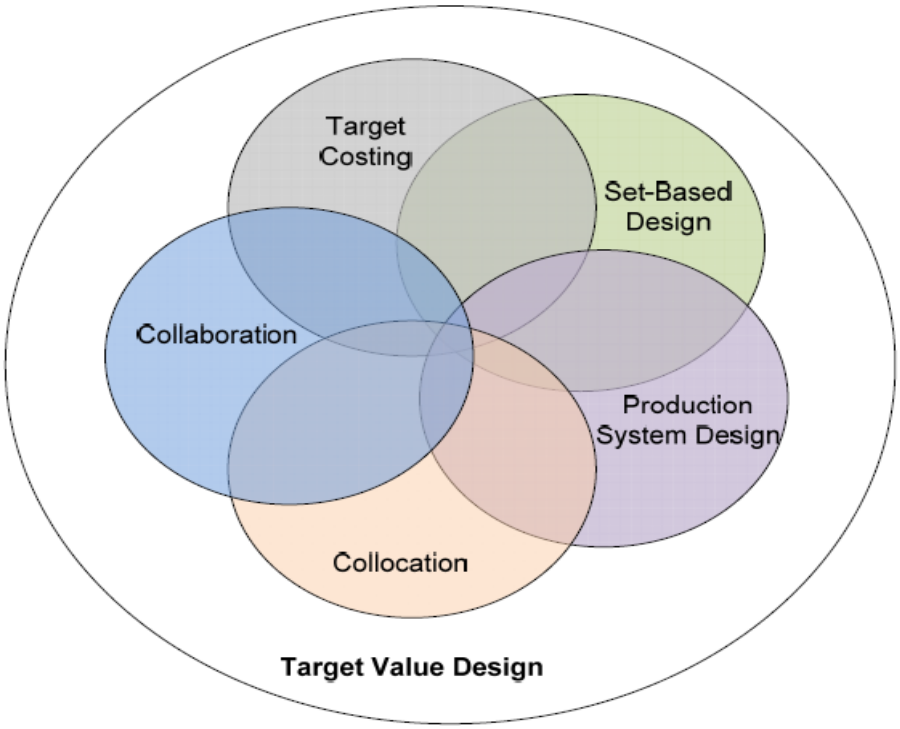


Figure 20. Fundamental components of TVD (Nguyen, 2010).

This chapter will therefore present the 5 mentioned Lean concepts to illustrate why and how Lean and BIM are complementing each other in design.

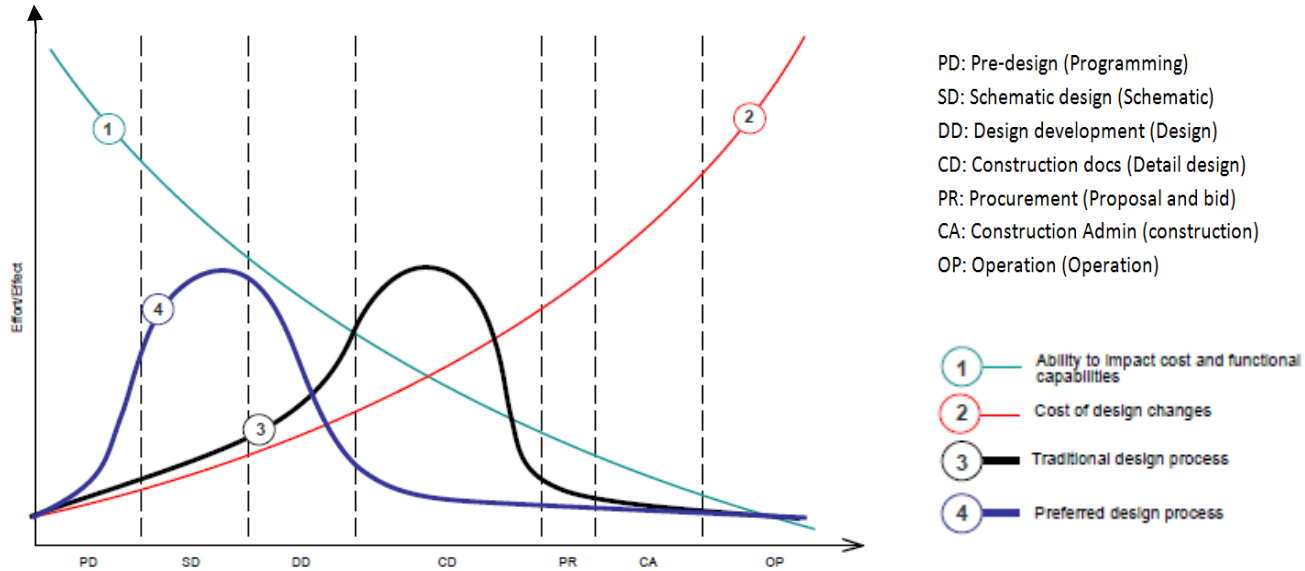
Finally, this chapter will discuss the concepts of creating a Lean environment and summarizes the possible synergies between Lean and BIM in design, which in conjunction with this chapter and chapter 3 will create the basis for the discussion further on in this report regarding the case study which is presented in chapter 5.

4.1 Production System Design.

Production System Design is in a design related aspect about how to structure the design phase in order to reduce waste.

In a report from 1992 by Lauri Koskela, it is indicated that insufficient design in a conventional project is causes between 23 and 78% of those errors which are causing rework. One way to address and reduce this waste is as suggested by Lean to engage people with knowledge about constructability, material, cost, schedule etc. early in design, which means that contractors and subcontractors have to get on board earlier to exploit their knowledge "Research has shown that 80% of construction cost are fixed in the first 20% of design of the design process" (Brookfield, 2004), so if their knowledge shall have an impact they must get onboard early. Bringing contractors and subcontractors on board earlier than traditional is fully in line with both the Lean philosophy and the current understanding of how the capabilities of BIM are being best utilized. (Eastman *et al.*, 2008)

Figure 21 illustrated the influence on having contractors and subcontractors on board early. Figure 21 consist of four different graphs later referred to as the MacLeamy curve. The green graph depicts how easy changes can be incorporated in a project according to when it is occurring; the red graph depicts the economical impact of a change. The black graph depicts when the knowledge about constructability is consolidated in a traditional project, which is not before after the design process has finished. The blue graph depicts how the knowledge is supposed to be consolidated in a Lean based project, to effectively utilize BIM. (Decker, 2009)



Graphic originated by Patrick MacLeamy, AIA/HOK

Figure 21. The MacLeamy curve consists of four different curves. Curve 1 depicts how easy changes can be abated into a project according to where along the process the change is suggested. Curve 2 depicts the economical effect of a change according to when along the process the change is implemented. Curve 3 and 4 respectively depicts when the knowledge about constructability is consolidated in respectively a conventional project and a BIM/Lean project. (AIA, 2010)

Figure 21 clearly illustrated the advantage of having people with constructability knowledge on board earlier, as fewer changes in the late process can be expected, where the changes are more expensive to incorporate. It is the goal that earlier engagement of people with constructability knowledge and integration of respectively BIM and Lean will help reduce these rework percentages and hopefully even eliminate them. (Koskela, 1992; Emmitt, 2004).

The approach with engaging contractors and subcontractors earlier in design is fully in line with the BIM theory presented in chapter 3. First the design becomes more **reliable**, because the people who have to construct the building have both had an influence on the design and providing information to the model (BIM model). Secondly it entails that people in construction are more **committed** to the design as they have a better insight in why different design solutions have been decided, and thirdly as a consequence of the two first mentioned entailments the **cost** is more likely to be less than the cost of a traditional managed project, even though the upfront design cost is higher because BIM coordination is more time consuming. It is anticipated that the savings made in construction based on the improved design with a BIM model will more than outbalance the extra cost in design.

4.2 Collocation.

Collocation is about assembling a design team consisting of designers, engineers, consultants, contractors and subcontractors in one location early in design to combine knowledge beyond the individual trades in order to deliver an integrated project. The concept of integrated project delivery is however originally neither a Lean nor a BIM concept.

The concept of delivering integrated projects was developed by a mechanical construction company in Orlando Florida known as an Integrated Project Delivery IPD – project in the mid 1990'. The company was ”*looking for a better way to use the creative abilities for the whole AEC team(Architect, Engineer, Contractor), not just their own employees*”(Decker, 2009).

The concept has since then been adopted by both the Lean Construction Institute LCI to describe the desired team structure to implement the Lean design and by the American institute of Architecture AIA as the best way to structure a team to utilize the capabilities of BIM. An interesting aspect is that on the homepage for both LCI and AIA the MacLeamy curve which is depicted in figure 21 is used to illustrated the respective benefits of Lean and BIM. On the homepage for AIA graph number four has been renamed to “BIM approach” and on the homepage of LCI graph number four has been renamed the “Lean approach” and actually it was initially developed to illustrated the benefits of using an IPD team, which underlines the bond between the three concepts Lean, BIM and IPD projects.

At the LCI homepage the IPD concepts is described as:

> *Integrated Project Delivery is a delivery system that seeks to align interests, objectives and practices, even in a single business, through a team-based approach. The teams primary Team Members would include the Architect, key technical consultants as well as a general contractor and key subcontractors. It creates an organization able to apply the principles and practices of the Lean Project Delivery System.*

AIA have developed a document called "The working Document Integrated project delivery"(AIA, 2007)Where the following definition on IPD can be found.

> *Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction.*
> *Intergrated Project Delivery principles can be applied to a variety of contractural arrangements…Integrated Project Delivery encourages contribution of knowledge and experience and requires proactive involvement of Key participants…. It is possible to achieve Integrated Project Delivery without Building Information Modeling, it is the opinion and recommendation of this study that Building Information Modeling is essential to efficiently achieve the collaboration required for Integrated Project Delievery.* (Autodesk, 2010)

The three concepts can work independently, but it is the synergy between Lean and BIM in an IPD based project that relishes their full potential, as indicated in the two definitions above.

4.3 Collaboration.

Bringing trades on board early challenges the project setup as well as the management approach regarding how to structure the flow of coordination, communication, and information sharing among all the actors which traditionally did and did not take part in the design.

According to the Lean philosophy collaboration is important. It is important that everyone knows the whole process (Liker, 2004) and that everyone understands why decisions are made in order to understand what creates value downstream[3] in order to eliminate waste upstream (Rother *et al.*, 2009; Emmitt 2004). To create an environment in design where everyone knows what everyone is doing and why, the BIG room concept c to enforcean be used structured collaboration. The concept originates from Toyota where it is called Obeya which in English means BIG room. The concept of Obeya was found by Uchiyamada chief engineer at Toyota regarding the design of the Prius car. The design of the Prius was done under dynamic circumstances which probably is the reason for the development of the BIG room concept. The Prius is Toyotas hybrid car, which has developed a new paradigm for car manufacturing. Uchiniyamada was announced the chief engineer of designing the Prius even though he had no experience with designing cars (he would be free to think new thoughts), and he was only given one year to design the car and make it ready for production.

As he did not know anything about car design, he had to make an alliance with someone who did. And in order to structure all this knowledge the BIG room concept was created. “For the Prius, Uchiyamada gathered a group of experts in the “BIG room” to review the progress of the program and discuss key decisions” (Liker, 2004).

In a building design related context the BIG Room becomes a platform for *collaboration* where discussions and decisions regarding the design can take place among all the trades as depicted in figure 22. There are many different types of meetings taking place in the BIG Room. One type of meetings are the meetings called Target Value Design (TVD) meetings. TVD is as earlier introduced also name for the overall concept for Lean in design. The reason why those meetings are called TVD meetings are that in those meetings everyone in the IPD Team member is represented and it is the overall decisions regarding design which are being made in this forum.

[3] Downstream and upstream are Lean expressions. In the Lean philosophy a process is considered as a stream therefore the end of a process is approached the further downstream you go.

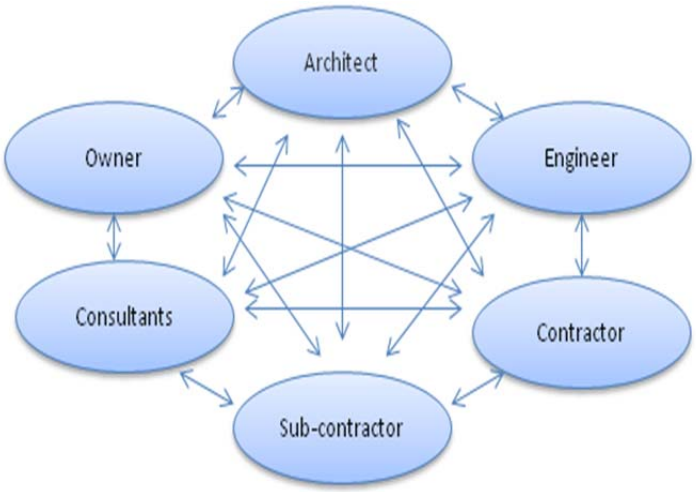


Figure 22. The BIG Room concept gathers all disciplines and encourage interdisciplinary *collaboration.*

To fully utilize the environment that the BIG Room creates where design alternatives can be discussed among multiple trades, a facilitator to systematize, visualize, and store that information is needed. This is exactly what BIM can provide, BIM can virtual present information through a digital platform where information can flow transparently among trades; it can also store multiple alternatives, it can systematizes alternatives, keep track of changes, visualize design clashes and make information accessible for everyone involved at any given time or place.

Effects of having contractors, owners and maybe even operators ***collaborating*** in the design development is that design solutions are more likely to accommodate and facilitate the actual needs for the building, which means **better operation** possibilities. Also the **safety** aspect on construction sites is being increased as the consolidated 4D analysis which can be made in a BIG Room environment should be able to foresee many of those safety hassles that can occur on site when several people are working in the same place or under or above each other.

4.4 Set-based design.

The concept of set-based design is also an important tangible aspects of the Lean culture, according to a senior manager at Toyota the most important lesson that senior managers are teaching young engineers at Toyota is "to *delay decisions until they have considered a broad array of alternatives*"(Liker, 2004). Set based design is in other words saying that determination of one design solution too early in any design process causes that the best design is not being developed. This section explains the difference between the conventional design process and the set-based design process plus two additional tools A3 and CBA which

are tools or processes that can help the decision of which of the different design alternative to choose now when more design solutions are being developed due to the set-based design.

Traditionally in a building design process overall decisions regarding design solutions are made before the detail design is beginning. This means that those who are responsible for the detail design are often "chasing" solutions to enable the overall design even though that solution might not be the solution with the most value for the client.

In figure 24 the concept of set-based design is illustrated, opposed to the traditional approach which is illustrated in figure 23. The traditional approach is called "point based design", because the overall design solution is decided early on in the design stage and everyone involved in the further design is thereafter chasing that particular design/point.

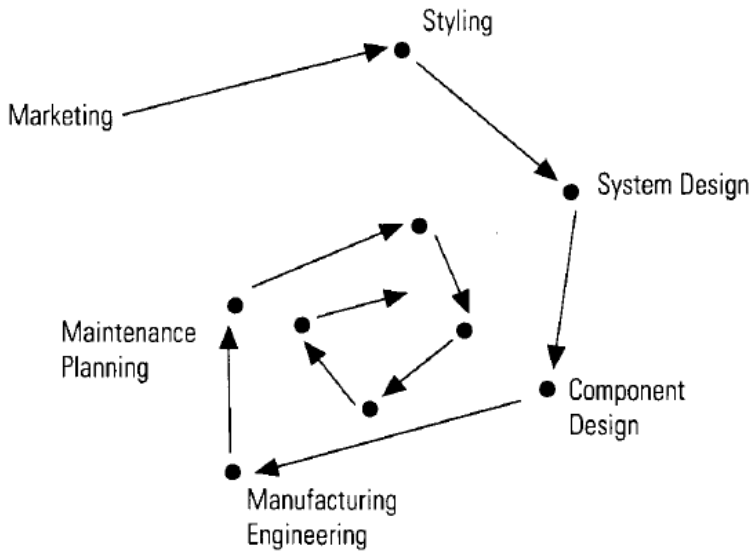
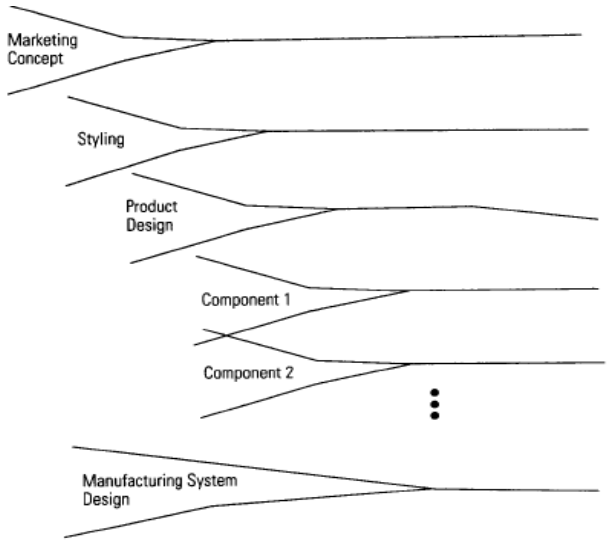


Figure 23. Point based design (Ward *et al.*, 1995).

Point based design, figure 23 documents how a feasible design concept in a traditional project is typically developed. Early in the design stage everyone settles for an overall design concept and from there on everyone is chasing that particular concept, independent that the design concept might not be the concept which will provide the most value for the client in the end. (Parrish *et al.*, 2007)



Set – narrow phase Problem correction phase

Note: Based on sketch by Toyotas general manager of today's engineering 1993

Figure 24. Set based design (Ward *et al.*, 1995).

Set based design, figure 24, is opposed to "point based design" waiting to make a decision regarding the design concept till "the last responsible moment" (section 3.3.4). Instead of deciding on one design concept early on, several parallel design proposals are being developed at the same time. Each of these individual parallel design concepts contain different advantages and only by an almost full development concept the impact of each can be estimated and possibly some of the solutions can challenge each other to achieve even more value than if only one solution would have been developed.(Parrish *et al.*, 2007; Emmitt 2004)

This means that the decision regarding which design concept to select happens much later as opposed to a traditional project. This way of waiting till all alternatives are known to make a decision is similar to waiting with planning tasks in construction till the moment where they can actually be planned which according to the LPS is called "the last responsible moment". Therefore "the last responsible moment" for design can be defined as the point where alternatives of design concepts are being deselected. (Ballard & Koskela, 1998)

BIM is an excellent facilitator for the set-based design concept as it can store information, create a platform for sharing information, and represent the data in 3D, 4D and 5D which can illustrate different aspects of a design concept that would or could not have been done if the documentation would have been 2D paper based.

Conversely BIM would not have been able to create the different high quality alternatives without Lean as the best solutions are developed based on the interaction between the people involved in the process. Lean provides a method to develop and evaluate multiple solutions,

which again is why the two concepts are complementing each other well. The approach about using set-based design in manufacturing has been proven to be a faster way to produce cars, but still need to be proven in building design (Liker, 2004).
The concept of making multiple design solutions sound as a sound approach as issues will be addressed from more perspectives and possible the combination of the different design solutions will enable a reduction in design based errors happening in construction. (Koskela, 1992)
Another benefit of BIM allowing multiple design solutions is that less stop gab solution are likely to happen, and through that have a directly impact on the **quality** of the building.

A consequence of developing multiple design solutions is that a decision at a certain point has to be made among the different alternatives developed based on the set-based approach. For this purpose the following two concepts can be used A3 or CBA or both. The A3 is a concept created at Toyota in Japan, A3 is a simple tool, and the reason why it is called an A3 is due to the size of the paper it is written on. At Toyota any documentation or explanation has to be able to fit on one A3 sheet, because first of all that is the largest size of paper that can go through a fax machine and secondly because in that way people are forced to only write the relevant facts that create good foundation to create a decision. The other tool is the CBA which has also been applied in this report and is therefore presented in chapter 2. CBA is as written about listing the different alternative and the weight the importance of advantages. CBA is not originally a Lean tool, but has been adapted by many people in the Lean environed and also used by the project which in this report is presented in chapter 5.

4.5 Target cost.

Target cost is an important element in the Lean design concept and a key element in the relational contract form called IFOA which is presented in chapter 3.1.3.
In a traditional project (section 3.1.1) a project is being designed and then contractors can bid on the project, and the contract normally goes to the contractor developing the lowest responsible bid. In a conventional project both the price and the content of the project has to be evaluated, and therefore the price becomes a factor and often the factor which determine who gets the project. Target cost is turning that concept upside down by starting out telling what the budget for the project is and then expecting the contractors to develop the best value project within that budget. *"Designing to target cost is a product development practice that converts cost into a design criterion rather than a design outcome" (Ballard & Raiser, 2004)*
Then, the **value** of the project is what is being discussed and not the price, as the price is already defined. Furthermore, when the budget of the client is known previous to the project, the whole team is more likely to commit to price, and target that budget throughout the whole process. Things that will impact the total price can and will often be discussed along the

process, so that the client in the end of the project is not receiving the bad news about either delays or budget overruns. (Ballard, 2004)
BIM has some explicit features through its 5D analysis capabilities that allow cost assessments to be an embedded part of the design development[4]. The cost of both the individual alternative as well as its impact on the whole project can be made, documented and shared among trade partners. With BIM the cost impact can become an integrated element when discussion different alternatives in the BIG Room according to the set-based design approach.

4.6 Creating a Lean environment.

The most essential part about Lean is that Lean wants to do things better; it is about incrementally improving a system towards perfection, even though no such thing as perfection exists, as there will always be something that can be done better. The tangible tools and methods which are presented in this chapter are all aspects that will help do things better and contribute to create a Lean environment which means to create a learning environment. The aspect of constantly trying to do things a little bit better is the most essential part of being Lean, and also the hardest aspect to explain as there do not exist any tangible tool or method to use for creating it as an isolated aspect. A learning environment is something that comes from the people involved in a project. It is about wanting to know more in order do things better and wanting to share knowledge, instead of being scared of sharing knowledge. (Liker, 2004)

The way of handling and encouraging incremental improvement is different from production to construction and again design.

At Toyota in Japan, improvements and mistakes are closely related. Mistakes are encouraged because through mistakes the system are learning and can be improved. Sometimes the management at Toyota will even enforce a breakdown by placing a “defective element” in the production line to find out when and how the error is detected. They want the workers to be committed and concerned about the end product.
When a worker find/discover a mistake, he or she is encouraged to shut down the whole production line and say “I made a mistake or I found a mistake”, to fix the mistake as quickly as possible, and to minimize the amount of sick items to get through the system. In Toyota, people who makes mistakes are being rewarded, because they are the one’s testing the system and really making sure that the end product is as good as it can get. The benefit of creating an environment where the employees are not scared of making mistakes is that more innovation is taking place, because people are not scared of losing their jobs.

[4] In theory, the technology is not quite there yet.

In construction, the way incremental improvements have been structured is illustrate in figure 25. Which is also called the "Built-in Quality Cycle" Here the approach is that a system or method has to be developed to **prevent** mistakes to happen. When and if a mistake happens it is important that the error is **detected** early and fast to be able to **correct** the error to minimize the amount of influence of the error. When detected it is important to **analyze the roots** that caused the errors to **prevent** it from happening again.
A Lean tool which is often used for analyzing the root of what caused the error of breakdown is the "5 Why" method (Liker, 2004).

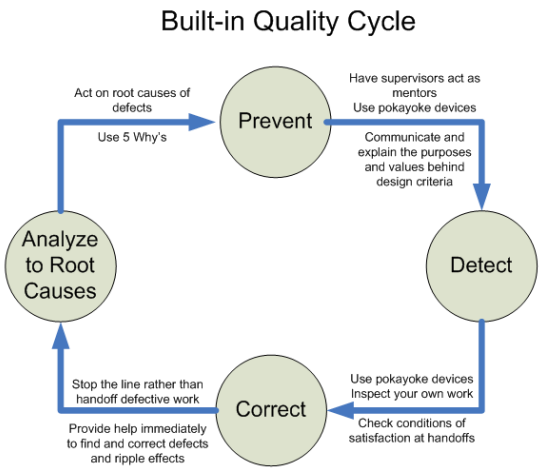


Figure 25. Build-in quality Cycle.

In design, design is about making decisions about something which is going to be made. A way to improve design is therefore to find ways to improve the decision making process. In order to improve the decision processes, systems such as the CBA systems (section 2.1) have been recognized by the LCI, US and a presentation on the CBA concept was actually given at the P^2SL –LCI Lean design Forum 2010 in January at Berkeley.

4.7 The synergy effects between Lean and BIM.

The overall idea behind BIM and Lean is to visualize problems in order to solve them before a design solution is going into either production or construction. In a Lean environment this is called lowering the water, to be able to see the rocks, (Ohno, 1988) which means that a production line for example is stretched to failure. The aspect causing the failure is then the weakest link in the production line.
If problems are not cut in design they will eventually reveal themselves in either production, construction or even worse in operation where it is going to be both more time consuming and costly to fix issues.(figure 21)
The problem with revealing mistakes in a conventional project or in a western country in general, is that there is no room for mistakes; someone always has to be made responsible immediately for the mistake. People tend to spend more time of clearing their own table and blaming the mistake on someone else instead of thinking "the system is not good enough, it was possible to make a mistake, and therefore the system has to be redesigned to be more solid". Which is the basis difference between a "learning" and a "knowing" culture.

BIM and Lean, can respectively be used to create a transparent flow of information "lowering the water" finding the problems and fixing them to minimize waste and rework. The tools and method listed in this chapter are able to help lowering the water.

4.8 Theory summary.

Possible effects of applying BIM and Lean are:

- Lower construction cost.
- Shorter construction time.
- Better quality.
- More reliable projects.
- Better safety.
- Better operation possibilities.

From this chapter and chapter 3, BIM appears to be a tool with lots of possibilities that possibly can revolutionize the building industry, if the building industry would be capable of making the initial changes are be required to reap the full potential of BIM.

An approach which in this report has been suggested as an alternative to enable the change in the building industry to implement BIM is the Lean philosophy. BIM and Lean are sharing many of the same values and are both aiming to reduce waste and improve transparency. Lean is able to create an environment where the right communication can take place, among the right people at the right time, which enables the right information to get into BIM in order to get useable information out of BIM.

It is also indicated how BIM is likely to be reduced to a 3D modeling tool, if it is applied in a conventional frame work, as there is almost no collaboration between the involved trades, which is needed to reap the full potential of BIM. Hereby not said that BIM cannot be applied in a conventional frame work, only indicating that it is more likely it without reluctant information input will be reduced to a 3D modeling tool. Furthermore BIM's capabilities in facilitating 4D and 5D are enabling the building industry to use and apply information which it never has been able to do before. Those kinds of information were unachievable before BIM. There do therefore not exist processes to handle that type of information, whether to provide the information that BIM needs to process those types of data or how to use the data when it has been processed. This indeed calls out for changes in project delivery management.

The Thesis of this report can therefore remain standing after this exposition of both a literature review and an analysis of the connection between BIM and Lean in design. As

“BIM promises to revolutionize the building industry in terms of better coordination and communication among the trades involved” (section 1.1) appears to still be a valid statement and also that “This revolution will by no means happen automatically, even if software technology is able to facilitate such a change. Changes regarding management, processes, and contracting are needed to enable the industry to fully embrace the concept and reap to benefit thereof” (section 1.1) also still seems to be valid statement.

The following chapter will present a case study from San Francisco where both Lean and BIM have supposedly been applied. The documentation in the next chapter will depict to what extent the two concepts have been applied and how they have been connected, and whether or not they have had positive effects.

5 Case study: Cathedral Hill Hospital (CHH).

This chapter will broach every theoretical aspect which has been documented up until this point in the report and document how those aspects have been handled at CHH. The chapter therefore consists of the following sections: A section explaining how BIM has been applied at CHH, how Lean design has been applied at CHH, how Lean design and BIM are complimenting each other in the design of interior wall systems at CHH, which trade and trade partners have been engaged in the design of interior wall systems and when they were engaged in the process, and finally how BIM and Lean is handling changes late in the process. Before all that, the case study itself and its contractual setup will be introduced, to show the framework of this project.

5.1 Introduction and background

CHH is an acute care and women's and children's hospital in San Francisco. (Lostuvali *et al.*, 2010). The hospital is a 15 stories building that will be build in the heart of San Francisco. The programming of the project began in 2007 and it is expected that construction will begin in 2011 and finish in 2015. The size of the hospital is 925,700 square feet (86000m^2) and it will house 555 beds. (LaValle, 2009)

Figure 26. Cathedral Hill Hospital.

CHH is a part of the California Pacific Medical Center (CPMC) a league currently consisting of four hospitals in the bay area. CPMC is an affiliate of the non-profit health care provider Sutter Health. In chapter 2 it was described how most hospitals in California due to seismic requirements have to be either refurbished or retrofitted, CHH is a product thereof.

In an analysis made by CPMC (CPMC, 2009) on how they would be able to meet the building requirements of BS1953 in 2030 (CHCF, 2010) and still be able to provide the same high service to all their users, they decided that the only way they could do that would be by building an additional new campus and refurbish the four old campuses. "*The only feasible alternative was to find a new site for a brand new, state-of-the art facility that met the highest seismic safety standards while offering our patients and staff a world-class facility in which to get and give health care for generations to come*" (CPMC, 2009) The overall budget for the CHH is $1,7B USD where almost a $1B USD is dedicated for construction cost.

Office of Statewide Health Planning and Development (OSHPD).

OSHPD is a state regulatory agency that has to approve any kind of construction documentation regarding hospitals in California. This agency has to be introduced as it has an impact on the design in that regard that the design has to be approved by them. It does not have a direct impact on how BIM is being applied in design or used in construction but it has an impact on the design submittal process, and it is therefore necessary to introduce this agency as it will be referred to throughout this chapter.

OSHPD was formed in 1978 and has the responsibilities for the following:

- Hospital construction and plan review.
- Collection and dissemination of healthcare information.
- Collection and reporting of outcome data selected medical conditions and procedures.

As a consequence, the building design has to be approved by OSHPD before the project can move from the design phase into the construction phase. (OSHPD, 2010)

5.2 Contractual setup.

This section presents a review of the development of the contractual setup of CHH with an emphasis on the current situation, as it has a great influence on how people can, will and are encouraged to collaborate, and therefore also create the environment in which Lean and BIM are being applied

The design of CHH originally began in 2003 as a part of an almost traditional DBB process (section 3.1.1). The cost of the design proposal at the time exceeded the available budget of Sutter Health and CPMC, and the project was therefore turned down in 2005.

In 2007 Sutter and CPMC re-opened the project but this time as an IFOA project (section 3.1.3). With the anticipation that this process managed by the Lean principals will be able to shave the construction cost down to meet the target cost (section 4.5).

In figure 27 it can be seen how the estimated cost of construction of the CHH based on the old design on the 23 of October 2007 was $976M USD (red dots) and how the target cost (the budget from Sutter and CPMC) was $911M USD (purple dashed line), which mean that the CHH project was launched with the anticipation that a higher degree of collaboration, communication, and coordination in an IPD team supported by an IFOA would be able to shave $65M USD of the construction cost.

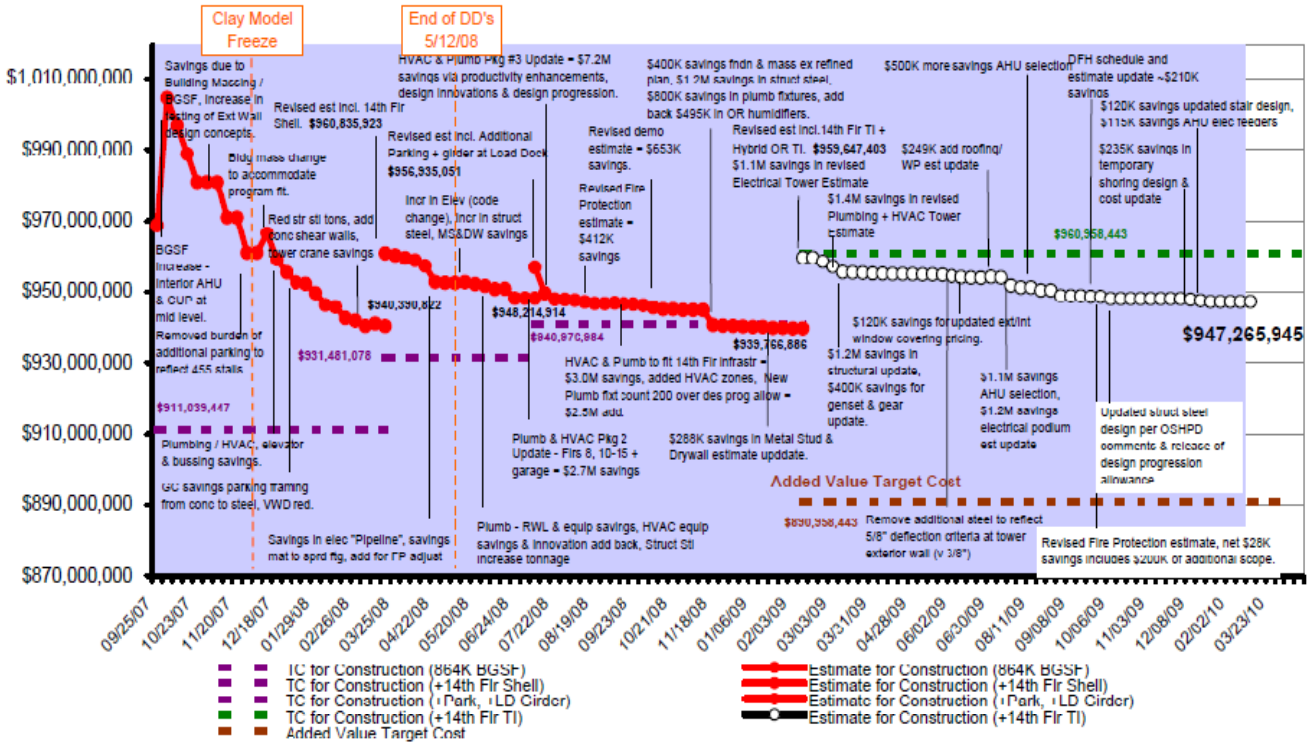


Figure 27. Budget development at CHH. This graph is also available in appendix E in a larger scale.

The red dots in figure 27 illustrates the development of the construction cost during the current design and the purple dashed lines illustrate the "target cost" before the "target cost" was met.

It can be seen that the construction cost have been reduced coherently in the design process and actually meets the "target cost" on November 18th 2008 on $940M USD. The target cost has likewise increased from $911M USD to $940M USD from September 25th 2007 to July 22th 2008 because the owners has wanted either more or increased their needs in a certain area. For example on the March 25th 2008 Sutter and CPMC requested an extra floor level, which increased the "target cost" to $931M USD

The right-hand side of figure 27 features a green dashed line and a white dotted line. The green dashed line indicates the "target cost" and the white dots the development of the construction cost, the reason why they have changed colors are that the construction cost is now below the "target cost" which is positive and indicates that the collaborative effort has had an effect, however the real result can first be seen when the project moves into construction.

IFOA

The IFOA at CHH is build up as depicted in figure 28. Sutter health is the owner in close collaboration with CPMC, which is the reason why CPMC are the one signing the IFOA contract with the architect SmithGroup and the general contractor HerreroBoldt a joint venture between Herrero and Boldt. In the beginning of this project the IFOA contract was not yet fully developed and the initial agreement was based on letters of intent.

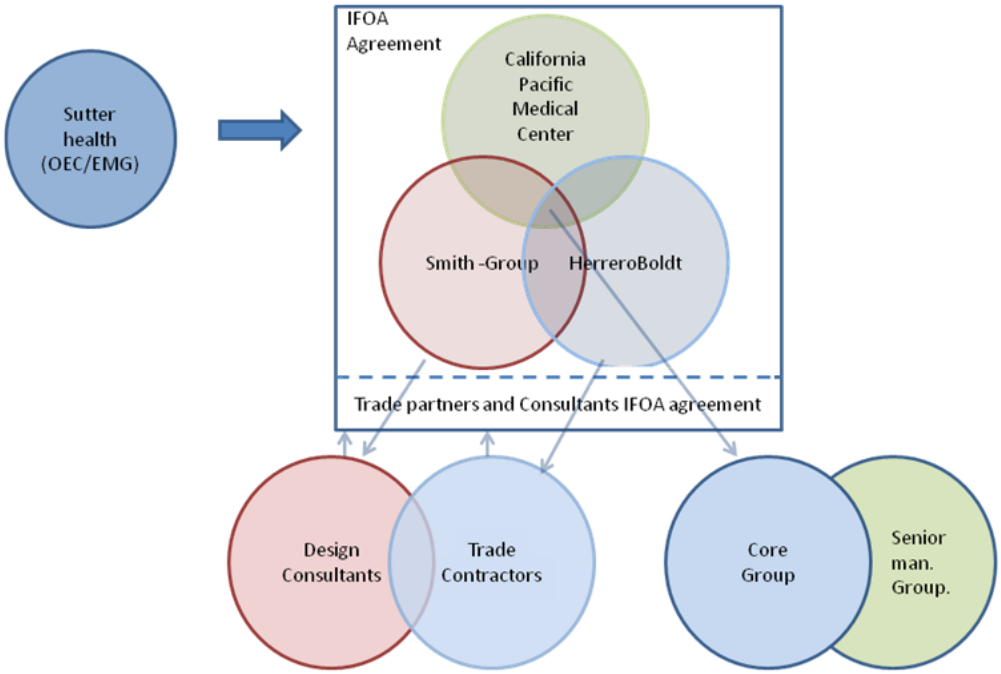


Figure 28. IFOA contractual setup at CHH.

As the agreement between CPMC, SmithGroup and HerroBoldt was set (based on letters of intent), SmithGorup and HerreroBoldt began to engage consultants and trade partners in line with the intend of the IFOA. The majority of consultants and trade partners were engaged during the schematic and no later than the design period as depicted with pink in figure 29. A full list of the consultants and trade partners is available in appendix F. Then the Full IPD team was set and the work of shaving down construction cost began.

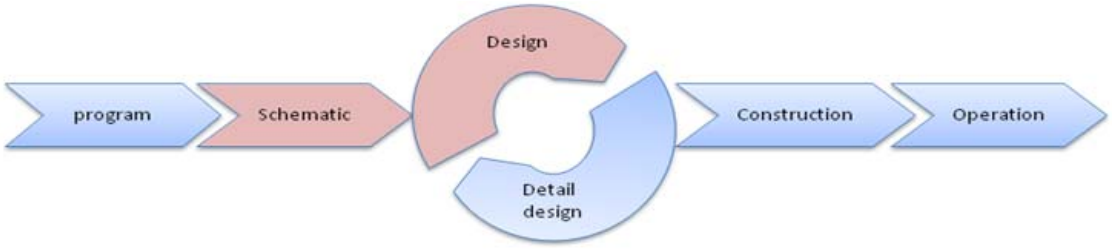


Figure 29. Semi linear phases of an IFOA building project.

It was not until 9.17.2008 that the IFOA was completed to an extent where the document could be signed by the parties depicted in figure 28. There is a difference between the main IFOA and the IFOA for consultants and trade partners, as indicated in figure 28. The IFOA for consultants and trade partners is developed at CHH by CHH, as it was considered necessary to have all trade partners and consultants involved in the incentive and added risk pool, to reap the full potential of the contractual setup. This was however not a part of the original IFOA concept. This amendment to the contract is therefore still under review by attorney William A. Lichtig, and the consultants and trade partners involved in CHH. The anticipation is that this amendment will become an integrated part of using IFOA.

In figure 30 a historic review of the project is presented.

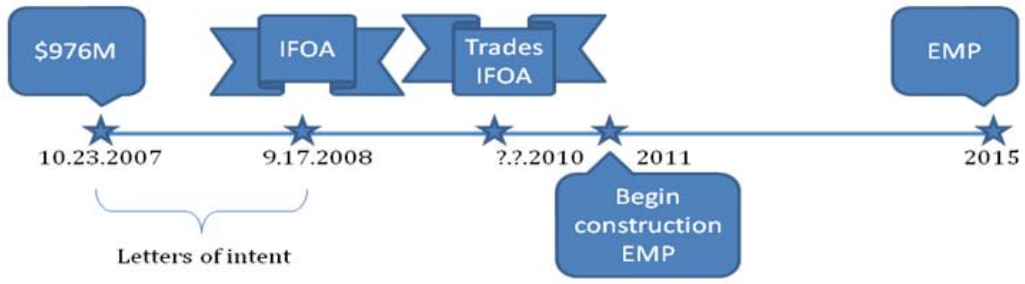


Figure 30. A depiction of the contractual time historic at CHH.

The figure shows how the project began with an estimated construction cost of $976M USD based on the design from the turned down project. It also shows how everyone involved in the project up until the 9.17.2008 worked based on letters of intent, as the IFOA agreement was not signed before, and how the trade partners as this project is written still works based on letters of intent.

The added risk pool and the incentive pool at the CHH project.

Before consultants and trade partners were getting a contract at the CHH, they had to present a transparent economical budget on how they were expecting to make their profit. In terms of how many percent of their fee would go to employment salary, profit, etc. Traditionally subcontractors were only competing against price, which forced them to shave of their profit in their bid and then during the project find their profit through change orders etc. By forcing contractors to play with open cards, bad surprises are less likely to happen during construction.

As explained in section 3.1.3 the “added risk pool”, consist of money which are held back from the individual company’s profit until completion of construction. In the case of CHH, the share in the “added risk pool” is 25%.

In section 3.1.3 it is also explained how the incentive pool is working. At CHH, Sutter health will reward the IPD team if the construction cost is less than the EMP (section 3.1.3) by sharing the saved money with the companies at the ratio that if they get in $10M USD under budget, then the companies get 10% of the savings, $20M USD under budget they will get 20%, $30M USD they will get 30% and anything lover than $40MUSD under budget the share will be on flat rate of 40%. This is done to motivate the IPD team to collaborate as it is the anticipation that better collaboration, communication and coordination will limit waste and eventually lead to bigger savings.

5.3 BIM application at CHH.

This section describes how the BIM strategy has developed during the design period at the CHH project from 2007 until present, 2010. The focus is on how BIM is applied in 2010, and how three out of the four selected interviewees from CHH presented in chapter 2 are viewing the current strategy of BIM application on this project.

5.3.1 **BIM deployment**

In 2007, when the design of CHH began, the ambitions regarding BIM implementation were high; the goal was to fully implement BIM, in terms of combining several models into one single database that would embrace all relevant data and use 3D, 4D, 5D and 6D modeling. Figure 31 was created to visualize what HerreroBoldt considered as needed data-output in order to utilize BIM. The ambitions were soon demoted as it was impossible to find workforce that was able to lift the burden."*When we started to bring team members on,*

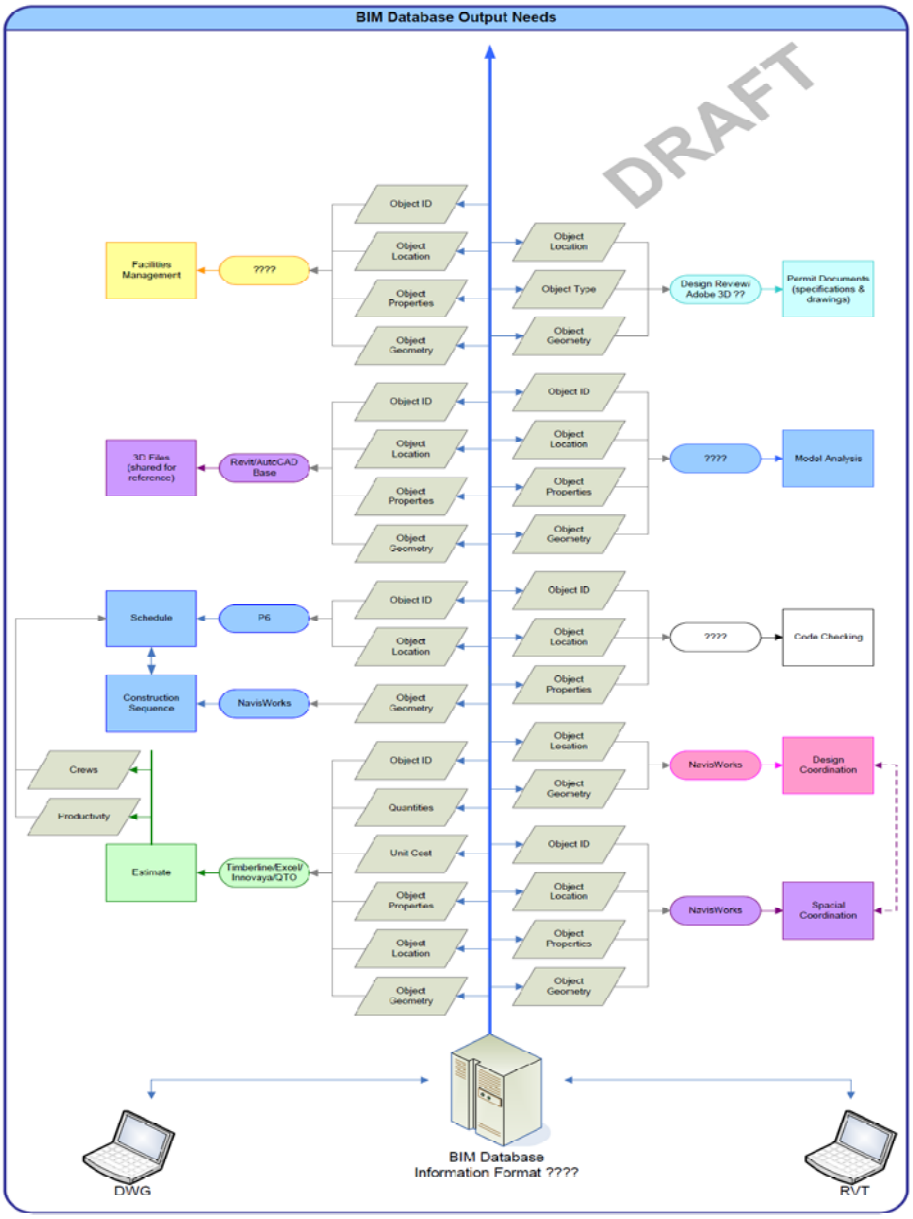


Figure 31. BIM database. (A diagram developed by HerreroBoldt)

we realized that a lot of the teams were lacking the expertise that we had expected and we realized that if we went after everything we would fail in all of them. So we kind of stepped back and said well, 3D is the low hanging fruit that has the best return of investment so let's really concentrate of spatial coordination" John Mack.

In figure 31, a representation of how HerreroBoldt imagined the management of drawings related documentation, before they began to engage subcontractors. The diagram is supposed to be read from the bottom up. In the bottom of the diagram it can be seen how it was considered that data would be collected in one BIM database from which data could be extracted. On the vertical axis it is illustrated what type of output from the BIM database that was expected to support the various needs for the respective areas of BIM.

Beginning from the lower left corner with the green boxes continuing clockwise, the output HerreroBoldt considered as necessary to apply 5D modeling are listed. 5D modeling has not truly been applied at CHH, some of the individual companies have tried doing different things such as quantity take offs but no general solution for the entire project.

The blue boxes above show how HerreroBoldt had imagined 4D modeling. HerreroBoldt has actually hired a person in the beginning of 2010 to begin the work on the 4D aspect and they are anticipating that they will be able to implement the full scope of 4D modeling at CHH, however if they are not able to make it they will be that knowledge more rich for coming projects

From the purple boxes, it can be seen which aspects are considered required to do 3D modeling. The goal is to fully implement 3D modeling at CHH.

The Yellow boxes are indicating what type of information are needed regarding facilities management, at present there is an ongoing discussion with the owner about what their needs are regarding facilities management. This part is therefore still open for possible fulfillment; the project still has at least 3 more years to play with regarding this part.

Jumping to the right side of the diagram with the light blue boxes, it can be seen how they envisioned submitting the permit drawings in 3D. According to the information available to the author of this project this has not been done, every drawing which has been submitted regarding the CHH project has happened in a 2D paper format, as also required by California state law (OSHPD).
Continuing to the slightly darker blue boxes, it can be seen how the model was intended to create a framework which could be used for various analyses, again according to the information available to the author this has not been the case at CHH.

Also code checking, as the next white boxes are indicating have not been done.

Finally, the pink and purple boxes indicating design coordination and spatial coordination in the lower right corner have been fully applied at the CHH project.

In the process of realizing that their ambitions were set too high compared to what the industry was capable to do, what was necessary and what was a reasonable goal to set, HerreroBoldt degraded their expectations to their trade partners to fulfill the following two aspects described in figure 32:

- Every trade partner should have access to NavisWorks Manager
- Every trade partner should be able to draw in 3D

Figure 32. BIM requirements to trade partners from HerreroBoldt.

There were no software requirements set by HerreroBoldt, every company could use whatever software they wanted, as long as it could be imported into NavisWorks.

The majority of the companies at CHH are using Autodesk Revit and AutoCad 3D, the reasons for that are many but a major reason is that the four major trade partners SmithGroup, D&J Tile, Bagatelos Architectural Glass, and Pacific Erectors all very early in the process settled on Revit. SmithGroup as the architect had experience with Revit from earlier projects. Bagatelos figured out a way to set up a connection between a Revit Model and their production system which convinced them about using Revit. The two other companies decided that they were also going to use Revit, because the two other companies were using Revit. The fact that those four companies are using Revit had the effect that many of other companies that later have joined the project also have chosen to use Revit, such as the drywall company KHS&S.

5.3.2 **3D and communication coordination.**

Implementation of 3D modeling and clash detection soon became the main target regarding BIM implementation at CHH. For coordinate of the 3D modeling and the clash detection HerreroBoldt developed the flow diagram (figure 32) based on the Lean philosophy. The flow diagram illustrates the structure of how HerreroBoldt had imagined the coordination of 3D modeling, clash detection, and communication flow to happen at CHH with them orchestrating the direct operation.

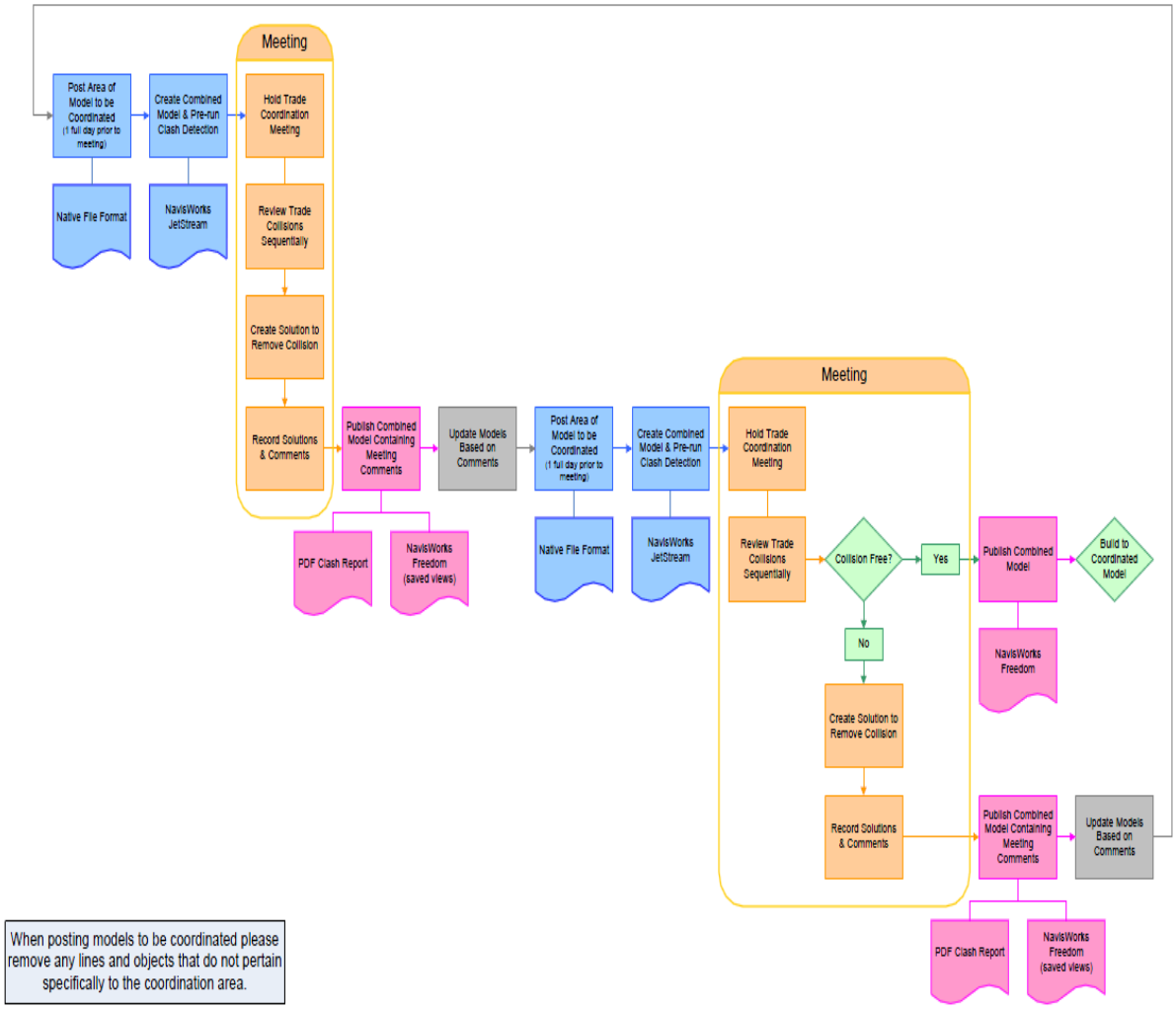


Figure 33. Illustrates how HerreroBold in the beginning of the CHH project thought that BIM was going to be coordinated – the illustration is developed by Herrero-Boldt.

Figure 33 describes how each trade would work on their individual model, meet once a week for a clash detection in a BIG Room environment, detect clashes (orange boxes), split up into individual trades, improve the detected design errors, and then to meet up again for a new clash detection meeting (next orange boxes). The process could then go on and on, week after week throughout the design period of this project.

This process was also demoted early on in the project as it was evaluated by HerreroBoldt that it was not providing the most value for the project. The process diagram in figure 33 did not utilize the fact the every trade partner in the project were collocated to the same location, and therefore were able to have daily informal meetings where clashes could be detected long before they would become issues. Informal coordination can possibly even prevent errors to happen with agreements such as “I’ll draw the pipes in this section today then you can fit your conduits tomorrow, instead of that we both are drawing in that area today and then we

have to detect clashes tomorrow". It would be much more productive if trades would solve clashes as they would appear among trades, or even before they occur, therefore informal daily communication is encouraged. An informal coordination process is relatively more complex and dynamic as the process of communication and information sharing is constantly changing and happening on an irregular basis. It has therefore not been attempted to illustrate such a process in a diagram like the one in figure 33.

HerreroBoldt have the responsibility for 3D modeling and clash detection at CHH. (As will shortly be explained, HerreroBoldt has the responsibility for the fabrication documentation.) The team within HerreroBoldt who is responsible for the 3D modeling and clash detection is called the Virtual Design Construction (VDC) team, and as updates occur they are supposed to receive the most updated model from each individual trade partners, combine them in a shared NavisWorks model to keep track on the progress and make sure that clashes among trades are being resolved.

The VDC team also has another function, which is kind of a helpdesk service function for the whole IPD team regarding BIM at CHH.

Figure 34 depicts the structure of the current 3D coordination and information sharing process at CHH. The figure illustrates how communication and information sharing *can* happen between the involved trade partners and consultants.

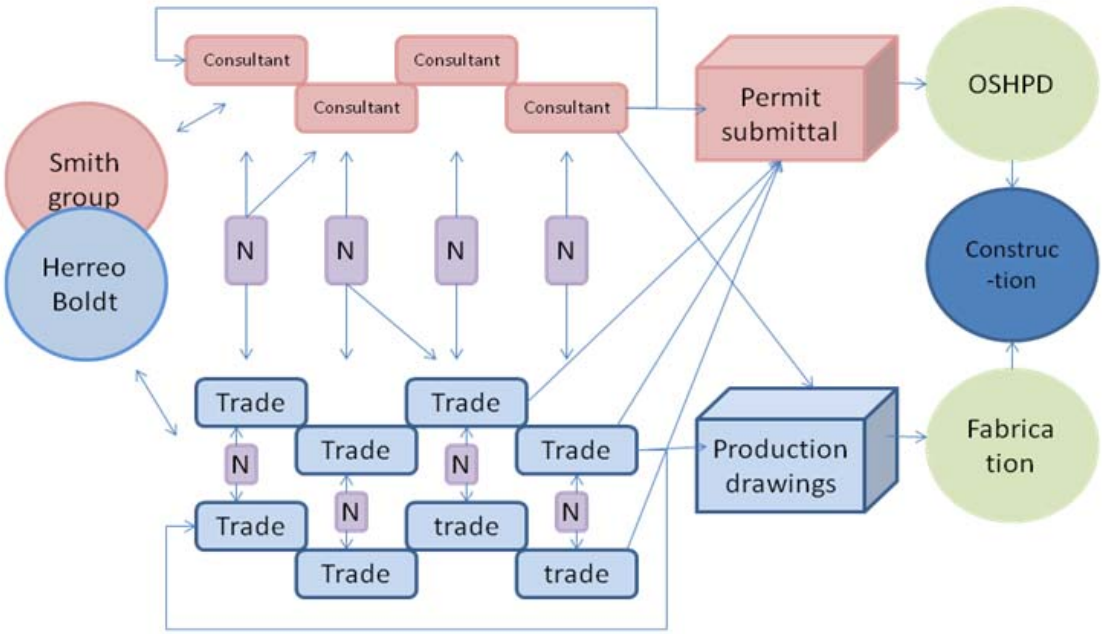


Figure 34. Conceptual depiction of 3D and communication coordination at CHH.

The diagram in figure 34 is supposed to be read from left to right. The two circles at the very left side of the diagram are taking their fundament in the IFOA concept depicted in figure 28. SmithGroup and HerreroBoldt are deploying consultants and trade partners on the conditions described in section 5.2. The diagram in figure 34 is not depicting the real number of consultants and trade partner, it is only trying to depict that there are more trade partners than consultants.

The double arrows between consultants and trade partners and between the trade partners alone with an N in a purple box in the middle indicates how the coordination *can* happen between everyone involved at any given time during the project. The N stands for NavisWorks as the involved partners at CHH have used NavisWorks for clash detection and coordination. HerreroBoldt has not been involved in every clash detection/coordination which has happened on a daily basis among the individual trades and consultants.

The next step in the diagram is how the documentation is transferred from design and being used for permits submittal and fabrication documentation. Initially it was thought that every detail was going into one database that would gather all the different software models which have been used, and from that database both permit submittal drawings and production drawings should be extracted. This was however demoted since neither the software nor the people involved in the process were ready for such a setup.

The main difference between permit submittal and fabrication drawings are the detail level, the fabrication drawing have to contain a lot more details than the permit submittal documentation. In some software programs the software is not able to alternate between a high and a low detail level, which means that once details are in the model they cannot contemporary be turned off. Two models therefore have to be maintained (kept updated) coherently as detailing is developed, to be able to facilitate the need for both permit submittal and fabrication drawings. Another aspect is the change in the work procedure. Traditionally, different trades are used to have the control over their own models and be able to make changes in them and be responsible for them. Especially Architects and design consultants find the BIM approach hard to “convert to” as they feel that they are losing parts of their contact with the owner as they are traditional used to work close together with the owner and provide the owner with a model which they themselves alone have developed. In a BIM environment the process will be different as every trade is working in and in between the models.

The differences in the work process between architects, consultants, and subcontractors cannot be neglected, and a consequence of those differences in this particular project is as earlier stated that the permit submittal and fabrication drawings have become two different models.

SmithGroup and their consultants primarily have the responsibility for the permit submittal documentation to OSHPD and HerreroBoldt has through their trade partners primarily the responsibility for delivering the fabrication documentation that besides from being used on the construction site also can be used for pre – fabricated units such as custom made piping etc. There are also trade partners who produced documentation for the design submittal and consultants who produce production documentation as depicted in figure 34.

The difference between the architectural permit submittal documentation and the production documentation can be seen in figure 35. The two figures are depicting a section of an interior wall.

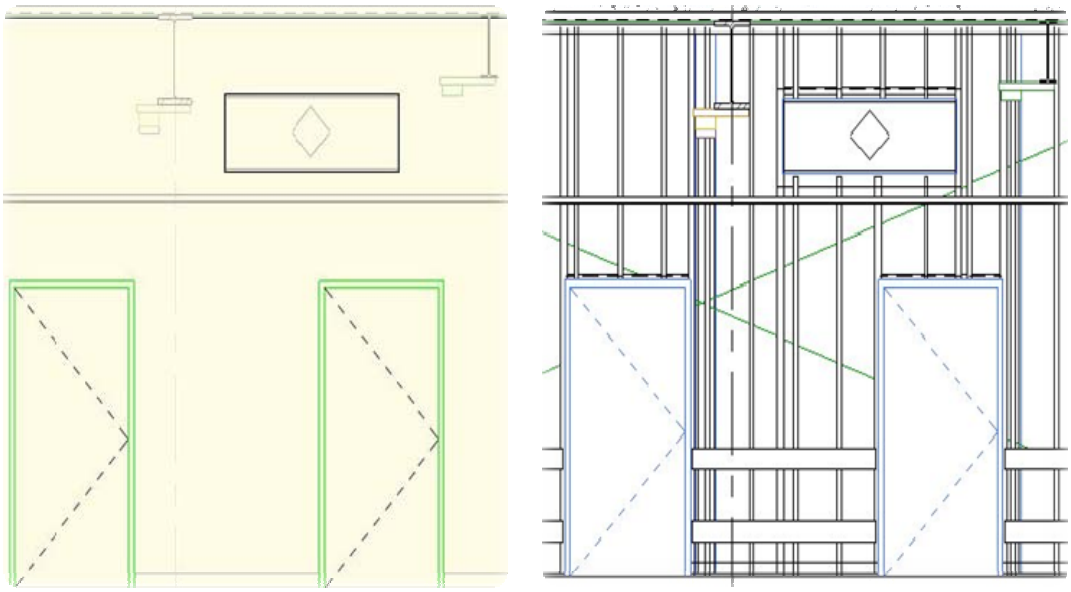


Figure 35. Left figure illustrates the architectural detail level, the right figure illustrates the level of fabrication documentation.

Both types of drawings are essential in construction as they provide different types of information and are therefore supporting each other as depicted in the last blue circle saying "construction" in figure 34.
The figure to the left provide information for inspection and the right figure provides information to those who have to construct the building.

5.3.3 **BIM deployment**

This section discusses the deployment of BIM at CHH from the point of view of three of the interviewee's presented in the methodology chapter: Arlee Monson, Architect from SmithGroup, John Mack a general contractor from HerreroBoldt, and David Lim an architect from the drywall company KHS&S. The full interviews can be found in appendix A, C, and D.

"We don't use BIM, because nobody uses it either" It is an interesting and relatively provocative statement from Arlee Monson who represents SmithGroup

The statement gets back to the question about how to understand the concept of BIM as introduced in chapter 1.
Is BIM one model where every trade will work in the same model throughout the whole project or is BIM more like a platform which can consolidate all the different software models into one final model or database? And how does each of those approaches affect the work process.

According to Arlee Monson BIM should be one model.

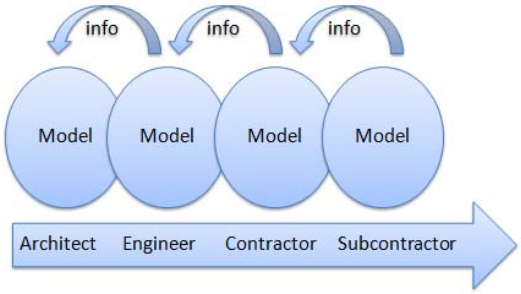


Figure 36. How to create flow according to Arlee Monson (appendix A).

"*I see that only one model should be in the game as depicted in figure 36, with a standard backflow of information to incrementally improve of the forward moving model*" (appendix A) and this is clearly not what is happening at CHH. As described in this chapter, almost every trade partner and consultants have developed their own model, which then concurrently with the design development have been used for coordination and clash detection by importing files into NavisWorks. In this context the statement about SmithGroup not applying BIM becomes understandable.

SmithGroup use Revit as a tool that allows them to use object based modeling and the ability to embed information, which according to the theory formation chapter 3.2 is one element of using BIM.

According to Arlee Monson they are connecting objects and information together as they are designing the building but *"we only have to give the wall data, in order to let the wall know that it is a wall "*.

Arlee Monson believes that the "single model" approach is difficult to establish because "*They (different consultants and trade partners) cannot trust our data necessarily"*, as their model does not incorporate waste factors for construction etc. and *"they have to base their cost of their construction on their models"* so they have to care about incorporation waste factors into their models. Therefore SmithGroup is not using BIM according to Arlee Monson when nobody else is using BIM, if the definition of BIM is to do all modeling in a single model.

Even though the BIM concept is not fully applied according Arlee Monson he still believes that fragments of the BIM concepts such as the 3D modeling process which is being used today in terms of coordination and clash detection does have positive effects *"We are doing the same handoffs today as that we always did; we are just doing it better and faster"*. Doing things better and faster, is the primary goal of applying BIM, so in that perspective some aspects have been obtained, even though there possibly are more aspects that could be done better.

Arlee Monson does not share the opinion about BIM having to be a single model in order to be BIM with neither the BIM manager from the general contractor HerreroBoldt John Mack nor David Lim from the drywall subcontractor company KHS&S on the CHH project. They both consider BIM as a platform where multiple software programs can be used, with the ability of consolidating all the models in one database where coordination and clashes can be worked out such as NavisWorks and Solibri. John Mack does not see it coming that someone will dictate which software different companies shall use, as some have more experience than others such as MEP trades which have used 3D modeling for decades and therefore have libraries within their specialized software packages that they will never disclaim.

"I don't see in the immediate future jumping up to Revit on the construction side even if Revit solves the problems and gets the contracting tool in there. There is so much money spent by the larger companies, with what they got in databases and libraries and years of putting the stuff together using the 3rd party AutoCAD software" John Mack.

Whether BIM is one model or not, is not important for John Mack *"When I think of BIM, I think more of the Information than Building and Modeling" John Mack.* For John Mack the essential aspect of BIM is that information can be stored and developed due to new

processes. In section 3.2 it is described how BIM is exploring new areas in the building industry that never have been accessible to the building industry before.

Before subcontractors were engaged that CHH John Mack thought that BIM could and should be applied on this project such as 4D, 5D, and 6D. That was however demoted as the lack of BIM expertise among the subcontractors were too big to carry out that goal and the expectations were degraded to only consist of 3D modeling and clash detection. Earlier in this chapter it is described how permit submittal and fabrication drawing at CHH at present are two individual models, which is not exactly the idea behind BIM. The reason for that was explained to be lack of software capabilities able to alternate between high and low levels of detail and behavior on the job. According to John Mack the behavior aspects has by far been the decisive factor for this split, as he refers to the Camino medical center (Khazode, 2008) where only one database was developed, so it can be done.

CHH has been managed differently from a conventional project however is there still room for improvements according to John Mack the crucial aspect of utilizing the capabilities of BIM is changing behavior and work processes on the job. According to John Mack the behavior issue is habit related. One example is the architects, they are used to have the direct communication with the owner and provide the owner with some "nice" drawings, which does not correlate with the spirit of BIM.

For David Lim the whole BIM concept was new as he got on this project, in general David Lim is positive about the concept. "*The tool is actually much more than just coordination as we thought as we looked at it in the beginning*". David Lim

In the short time that David Lim and KHS&S have been working with the BIM concept on this project they have made interesting work that will be explained further in this chapter section 5.5. Generally about the BIM structure on this project David Lim primarily focuses on the advantages like the integrated and more coordinated process BIM is providing for KHS&S "*Also the opportunity to monitor productivity from the distance is considered an advantage*" "*Another side effect but very effective side effect is that the IOR (the inspector) can come to such a tag, slide his phone over the tag, and it will bring up locations of all the associated information UL, EG and hilty information details*" David Lim.

In short the architects are more reluctant towards BIM than the general contractor and the subcontractor. Both the general contractor and the subcontractor recognizes that there certainly is room for improvements but also recognizes the process that this particular project has made regarding improving the implementation of BIM and the effect that it has had.

5.4 Lean application.

This section describes how Lean design is applied at CHH and how it has influenced the use of BIM. Followed by a discussion of how three out of the four selected interviewees presented in chapter 2 are viewing the current Lean application situation at CHH.

As introduced in chapter 4 the following Lean concepts can possibly complement BIM in the design by the use of the following tools:

- Production System Design
- Collocation
- Collaboration
- Set-based design
- Target costing

5.4.1 **Production System Design.**

To reduce waste caused by design errors, CHH has according to both the BIM and Lean theory (section 3.2 & 3.3) and the MacLeamy curve (figure 21) engaged contractors and subcontractors early in the design phase. At CHH some consultants and subcontractors were engaged by Sutter Health at the same time as the architect and the general contractor, because of the extraordinary situation for this project being one of the first projects applying the IFOA. The majority of the subcontractors were first engaged from mid schematic to mid design in line with the IFOA, which is earlier than in a conventional project. The early engagement of contractors and subcontractors has made it possible to exploit their knowledge through an iterative design process. This process has made it possible to get more of the information that the contractors and subcontractors need during construction into the model.

5.4.2 **Collocation.**

CHH is contractually an IFOA project which directly induce that it has been an IPD team project. The CHH IPD team members have all been collocated in an office facility belonging to Sutter Health in the heart of San Francisco where the IPD team is able to work in collaboration. It is difficult to evaluate the output of an elaborated design process before the project actually moves into construction and the true picture can reveal whether or not this approach has eliminated design related errors in construction.

Independent the specific outcome of this project, then the IPD team approach at CHH has provided the project with a high degree of collaboration, communication and coordination that has had the effect that design errors that might not would have been found in a conventional design project have been cut. The reason why the design errors were cut was due to a combination of BIM's ability to visualize a situation, Lean's persistency in wanting to improve the design, and the whole IPD team being located in the same location so that the right discussions could take place among the right people. The conviction in the CHH IPD team before the design moves into construction is positive. Arlee Monson the architect from SmithGroup even mentions that a benefit of using IPD and BIM is: "*There is a greater chance for the building to be constructed as designed"* Arlee Monson.

5.4.3 **Collaboration.**

Collaboration has been a key word throughout the design process at CHH. As through a good collaboration constructive communication and coordinating can take place. In the CHH project the contractors and subcontractors have first of all, all been engaged early in the design phase and secondly been collocated to the same office. These two elements are crucial for creating an environment where collaboration can take place. Collaboration can be both structured and unstructured. At CHH both types of collaborations have been encouraged, as each of them has their own strength.

Unstructured collaboration is what people do on a daily basis, normally in an informal environment. The strength of informal collaboration is that constructive communication and coordination can take place between individual people on the personal level. Through such collaboration, design issues can be addressed even before they become design errors. Unstructured collaboration is hard to quantify, but as an example to show that unstructured collaboration has been recognized at CHH is that HerreroBoldt demoted their clash coordination system (figure 33), because it did not incorporate the unstructured collaboration and coordination which was happening between the IPD member which therefore got the model out of the game.

Unstructured collaboration however will not alone be able to structure the whole design process. To create structured collaboration in the CHH design process the BIG Room concept has therefore also been used. Three times a week the BIG room was dedicated to facilitating TVD meetings to discuss the overall design progress and solve eventual problems.
Besides the TVD meetings, cluster group meetings were also a part of the structured collaboration process at CHH. Cluster groups are a subdivision of the TVD group. The

purpose of the cluster groups are that more detailed coordination can take place as oppose to the TVD meeting were everyone is participating. At CHH the project team was early in the design divided into the following four cluster groups:

- Mechanical, Electrical, and Plumbing MEP cluster group.
- Exterior cluster group.
- Structural cluster group.
- Interior wall system cluster group.

In each of these cluster groups the planning follows the principles of the LPS^{TM} as depicted in figure 37. Each cluster group have a phase schedule closely connected to the master plan, a look ahead, a weekly plan, and a backflow of information just as described in section 3.3.4 for the LPS^{TM} in construction.

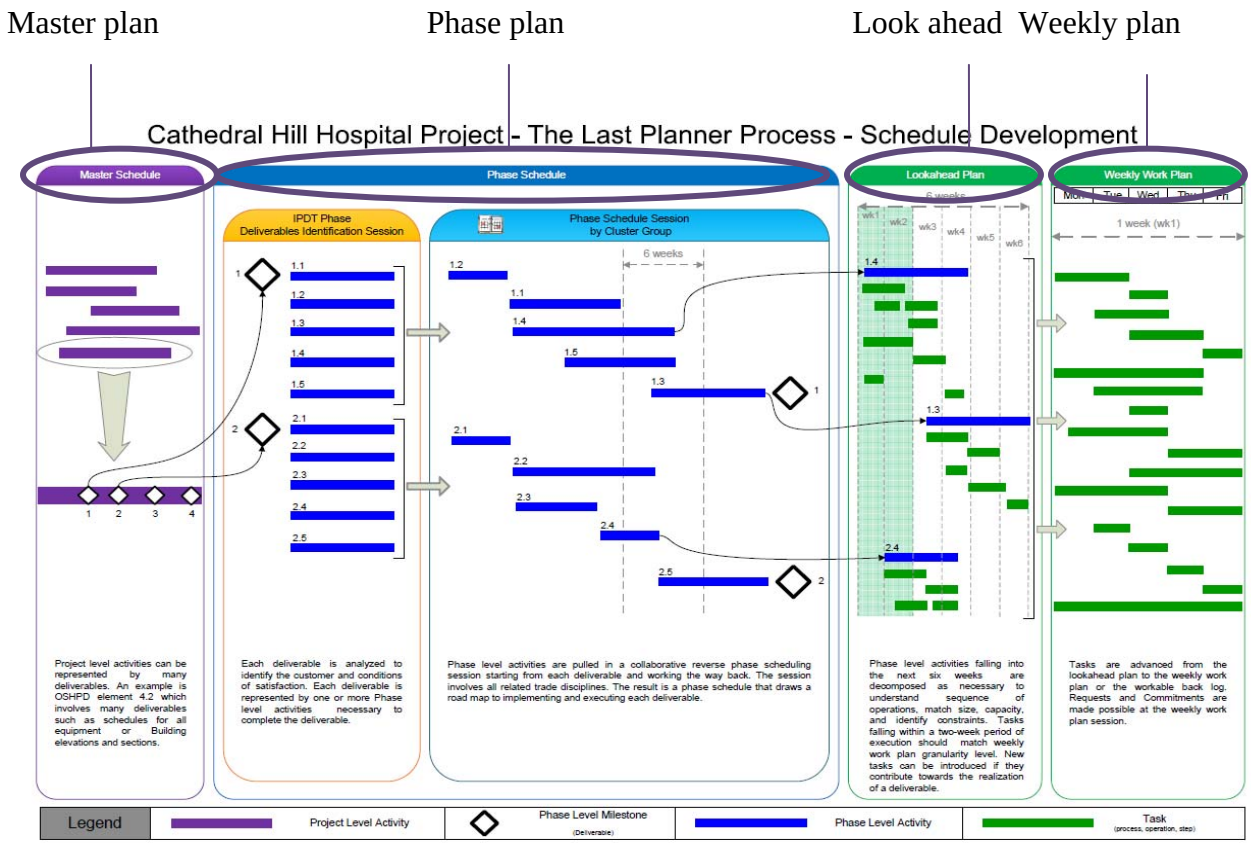


Figure 37. Conceptual layout for application of LPS in design at CHH developed by HerreroBoldt.

TVD meetings and the BIM model are representing kind of the same function. They are there to gather ideas, thought, suggestions, etc. and structure those into the best possible design solution. TVD creates discussion and BIM creates a visual model, based on that the design progress continues.

Both the cluster group and TVD meetings have therefore both gained and been depending on the BIM to visually illustrate issues in a way that makes a problem clear. *"The visual aspect of BIM allows you to make better decisions on your design as you move forward to construction." John Mack.*

5.4.4 **Set-based design**

Set-based has not truly been applied at CHH, even though it has been discussed how it could be applied. Initially it was discussed how the project could be divided into zones, and through that how individual segments could be developed to a high level before a decision should be made.
That did not happen, the design process was instead split up by floor levels, which means that the IPDT initially worked on the tenth floor to fully design that level before progressing to the other floor levels, and only one solution for the tenth floor was developed.

"In some perspective we did set-based design, but when it comes to several alternative solutions for the 10th floor, then we did not." David Lim.
The idea behind having all trades and consultants working on the same floor at the same time, is to make the trades able to coordinate and make clash detection as they progress in their design. That however does not mean that set-based design has been used, as only one proposal for each floor level has been developed.

In section 4.4 the tools A3 and CBA were mentioned as tools to use for making decisions among certain alternatives derived from the set-based design. Even though the Set-based design has not been used the concept of documenting design solution has however still happened on an A3 format and CBA analyses have also be used for example regarding the design of viscous damping walls – it has not been on a regular basis. There has for exampel not been used any CBA analysis regarding any of the decisions made regarding the design of the interior wall systems, which is the focus of this report.

5.4.5 **Target cost.**

The concept of target cost is explained in section 4.5. Target cost has indeed been applied at this project. This project was launched with the anticipation that the process applied on this project would make it possible to shave more than $65M USD of the original estimated construction cost which was $976M USD (see figure 27). At present it seems as if the target cost is met, but again it is difficult to evaluate numbers like these before the project moves into construction. Independent that the concept of target cost have been applied at CHH, it has not been applied through a 5D perspective, the cost evaluation is based on off screen take offs and other conventional cost evaluation tools and methods.

5.4.6 **A Lean environment.**

A Lean environment is as stated in section 4.6 hard to define, as it is the whole attitude towards wanting to improve and learn, which are the crucial aspects of being Lean and creating a Lean environment. In this case it is about wanting to improve the design process of CHH and improve the basis of which decisions are being made in order to make sound decisions. In many aspects this project has tried new things in order to do things better such as BIM, IFOA, IPD, CBA etc. which all calls out for this project to be a Lean project.

Many of those mentioned aspect were new to most of the trade partners as they got engaged in this project. Therefore to as a part of being part of a Lean and learning environment everyone involved in the CHH project had to read the book “The Toyota way” by Liker 2004 and follow reading sessions were the contend of the book was discussed. Also regarding the CBA implementation, all IPD team members were offered a three day session where instructions are given by Jim Suhr, the founder of the concept himself.

In the aspect of sharing information the IPD team at CHH has also been progressive. The IPD Team has and is often presenting their experiences from this project at various meetings and conferences all over the country.

The CHH IPD team is also directly passing their knowledge over to new design projects, but so far only to other Sutter Health projects. The building where the CHH IPD team is collocated belongs to Sutter Health and here at the end of the design period of CHH, (March 2010), CHH, new Sutter Health projects have been collocated in the same building and on the same floor to learn from the IPD team at CHH.

5.4.7 **Discussion on Lean deployment at CHH**

This section discusses the deployment of Lean at CHH based on the interview with three of the four interviewee's presented in the methodology chapter, chapter 2: Arlee Monson, Architect from SmithGroup, John Koga a general contractor from HerreroBoldt, and David Lim an architect from the drywall company KHS&S. The full interviews can be found in appendix A, B, and D.

At CHH it was the general contractor HerreroBoldt who was engaged to introduce Lean, such as introducing the BIG Room, cluster groups (sub division of the TVD group), Lean environment, CBA etc. they did however not have a lot of experience with Lean design as they have never really used it before so as John Koga says "*We have as a goal to develop Lean to develop flow such as product flow in the way Lean talks about it; that is our goal. We have a long way to go to figure that out yet.*

That HerreroBoldt did not have experience with Lean design apparently took at least SmithGroup by surprise *"We expected that people like Boldt who were already into Lean, should have brought a process, a working process, with them. Meaning they should have known how to do a certain amount of this, and they did not."Arlee Monson.*

"They had an idea of the cluster groups, but they could not tell us how that worked. They had an idea about Target Value Design, but they could not really make it work. So there were a lot of words but not a lot of real process behind it, the process had to be created." Arlee Monson.

In section 4.6 it is described how the most essential aspect of Lean is to create a Lean environment, with the attitude of wanting to learn and do things better, incrementally improve a system by eliminating waste and improve flow and value. One way to establish such an environment is by using the Lean tools and methods listed in chapter 4. In section 5.4 it is described how those tools and method have been used at CHH. Due the fact the CHH is among the first projects to try both IPD, Lean and IFOA they have faced challenges and difficulties during the design process that have prevented them from succeeding in every aspect, but does that mean that they did not do Lean because they did not succeed 100% in applying every single tangible Lean tool? Probably not, as the core of Lean is "to do better" by incremental improvements.

"The biggest problem right now is that still not everybody understands the concept." John Koga.
Not everybody understands that Lean is not a protocol that can be pulled out from the drawer and then be schematically followed and then be Lean. Lean in general is a new concept in applied design, so the experiences are limited.

"I would say that on this job we were all learning to work together, you have so many different partners; we had not worked together before. I would say if we stayed together and worked on a second job, we would do it better and maybe on a third project we might have a Lean system." John Koga.

The way SmithGroup have contributed in the Lean design is by using and contributing to the cluster groups, VDC meetings and others tangible Lean tools encouraged by HerreroBoldt "*We apply Lean by using the Lean tools in a cluster environment…We participate in collaborative effort using tools that reflect the Lean principles, so things like last planner, A3's, the last responsible moment, set-based design, and target value design." Arlee Monson.*

KHS&S has also participated in the cluster environment, Last Planner process, TVD meetings etc. For them however things regarding the Lean structure were determined when they got onboard, and they were therefore aware of the conditions for this project *"before you signed up for this particular contract you signed up for this certain level of flexibility with coordination of work and rework. I think that this approach opens everybody up to be susceptible to change." David Lim.* David Lim is therefore possibly a bit more reluctant in his observation of how KHS&S have used and taken advantages of the Lean approach."*Various ways I suppose, like looking into productivity mechanisms that we can extract. All these coordination works that we do, make us end up with a boat load full of information's and then it is like "how can we best use it.? I think the way we use Lean is the way we are trying to fully utilize the capabilities that we have, compared to just use bits and pieces."* David Lim.

5.5 Interior wall systems.

This section consists of the following parts. An analysis of why design of interior walls is interesting, when trade partners were involved at CHH and whether or not that was a good time, and which trade partners at CHH that were involved in the design of interior wall systems. Followed by an exposition of the design process of interior wall systems at CHH, which explains hands-offs among trades and how models have been shared and information exchanged. Followed by an analysis of how the application of BIM and Lean has influenced the design process.

5.5.1 **Introduction to the design of interior wall systems at CHH.**

The design of interior wall systems is an area of design which has appeared due to the application of BIM, Lean, and IPD.
"In a normal process we don't care, I mean nobody coordinates that (Interior wall systems). But in this project we decided that it is important. The reason why it is not important and why we don't coordinate in a normal process is that there is plenty of room inside walls. In 90% of the walls, there are not enough clashes to make it a problem" Arlee Monson Appendix A.

This means that around 10% of the walls actually are causing problems in construction, and some of those can directly be lead back to missing design coordination. In a project like the CHH project the drywalls comprise around 7-10% of the total construction cost, which explains why the area of interior wall design is actually interesting. Another but also very important reason why coordination of drywalls has become a new design area is the opportunity for prefabrication, which potentially can reduce construction cost.

5.5.2 **Engagement of subcontractors.**

In line with theory of BIM, Lean and the MacLeamy curve presented in section 4.1, consultants and trade partners in the CHH project were all engaged somewhere in between schematic design and design. KHS&S was engaged in the middle of design (figure 29) which made them one of the last trade partners to join the IPD team.

According to all four interviewees, engagement of trade partners from mid schematic to mid design is the best time to engage trade partners. Before schematic there will be nothing for the trade partners to do as the initial concept is not even defined, and after design, their knowledge about material, durability, lifecycle cost and constructability gets harder to fully exploit.
"We draw on a blank piece of paper, there is nothing when we start a project, and therefore there is nothing trade partners can do for us at this point in the design." Personal conversation with Arlee Monson.
"In this project we were engaged in the middle of the design development, so we were engaged at an appropriate time I suppose, but a little earlier would have been fine too." David Lim (Appendix D).
The experiences from this project, has lead to that that KHS&S most likely will aim at being engaged a little earlier, in coming project, possibly already by the mid or end schematic design.

5.5.3 **Trades involved in the design of interior wall systems at CHH.**

The focus on design of interior wall systems is new due to the application of BIM, Lean and the IPD concepts which have lifted the standard for coordination and precision. The coordination of the design regarding interior wall systems implies that trades that have never worked together before certainly have to work together. Traditionally it has only been the MEP trades who have had to detail coordinate their systems, if suggested by the architect (section 3.1.1).

At CHH the design process of interior wall systems have been driven by the drywall company KHS&S. For KHS&S, the CHH project is one of first projects where they are engaged this early in a project, their experience with design related aspects are therefore significantly less compared to for example the MEP trades, which for many years have been involved in design, as coordination of their trades for decades have been recognized as an area that requires coordination to avoid clashes in construction.

CHH consist of 34 different interior wall types where the differences consist of variations such as the width of a wall, rated or none rated walls, acoustical walls, walls with or without lead etc. and on top of that comes the utilities that go into the walls.

In table 3 a list of the trade partners with whom KHS&S is doing coordination regarding interior walls systems at CHH are listed. From the list it can be seen that KHS&S is doing coordination with more than 23 different trade partners. The fact that so many trade partners are involved in the coordination at CHH documents that there are many different types of knowledge involved in the generation of interior walls. Knowledge which traditionally has been given little attention, as it has been considered as part of the coordination which takes place in construction.

Now with the Lean, IPD and BIM concept the focus has been turned on areas like these, and this obviously requires new processes. In figure 38 the process of drywall coordination has been depicted. Figure 38 illustrates the process of designing interior wall system as an iterative process among all the IPD team members and not a consecutive process as in a conventional project (section 3.1.1).

Table 3. Trades involved in coordination of the interior wall systems.

IPD Team Members	***Role/Specialty***
Smith Group	Architect/Engineer
HerreroBoldt	Construction Manager/GC
Degenkolb	Structural Engineer
Charles Pankow Builders	Concrete Structures Contractor
Olson Steel	Miscellaneous Steel Fabricator
Herrick Steel	Structural Steel Contractor
Pacific Erectors	Steel Erection Contractor
DIS	Viscous Wall Damper Fabricator
Ad-In Inc	Acoustical Contractor
ISEC	Doors/Frames/Hardware Contractor
KHS&S Contractors	Metal Frame and Drywall Contractor
Bagatelos Architectural Glass	Curtain Wall Contractor
D&J Tile & Exterior Stone	Exterior Stone Contractor
The Lawson Roofing	Roofing Contractor
Ted Jacob Engineering Group	Mechanical Engineer
Southland Industries	Mechanical Contractor
Rosendin Electric	Electrical Contractor
Silverman and Light	Electrical Engineer
Otis Elevator	Elevator Contractor
RLH Fire Protection	Fire Protection Contractor
Fuel Oil Systems	Fuel systems contractor
Advanced Pneumatic Tube	Pneumatic systems contractor
Rescue Air	Rescue Air contractor

The only trades which KHS&S have not done coordination with regarding the design of interior wall systems are the foundation and excavation trades. All the companies which have been involved in CHH are listed in appendix F.

5.5.4 Design process of interior wall systems at CHH.

The design process of interior wall systems at CHH is depicted in a cross-functional diagram in figure 38. The diagram shows the iterative design process at CHH among the entire IPD team. The plumber, electrical, mechanical and structural trades have been listed separately even though they also are a part of the IPD team. They have been listed separately because the majority of the coordination on drywalls is happening among those particular trades and the drywall trade.

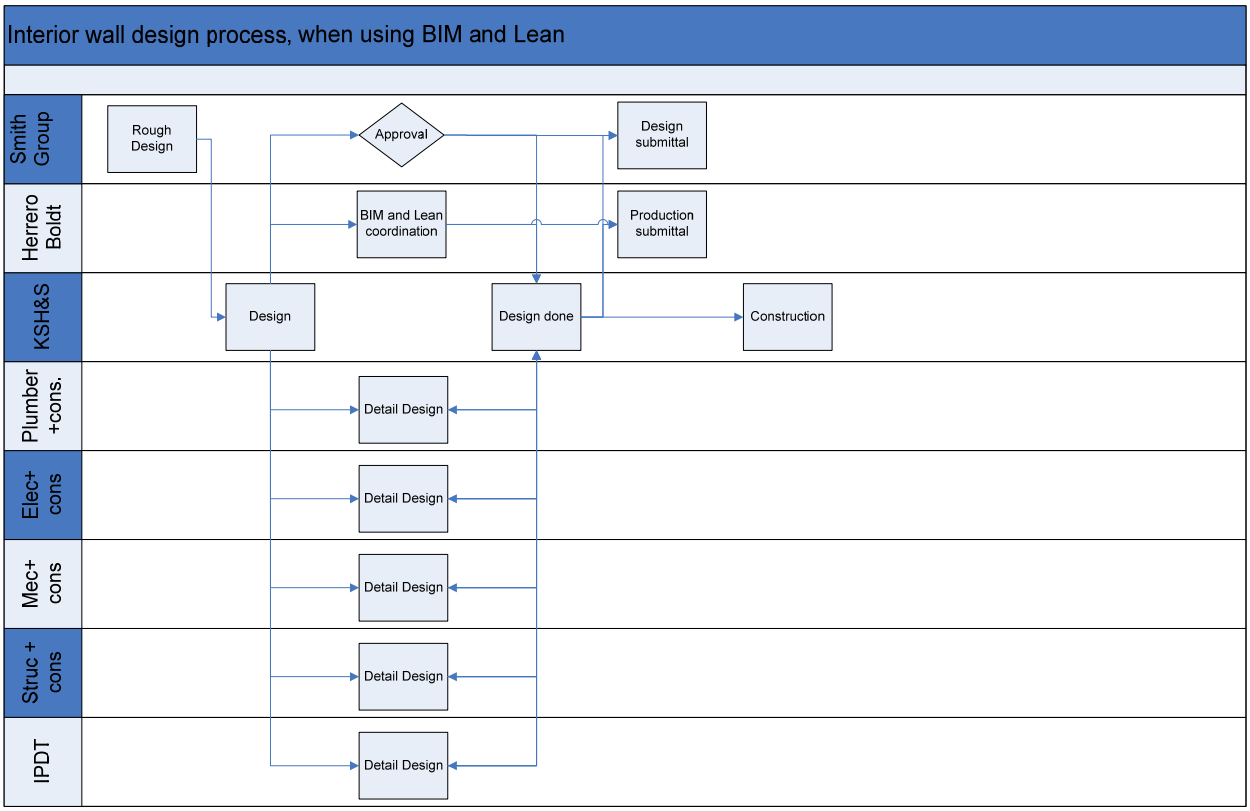


Figure 38. A cross functional diagram of the design process of interior wall systems at CHH.

The diagram is supposed to be read mainly from left to right, where it can be seen that the architect is initially producing a design for the project. Then the drywall contractor receives the model and makes their contribution and then shares that model with the whole IPD team, in order for them to place all the utilities in the walls.

All trade partners are working based on the model from the drywall company at the same time. While updates are occurring the drywall contractor is constantly coordinating with the architect in order to let them know if a change happens in the fabrication documentation that has an influence on the permit documentation. When the design has been confirmed by the whole IPD team the architect will finish the permit submittal and send them for approval by OSHPD and the drywall company will send the final design to the general contractor to be a

part of the consolidated model. The drywall company will also use their own model in construction.

In detail what happens is that the architect (SmithGroup) provides a design model and hand that electronically over to the drywall company (KHS&S). The design model by SmithGroup is developed in Revit and contains according to Arlee Monson only of the necessary information in order to let each object know what it is (appendix A).

In figure 39 a screen print from the architectural design model from SmithGroup can be seen.

Figure 39. Revit model of interior walls developed by SmithGroup.

Due to the IPD team concept SmithGroup share their models with the IPD team; in a traditional project they would never do that. "*Before, handoffs were made with paper, we would not even give them an AutoCad drawing electronically we would give them everything on paper and they would do their takeoffs from the paper.*" However that does not mean that they are providing more or less information, only that they now provide an electronic model. "*We are doing the same handoffs today as that we always did, we are just doing it better and faster." Arlee Monson.*

When Smith Group is handing over their model to their trade partners it does not mean, that they are finished with their work on the model (section 5.3). They will continuously refine the model throughout the design process comparing it to the fabrication documentation model which is being developed based on the iterative process in the integrated environment, in order to be able to develop permit submittal documentation.

When KHS&S receives the Revit model from SmithGroup, it contains all the different wall types, such as whether it is a rated or a non rated wall or whether it is 6 inch or 8 inch wall. It is SmithGroups responsibility that the walls meet the requirements by the CBC-standards (chapter 7, California Building Code).

The walls configuring in SmithGroups design model does not consist of the different elements that a wall actually consists of. The walls in SmithGroups models only provide a solid representation of the walls. This means that the information that KHS&S needs, in order to know how to build a wall is not embedded in the model. Revit is via a section view able to provide an image of the different elements that a wall consist of. This is however only a surface image attached to each object to be able to show the different parts that a wall consist of and has therefore nothing to do with the individual elements that a wall actually consist of. The surface image on the section view is enough for the permit submittal documentation for OSHPD but not enough for fabrication documentation (figure 34).

Therefore when KHS&S got on this project they had to find a software program that could actually model each individual element of a wall. They were looking into several different types of software solutions; before they finally decided to use a program by Strucsoft called Metal Wood Framer (MWF), which is an add-on program to Revit. The fact that MWF was an add-on program to Revit was the decisive factor for KHS&S to select this software package ahead of others as they were interested in the best possible interoperability with the design model from SmithGroup who uses Revit. MWF is able to convert solid walls in Revit into walls consisting of the different elements that a wall actually consists of. To perform that transformation KHS&S had to manually define all the wall types that they were going to use at CHH and add them to a library in the MWF program. Figure 40 shows a screen print from the Revit model with the MWF “branch” open.

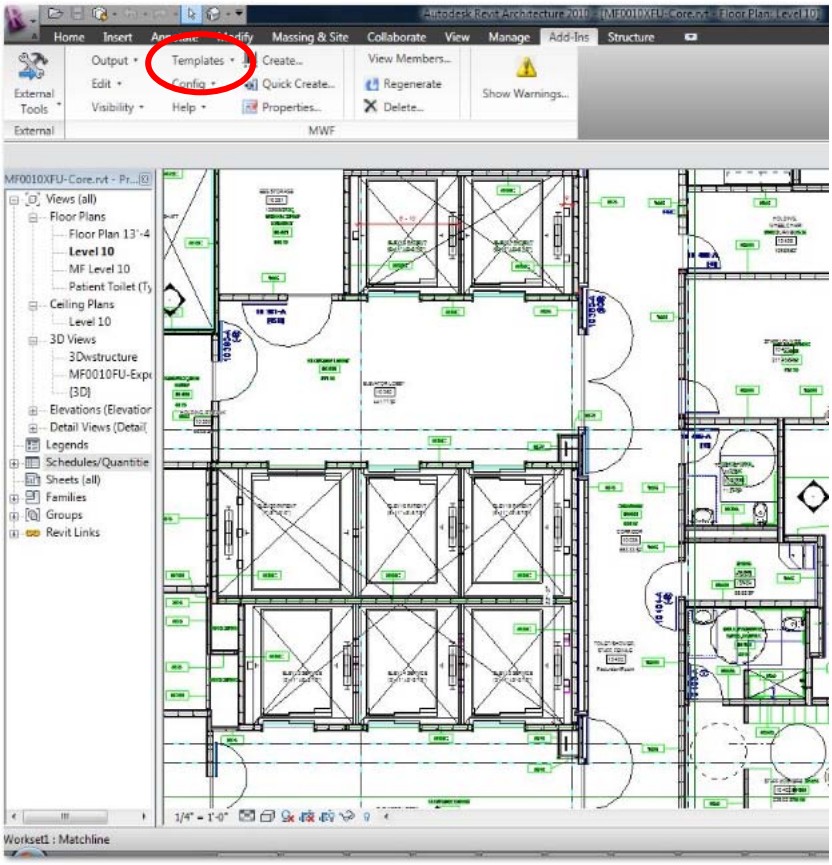


Figure 40. Revit file with the attachment program MWF open.

In figure 41 the principle of the MWF software is illustrated. KHS&S selected a wall in the Revit model from SmithGroup by basically clicking on a wall in the model and then hit the template icon in the MWF branch (figure 40), the program recognises a wall type defined by SmithGroup matches it with the corresponding wall from the KHS&S wall library, and then transform it into a unit of elements representing the wall in a way that makes KHS&S able to use the drawings for

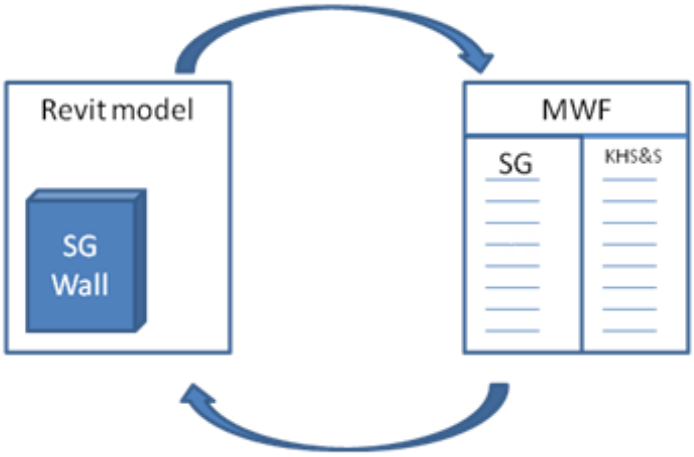


Figure 41. MWF wall transformation, SG=SmithGroup.

production documentation, everything happens and stays within the Revit model. When MWF transform a wall, it places studs, it stud boxes any element which penetrates the wall, insulation, place the sheetrock etc.

As it is new for KHS&S to be a part of the design this early, MWF software is also a new program. KHS&S have therefore experienced software issues and have during the design process at CHH, collaborated with the software developers of MWF to improve the software packaged. KHS&S have among more had problems with the program to recognizing intersection configurations, backing etc. but all those problems seems to have been solved now. Because KHS&S both had to get familiar with the program and the new processes concurrently with the design process, many lessons have been learned. This is why this chapter ends with a section called aspects learned from the CHH project, section 5.8.

As KHS&S transforms the walls into real virtual elements, they also share their models with the entire IPD team. For coordination, KHS&S models are more reliable as their models depict how the walls are actually going to be constructed. The total width and the capabilities in terms of fire rating, acoustic capabilities etc. of the walls in the architectural model and the fabrication model have to be the same. The placing of the different objects within the wall does not necessary have to be the same. This means that cavities for utilities in the design model and the fabrication model not necessary are in the same place and therefore KHS&S's model is the model used for design coordination as their model depicts how things will be constructed. Figure 38 depicts how the coordination between KHS&S and the remaining IPD team has happened at the CHH project. The design coordination regarding drywalls is as earlier stated an iterative process where the whole team in a collaborative effort develops a design where all the utilities fits inside the walls or if required comes to an agreement on an alternative design solution. HerreroBoldt and SmithGroup are also taking part in the iterative process. HerreroBoldt has the overall responsibility for BIM coordination, clash detection, TVD meetings, and that the cluster groups are following the Last Planner system etc.. SmithGroup is contributing as a custodian for the design values and to maintain the permit submittal model updated compared to the fabrication documentation. If the IPD team encounters an issue and the solution is that the wall either has to be moved a few inches or made wider or narrower then the architect has to approve the change and update that change in the design model.

5.5.5 Design coordination of interior wall systems at CHH

The coordination of interior wall systems at CHH has happened through BIM coordination, clash detection, TVD meetings and cluster group meetings etc.. Notably most of the coordination has happened individually and informally between KHS&S and the different

IPD team members, which has been possible because the IPD team has been collocated to the same place and people therefore know each other personally and not "just" as trade partners. The good thing about informal coordination is that design issues can be addresses before they actually become design errors. The problem however with informal communication is if someone unintentionally is not receiving the newest "updates" because everyone thinks that everyone knows what is going on everywhere. This is the reason why the Lean principals are important as they create structure regarding coordination and communication such as what is happening in the TVD meetings and the cluster group meetings.

At CHH the BIM coordination and Lean coordination meetings such as the cluster group meetings have been two separate coordination approaches. HerreroBoldt has as described in section 5.3.2 created a VDC team to be responsible for the overall BIM coordination, where each IPD team members have to upload their model as updates occur for an overall coordination. At the same time HerreroBoldt has another group of people responsible for the LPS^{TM} coordination in each of the different cluster groups. The two coordination approaches are as such not overlapping, but if clashes are detected in the coordination of clash detection then the job of solving the issue becomes a job for the cluster groups to solve. The missing coordination between the two coordination aspects is one thing that the general contractor KHS&S are calling out as a missing part or as aspect that could be improved *"You need a strong facilitator on behalf of the owner or the GC to say "what's the most economical in a broad sense for the projects and force the different trades to do clash detection more often I think." David Lim.*

The interior wall system has an independent cluster group that meets every Wednesday where it primarily is KHS&S, SmithGroup, and HerreroBoldt who takes part, sometimes one or two more IPD team members takes part but that varies from week to week. A cluster group meeting for the interior wall system normally consist of 10 people. The agenda for these cluster group meetings are following the LPS^{TM}, which is described in section 3.3.4 A specific Last Planner spreadsheet for the interior cluster group meetings can be seen in figure 42.

Before each cluster group meeting, an agenda for the meeting is send out by the chair of the cluster group. It is Larry Bailey from SmithGroup who is the chair of the interior wall system at CHH. The agenda is developed based on what is agreed upon during the previous meeting and what anyone will bring forward during the week "as something" that would need to be discussed or coordinated.
The meeting will begin with a follow up (backflow of information) on whether or not the "issues" from last week have been solved if "yes" how? and if "no" why not and the same for agreements made last week, did they get followed up upon etc.
Next on the agenda is to discuss new design details.

An interior cluster group meeting will end with planning and agreements for the goals of the coming week, based on the “look ahead” schedule (figure 42).

Interior Cluster Group Plan

Plan Starting On: **March 25, 2010**

CATEGORIES OF VARIANCE			
1	Contracts / Revisions	9	Incorrect Time Estimate
2	Prior Work Not Complete	10	Off Project Demands
3	Information Not Available	11	Unforeseen Conditions
4	Poor Task Description	12	Other Project Demands
5	Staff Not Available	13	I Forgot
6	Materials Not Available	14	
7	Conditions of Satisfaction	15	
8	Task Sequence Change	16	

LOOK AHEAD TASKS ANTICIPATED	
Anticipated Tasks on WWP	0
Percent Anticipated Tasks	N/A
PERCENT PLANNED COMPLETE	
Tasks Completed	0
Total Tasks	0
Percent Planned Complete	**N/A**

Interior Cluster Group
California Pacific Medical Center
Cathedral Hill Hospital Preconstruction

As Planned	x
Repeat	x
Repeat More than Once	x
Shifted Planned Task	x

ACTIVITIES AND TASKS	REQUESTOR	RESPONSIBLE PERSON	Weekly Work Plan: Week 1 Thu 25 Mar	Day 2 Fri 26 Mar	Day 3 Mon 29 Mar	Day 4 Tue 30 Mar	Day 5 Wed 31 Mar	Tasks Anticipated (x)	PPC DONE ? YES	PPC DONE ? NO	CONSTRAINT SHEET	Look ahead: Week 2 Thu 1 Apr	Day 2 Fri 2 Apr	Day 3 Mon 5 Apr	Day 4 Tue 6 Apr	Day 5 Wed 7 Apr	Week 3 Mon 12 Apr	Week 4 Mon 19 Apr	Week 5 Mon 26 Apr	Week 6 Mon 3 May	WHAT MUST HAPPEN TO RELEASE THIS TASK
TILE AND STONE																					
Update L 10 estimate based on tile typology for L10	Matthew B.	**Jaleh**	x																		
Draft A3 to Provide information about Epoxy flooring for L1 Kitchen and L2 back of house kitchen spaces vs Quary tile with D and J Tile, CPMC, SG Designers, Martial Associates (Durrability, Installation, Repair, Waterproofing)	Matthew B	**Jaleh**	x																		
HEADWALLS																					
Provide section drawings and sample profiles for architectural features on your recommended headwall solution. 1) finish face @gyp board, 2) Finish panel to accessory rail 3) Headwall to ceiling connection.	Matthew B	**Jeff o**									x	x	x	x	x	x					Finalize terms of LOI agreement with Modular Services.
Finalize terms of LOI agreement with Modular Services.	Matthew B	**Rob P.**									x	x	x	x	x	x					Agreement with CPMC/ Sutter on Confidentiality agreement
Interior Detailing subgroup.																					
Model King studs on posted L6 drawing	Matthew B	**Kale W**									x	x	x	x	x	x					Arch background posted for L6 redesign
Model King studs on posted L7 drawing	Matthew B	**Kale W**															x				
Model King studs on posted L8 drawing	Matthew B	**Kale W**															x				
Model King studs on posted L2 drawing	Matthew B	**Kale W**																x	x		
Model King studs on posted L3 (Excl ED) drawing	Matthew B	**Kale W**																			
Model King studs on posted L3 (ED) drawing	Matthew B	**Kale W**																			
Model King studs on posted L4 drawing	Matthew B	**Kale W**																			
Send OSHPD comments on slider door to																					
Send details to Besam to review slider door at Back to Back bathroom	Matthew B	**Dan D**		x																	
Obtain and distrubute sales brosure on Besam single slider with breakaway feature for patient toilet rooms to Matthew B, Larry B, Rob P, Arlee M. Greg G, Faz Roger M.	Matthew B	**Dan D**					x														

Figure 42. Last Planner schedule for the interior cluster group.

In figure 42 it can be seen how Kale W. From KHS&S have no planned tasks for the coming week from the 25 of March 2010. The week after though, he is most likely going to model king studs on various post drawings, and also for the next five weeks he is assumed to be working on the king studs. What is depicted in figure 42 is only a section of the spreadsheet, which is the reason why only a few people’s work plan can be seen. In those meetings the following two examples have been discussed.

First example is the connection between drywalls and structural beams. In figure 43 two different examples a connection between a drywall and a structural beam can be seen. The example furthest to the left is the preferred solution and the solution to the right is the less preferred solution.

In the figure furthest to the left it can be seen how the beam and the drywall (stud) is meeting each other which means that the sheetrock can end below the beam. In the figure to the right there is a gap between the beam and the stud, which means that the sheetrock has to go the whole way up to the ceiling. It will be difficult to install the sheetrock in those areas as the

beams are blocking the way, and the sheetrock has to go the whole way to the ceiling due to fire regulation. This particular problem was cut by KHS&S who therefore contacted Dagenkolb, the structural engineer to figure out whether or not it would be possible to move the beam a few inches to create the situation like the one on the left figure where the sheetrock will not have to go the whole way to the ceiling. It was not a problem for Dagenkolb the structural engineer to move the beam and therefore it was moved. However as the beam was moved and the new model was send to HerreroBoldt for overall coordination it turned out that the replacement of the beams caused that the beam would clash with the plumbing. Therefore the beams were moved back to the original position.

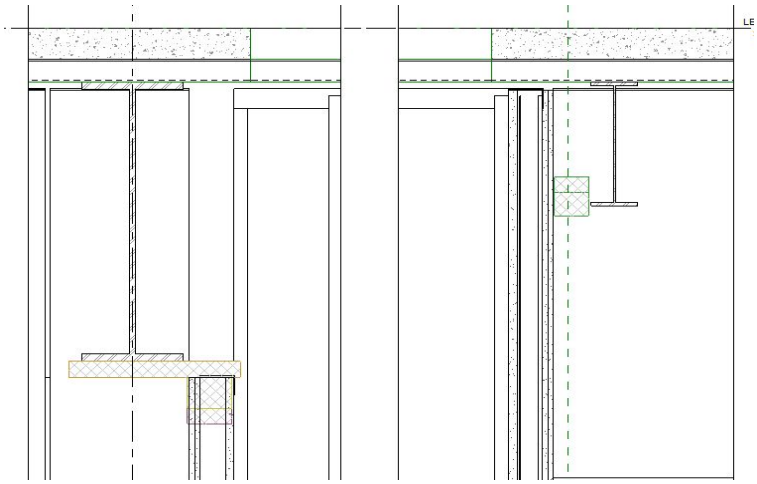


Figure 43. Coordination among structural steel and drywalls.

Another example is the waste piping down through the building. The different floor levels were designed with different floor plans which means that the walls from floor to floor were not placed above each other which caused the plumber difficulties with installing the waste pipes in the walls due to resound/noise from the pipes. The Southland industry and KHS&S met several times to find a solution. A solution was first found when someone came up with the idea of changing the floor plans to enable the wastepipe to go down straight through the building.

These two examples of design errors, are design errors that would not have been cut without BIM and solutions that would not have been found without Lean.

"I think that it was cut due to the BIM design but it was brought forward in the Lean implementation, because the Lean implementation allows them to speak forth and get an issue addressed and BIM backed up that thought." John Mack.

5.6 Design changes.

"Changes in general are complicated" Arlee Monson.
Changes are never easy to incorporate, as it means that something has to change. The question is whether or not the application of BIM and Lean makes it easier or more difficult to incorporate changes.

The process of making a change consists essentially of three steps.

1) Find the problem
2) Understand the problem
3) Implement the change

Find the problem:
3D modeling and the coherent clash detection highlights clashes automatically, which make the process of finding problems/clashes much easier than in a 2D model. In a 3D model it is also possible to navigate inside a virtual building and through that discover things such as pipes or beams "sticking out" which where they are not supposed to stick out. This means that it is not a traditional design error that clash detection will catch.

The visual effect/aspect that 3D provides makes it easy to find the clashes of lack of the same, and the coordination which Lean persistently calls out for, throughout the design, implies that problems are found early or at least earlier than in a conventional process where coordination is first done as a project moves into construction.

Understand the problem:
If a change implies a snowball effect of changes throughout the building, then it is important that everyone affected by the change understands why it has to be changed, in order to coordinate and collaboratively develop a new design proposal.
"Lean and BIM makes it easier to coordinate and to understand a change, but it does not make it less hard." Arlee Monson (appendix A).
Another pipe issue at CHH regarding how the piping were coming down a certain way in the parking lot caused problems with the minimum height requirements. It did not call out for any clashes, but it was still a design error. As the problem was found, it was easy for everyone involved to understand the problem and the whole IPD team was aware why it had to be changed and was therefore flexible towards finding a solution.
"Because they could model it and everybody could talk about it, and everyone could see what the problems were more clearly, they worked out another solution."John Koga, (appendix B).

"..BIM and Lean are allowing people that are receiving the changes to say and show and explain what the impact to them is before any work on the change happens." John Mack, appendix C.

The visual effect of 3D modeling has a great impact in how much easier it is for the involved partners to understand a problem and collaboratively discuss and find alternative solutions.

Implement the problem:

One aspect is that changes/design errors have become easier to detect and understand, but they have not become easier to implement in design.

"Change in any form is difficult, but it is more difficult in 3D and BIM, BIM is more accurate than what we have ever done, so we care about even small changes. When changes come in you have to do a lot more coordination because you have more details and more complicated drawings. If a change occurred as I was working with sketches, a change would not matter a great deal.

In AutoCad it got worse and in Revit it got even worse because now I have to care about all kinds of things such as what the walls are made out of, not just the thickness. I have to care about the location of it within fraction of inches, etc. So BIM has made it more complex to make changes."Arlee Monson

Due to the higher detail level, changes have become much more difficult to implement in design, because a change only can be made if nothing interferes with that change, and it is seldom that a change does not have an influence on something else. In the conventional approact, changes like these would be solved in construction, therefore the designer would not care so much, but now the changes have to be solved in design. It is therefore obvious that changes in a designer's point of view have become more complex. However, the actual process of changing one element has become easier if the affected aspects are neglected. According to Arlee Monson: *"… the software makes it easier to make a change, so it is kind of that there is a tradeoff that makes it easier to work with. If I had to make a change to a wall, all those walls changes at the same time, so I don't have to go through and find them, so there is a lot of advantages".*

According to drywall subcontractor David Lim, changes in respect to the CHH project have been "*.. embraced easily, but that has more to do with the environment of change that we are currently working in. I mean we are in this whole IPD process, we are more used to changes and we are definitely more flexible." David Lim, appendix D.*

The whole design process is one big iterative process as depicted in figure 38, and if a change must be made, the whole process starts over again. It is therefore possibly more difficult to make changes as well as it is more time consuming to make a BIM model, but again that is the whole idea of eliminating design errors in construction by making a more solid design

which provides the circumstances that the model can be trusted more than a conventional model.

5.7 Lessons learned regarding design of interior wall systems at CHH.

CHH is one of the first and largest projects where aspects such as IFOA, IPD, BIM, Lean Design, and CBA have been applied. Therefore they have faced challenges that they have had to solve coherently with the design process and then possible later realize that the challenge either could have been avoided or at least have been a smaller issues if something would have been done differently. This section will highlight some of those challenges, issues, and future possibilities that the application of the above mentioned aspects have discovered during the design process of interior wall systems at CHH.

Regarding the design model of interior walls there have been issues, such as whether a wall has been drawn from one end to the other. For architects it does not matter, but for KHS&S it does because a wall has two sides and they might not be the same. Issues like this have caused small problems that possibly could have been solved easier if KHS&S would have been engaged earlier to “catch” those types of errors coherently with the design instead of working in a loop with the designers regarding the initial design of interior walls. Therefore even earlier engagement of KHS&S is discussed for future projects. It is by KHS&S suggested that they should be engaged at the end of schematic opposed to mid design, so just a little earlier with some of the other trade partners.

Coordination of backing is another design aspect which was not addressed in the design of CHH, but possibly can benefit from Lean coordination and BIM application. Backing is a piece of metal which is pinned directly on the studs, and then sheetrock on top of that. Backing is used in places where it is anticipated that something will be hung on the walls such as cupboard, equipments etc., as sheetrock itself is not strong enough to carrying any heavy weight.

The issue with backing is that it is traditionally placed before anyone knows exactly where all the furniture and equipment are going and likewise it is difficult for those that have to place anything on the wall to know where the backing is when the sheetrock have been placed.

With the 3D model it is possible to design the rooms exactly with cupboards and equipment and through that know where to place the backing. CHH however was not been able to coordinate backing as the software to manages placing of backing was not developed before the design was submitted to OSHPD, which lock the design because any change in design

from that point and onwards will cause an extra OSHPD submittal and this is both to cost and time consuming that this is not an option. At CHH all the walls therefore have backing placed in two standard heights from the floor level as depicted in figure 44.
Backing makes up a large part of the drywall expenses, therefore it is anticipated that by only placing the backing where it is needed that the cost of drywalls all together can significantly be reduced.

KHS&S had little experience with BIM and Lean, as they got onboard on this project, so they have faced a lot of things where they see potential. For KHS&S the increased design accuracy does that they dear beginning to try out certain areas of prefabrication etc., They among more considered having precut studs delivered in bundles for each wall, to improve the installation process, again this will not be implemented in this project as the design was submitted to OSHPD before a complete prefabrication solution could be developed.

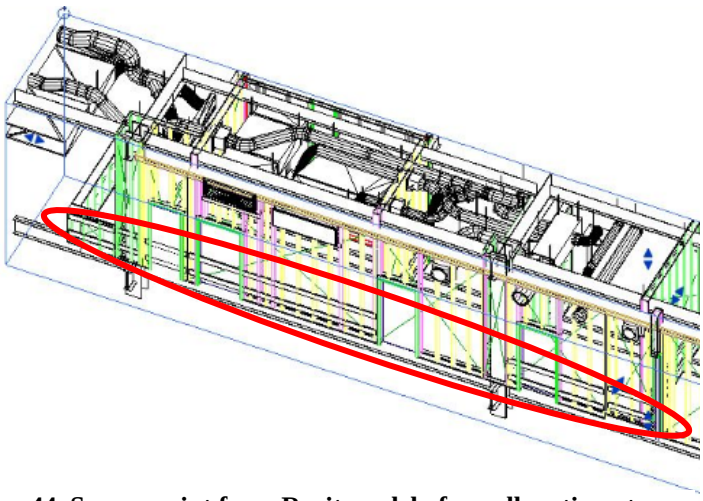


Figure 44. Screen print from Revit model of a wall section at CHH depicting backing.

6 Discussion

First this chapter discusses why the industry has to change processes in order to reap the full potential of BIM, and why BIM cannot alone facilitate the needed transformation. Second. This chapter discusses how Lean possibly can facilitate this transformation and how BIM and Lean complement each other. Finally, this chapter discusses the specific application of BIM and Lean regarding interior wall systems as presented earlier in this report, in the case study and how this application could be done better or differently in future projects.

BIM is a concept for project delivery which aims to consolidate all facets of a building project in one digital entity. This requires a high degree of transparency, collaboration, communication, and coordination between every trade partner involved. Everyone is supposed to contribute though an iterative process to develop the best possible product within a certain framework.

The conventional project delivery is the opposite; there exists a minimal amount of communication, coordination, or collaboration among designers in preconstruction to contractors in construction and again from contractors to those who have to operate the building. Mosey 2009 and Bernstein 2005 describe the conventional process of project delivery as a linear process, where trades are working in “silos” protecting themselves and their responsibilities, as opposed to considering the project as one entity.

These two approaches do therefore not match each other. If BIM would be applied in a conventional project delivery process, its potential will most likely be reduced to a simple 3D modeling tool, which will provide advantages as opposed to 2D modeling, but these advantages will be far from revealing the true potential of BIM. BIM is about the whole process from where the design is being developed, through an iterative process where several alternatives can be discussed to building delivery and operation. This process cannot take place in a linear process where trades are working protectively as opposed to openly.

Therefore the industry has to change if it wants to reap the full potential of BIM, and BIM cannot facilitate that transformation. BIM is a tool, but for that tool to be used successfully that use must follow a certain process. It is similar to giving a tradesman a new toolbox consisting of new tools, which he has never seen before, and expecting him to start using them differently. It is not going to happen, he would possibly look at the tools and connect them to tools he knows, and start using the tool that looks the most like a hammer as a hammer even though the new “hammer” might be capable of doing many other things. Only if someone explains and shows what these new tools can do, he would start using those

abilities. It is the same with BIM, BIM is capable of doing 2D and 3D models, but it can be used for so much more than that.

To transform the conventional project delivery to a BIM project delivery, this report suggests Lean as a facilitator for this transformation. Lean is a philosophy that seeks to improve something by incremental improvements, in this case the project delivery process. According to Ballard and Koskela *Lean is not a state of being, but a way of acting in the world* (Ballard & Koskela, 1998). In order to create such an environment, Lean has some tangible tools and methods to encourage communication, coordination, collaboration, and transparency. In other words, the way Lean and BIM complement each other is by the fact that Lean is able to create an environment where the right communication can take place (flow), among the right people at the right time, which enables the right information to get into BIM in order to utilize BIM.

Now continuing to the discussion about how BIM and Lean have been applied in the case study which has been investigated in relation to this report. Before beginning the discussion, a summary of key aspects of the case study project is in order, as this project has created unique conditions for BIM and Lean to display their potentials. This project is among the first projects in the US to use a relational contract form called an Integrated Form of Agreement (IFOA) which is developed based on the Lean philosophy. Two important elements of an IFOA contract are (1) Use of Lean of management and (2) Design development has to happen in an Integrated Project Delivery (IPD) environment. This means that the designers, consultants, contractors and subcontractors in the project all are engaged in the design phase and that the project team is collocated in the same building. The IFOA contract obviously creates a unique environment for BIM and Lean to show their potential.

At CHH, contractors and subcontractors were engaged early in design which has made it possible to exploit their knowledge about constructability, material, durability, etc. and use their knowledge to develop a better design. In this case with focus on drywalls, this project team has, through an iterative design process, reaped the benefits of having the full design team located in the same building. The combination of the iterative process encouraged by Lean and the visual documentation of BIM have imposed a reliable design, which has given the drywall company confidence that this approach can allow them to use prefabrication. That confidence has increased to a level where prefabrication is considered on this project. It is interesting as neither BIM nor Lean has been fully implemented, nor have they been applied in a consolidated effort yet. The effect of their connected use has been measurable and positive in terms of raising team member’s confidence in the model.

Regarding the objective of this report, it does not matter whether or not BIM and Lean individually have been applied to their full potential; the interesting aspect is how the two concepts have complemented each other in meeting the goals which have been set. At CHH, members speculate that their application of both BIM and Lean has enabled them to identify design errors altogether. This case study therefore shows that BIM and Lean do complement each other during design development, but it also calls out for further research regarding what the effect would be of implementing both concepts in an even more integrated form.

Due to the application of BIM and Lean issues regarding sound propagation in the waste pipe system were cut in the investigated case study. The true benefit however of applying BIM and Lean together is reflected in numerous small coordination issues that are addressed even before they become problems. For example, a beam was moved from request of the drywall company and then moved back as the change resulted in the beam clashing with the pipe system. Issues like these were solved much earlier than might otherwise be the case due to the elaborate coordination, virtual coordination communication, collaboration and flow that the two concepts calls out for.

There is however room for improvement, because BIM and Lean have not been fully implemented, nor have they been implemented in a consolidated effort. The structure of BIM coordination at CHH is that the IPD members are supposed to send changes to the general contractor HerreroBoldt when changes occur. So that HerreroBoldt can conduct an overall clash detection and coordination to keep track of the overall progress of the design development. Parallel with the BIM coordination, the design coordination is taking place in the TVD meetings and Cluster groups. These two coordination efforts presently works only indirectly connected. Design issues discovered in the BIM coordination become problems for the IPD team to solve, and therefore also problems for the cluster groups and TVD group to solve. When the problem is solved the BIM model gets updated, possibly to reveal new design issues.

This coordination structure has as said, caused many good things for the overall design process, however also some problems that might be solved with a better integration of BIM and Lean coordination.
From the drywall company perspective the BIM coordination itself has first of all been too loose, as “upload changes when they occur” can be interpreted differently in terms of how big a change has to be in order to be recognized as a change and therefore uploaded, and so forth. Another problem is that the overall coordination of the cluster groups also has been too loose, even though they independently have worked well with the LPS^{TM}. Early on the design, the IPD team decided that to focus on the design of the tenth floor, but not more specifically how they would design the tenth floor. Accordingly different cluster groups started their design in different parts of the tenth floor. This led to uncoordinated information

exchange. An example could be that the drywall company needed information on a particular area from the structural engineers but had to wait for the engineers to progress in their design to be in this particular area.

A way to address those issues would be to divide the project into even smaller sections than a floor level such as units like a toilet, a patient room, an operation room, etc. in line with LPS^{TM}. The issue of breaking the design down to for example a toilet is that the structural trades are not working on this scale as for example the drywall company. Therefore another suggestion could be just to break the floor into even smaller section such a north corner, south corner etc., to break down the design unit to a size where everyone really will be forced to work in the same area.

Another thing that could be done in order to implement BIM better would be to make BIM an integrated part of the cluster group meetings. This obviously would require that everyone posses a high understanding of using BIM as a tool. In turn, that would make the actual modeling and discussion of the design even more integrated. Integration of BIM in the cluster groups will, however, not reduce the need for a BIM coordinator of the overall BIM efforts of the cluster groups like the TVD meetings are for the cluster groups design meetings.

7 Conclusion

The purpose of this report was to investigate the thesis: "Building Information Modeling (BIM) is a concept that promises to revolutionize the building industry in terms of better coordination and communication among the trades involved. This revolution will by no means happen automatically, even if software technology is able to facilitate such a change. Changes regarding management, processes, and contracting are needed to enable the industry to fully embrace the concept and to reap benefit thereof."

To investigate the thesis the following two research questions and their sub questions, were aimed to be answered: 1) How and why do BIM and Lean complement each other in building design? 1.1) How, where and when does communication flow? And 2) How do BIM and Lean impact coordination of interior wall systems among trades? 2.1) Which trades are taking part in coordination of interior wall systems? 2.2) When is the right time to engage sub contractors? 2.3) How does BIM impact design changes?

To study the thesis, both theoretical and empirical data have been collected and investigated. The theoretical data is based on a literature review and the empirical data is based on a single case study of a hospital project in San Francisco, California. The case study was conducted on the basis of:

1) A weekly visit in the office where the whole IPD team is collocated, to follow the design process.

2) 4 interviews with key players from the IPD team, with the focus on interior wall systems.

Based on the literature review and the empirical data ***the thesis can remain standing,*** which means that in the light of this research the thesis cannot be rejected and are therefore open for further research.

The presented literature in this report is positive towards the BIM concept's capabilities of revolutionizing the building industry in terms of facilitating better coordination and communication, but also vigilant to its ability to solely facilitated the transformation that is needed. The case study conducted in San Francisco which is called Cathedral Hill Hospital (CHH) is also confirming that even though the software technology is to some degree able to facilitate this new approach regarding project delivery, this does not mean that BIM can be fully implemented and used alone. In the beginning of preconstruction the general contractor at CHH thought that BIM was going to be fully implemented. That however had to be demoted due to lack of qualifications and understanding for the concept among the engaged trade partners. The ambitions regarding BIM implementation on this specific project is therefore degraded to consist of 3D modeling and clash detection (with the ambition of embracing 4D modeling).

The literature also recognizes the need for changes regarding traditional contracting, processes and management in order to facilitate the use of BIM. The contractual change that the literature calls out for is a relational contract form as opposed to a traditional DBB contracts. A relational contract is a contract that encourages early engagement of the contractor and subcontractors in design and collaboration among trades. (which is opposed to the conventional DBB process). Application of a relational contract implies that new processes and management strategies are needed. In this regard, this project suggests Lean management as a new management strategy as Lean is able to create an iterative process, where the right communication can take place, among the right trade partners at the right time, to enable the right information to get into BIM in order to successfully implement BIM.

At CHH a relational contract form called IFOA is applied. CHH is one of the first projects in the US to apply a relational contract form. The IFOA contract is based on Lean principles which imply that Lean management is being used on this project too. In line with both the BIM theory and the Lean philosophy, contractors and subcontractors were all engaged early in design at CHH. The whole IPD team was furthermore collocated in an office facility in San Francisco to enable a higher degree of collaboration, communication, and coordination. At CHH the design process has been an iterative process where the communication both has happened informally and at the same time structured by the principles of the LPS™.

Due to the Lean processes and BIM's abilities to visualize the design, several "design errors" were avoided. At present, the application of IFOA, BIM and Lean therefore appears to be successful in terms of meeting the success criteria for this particular project. However it is not until the project moves into construction, that it is fully revealed whether or not the design approach has been successful.

Regarding the design of interior wall systems, the application of BIM and Lean has first and foremost resulted in subcontractors taken part in the design. Subcontractors can now impact the design. In this project, only the foundation trades and excavation trades have not been involved in drywall design.

The application of BIM and Lean provides a higher level of accuracy and, through that, trust in the model. This increased trust in the model has provided the different trade partners involved in the drywall design with the confidence to prefabricate elements which again opens up for new possibilities on how to manage construction of drywalls.

Regarding design changes, BIM has not made the actual process of making changes easier. A BIM model contains more details which makes a change more complex than for example a change in a 2D model. It is similar to the design process of a BIM model; it is also more time

consuming to develop a BIM model than a 2D model. The extra time spend in design or on incorporating the change is however what should be outbalanced during construction. As a BIM model, and a change in a BIM model, should be able to be constructed without change orders and rework, opposed to a 2D model and changes in a 2D model.
In the bigger picture a change in a BIM model is therefore easier, but in the design process itself it has become more difficult.

The potential outcome of connecting Lean and BIM appears to be very promising as both theory and practical experience confirm the synergy between the two concepts.

8 Perspective

This report proposes that the following aspects will become reality if BIM will be implemented successfully: 1. Lower construction cost and lifecycle cost, 2. Shorter construction time, 3. Higher quality, 4. More reliable projects, 5. Higher safety, and 6. Better operation possibilities. This report also proposes that BIM cannot successfully be implemented within the conventional framework. The transformation that is needed in order to create an environment where BIM can be implemented successfully is not going to happen automatically, even though the software technology makes it possible.

To make this transformation in order to implement BIM successfully, this report notes that the building industry is facing at least the following challenges:

1. BIM is not only a CAD or a 3D modeling tool. Instead, BIM is a platform were design solutions can be developed, based on intelligent objects that can contain information for construction and operational purposes. The aspect about handling and coordination information is the most essential part of BIM.

2. BIM is more than just a tool, but a process, a process that requires that the industry has to change the traditional perception of how to design and construct buildings. New project structures are needed to integrate BIM – from design to and throughout the lifecycle of the building.

3. BIM alone cannot transform the traditional perception of how to construct buildings to the BIM perception. A new management philosophy is needed to facilitate this change, and for that purpose Lean is an alternative.

4. Understand the connection between Lean and BIM, and avoid making it complicated because it is not! It is logical!

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Appendix A Interview with Arlee Monson from SmithGroup

Question frame regarding:

SmithGroup Knowledge sharing and communication with their trade partners.

Tools:

1. **Which IT-programs are used by SmithGroup to handle (drawing material), time schedule, economy and related information's regarding the Cathedral Hill hospital?**
   For production drawings we use AutoCad and Revit, but we also still use Sketch-up and Illustrator for graphic drawings.

2. **How does Smith-group apply BIM?**
   The answer is that we don't use BIM, because nobody uses it either but that's more like a clinical answer. The reality is if you look at BIM, what we do in house; in some ways BIM is what we put in Revit generically for our own use. The information we put in are doors and finishes, which comes out as the schedule for us. I see BIM as the data that we put into a door. A door has attributes, and those attributes are the data, and the data extracts into a schedule. When we design a wall we put data in such as a 6' stud wall; it has sheetrock, one layer~~ed~~ or two layers with insulation. However, nobody uses that compiled data, internally we don't use it, we only have to give the wall data, in order to let the wall know that it is a wall.
   When we pass the model over to the trades such as KHS&S, they will use that data only to let them understand that it is wall, but they wouldn't extract the data directly into their programs. So it is not being used as data anywhere.
   They cannot t~~h~~rust our data necessarily, and I think that is where we are finding the core issue, those who have to use 3D or BIM in their field cannot trust what is coming out of the design model, they have to only trust themselves. They have to build the model themselves to get a reliable model, because they are pricing out of that model. If they just took the design model, the takeoffs would be wrong.
   Now that means that either they are wrong or we are wrong, but neither of us is wrong, we are both right. But they have to base their cost of their construction on their models, because their model include waste factors such as jobsite conditions etc. We don't care about those things, but because they have to price it, they have to care.

   We are doing the same handoffs today as that we always did, we are just doing it better and faster. Before handoffs were made with paper, we would not even give them an AutoCad drawing electronically we would give them everything on paper and they would do their takeoffs from the paper.

The only thing which has changed is that we can give them better and quicker information and more accurate, but they still cannot trust it, they cannot use it because it does not reflect what they need from at cost standpoint.

3. **How does Smith-group apply Lean construction?**
We do so through our participation in the cluster groups, so I think my answer is that we apply Lean by using the Lean tools in a cluster environment. We participate in collaborative effort using tools that reflect the Lean principles, so things like last planner, A3's, the last responsible moment, set-based design, and target value design. We are using the tools that Lean provides us within a collaborative environment.

Now we do other projects that are design – build not this total collaboration, they also use the Lean tools, but not as much in the cluster group's collaborative sense that we are doing here.

So we use Lean in some ways in other projects, but not in an overall structured environment. So they use Last Planner, they don't use target value design, they may use some set-based design ideas, but it is more of a design-build atmosphere.

We have never really been able to implement one piece flow idea in design, because it does not really work in design or in collaboration. Let say that I would design a door schedule; I can do a one piece flow within my process to get from design into the final product. When that piece is out of my control it is not working any longer because the process is too iterative.
We have not really found a way to apply one piece flow outside of our firm. This is where manufacturing and design does not really correlate very well, because in a manufacturing environment you can follow the flow of the small piece all the way from inception to final product, you can do that in design. We tried, we looked at it but then in the end we gave up regarding CHH.

We have to look at it as an approval document, not as what it is but what it represents. A set of drawings could be treated as a product, and say what does it take to get to construction level document. Well, it has to go through these modifications or improvements till it gets to that level that it can be handed off. I can look at that as a one piece flow but you cannot take the construction of an object through a design phase and call it a one piece flow because it is to iterative.
I think it is what we look at for one piece flow in design - versions of a physical product in manufacturing. First of all in manufacturing they already got the design done. I look at drawings as the production of a product. I am inputting information to these pieces and to each of these pieces there is an iterative process, but in the end it

is a product. I can look at the piece of paper (a drawing) as the product that I'm mass producing. Then it makes a little sense.

4. **How is the communication between Smith and their trade partners? How has Lean construction and BIM influenced that?**
   All in all it is much better communication, it is different and it is better, but I'm not sure that I'm able to answer how it is better.
   Definitely the coordination is better, all of that is an improvement. Better communication leads to better coordination.

Processes:

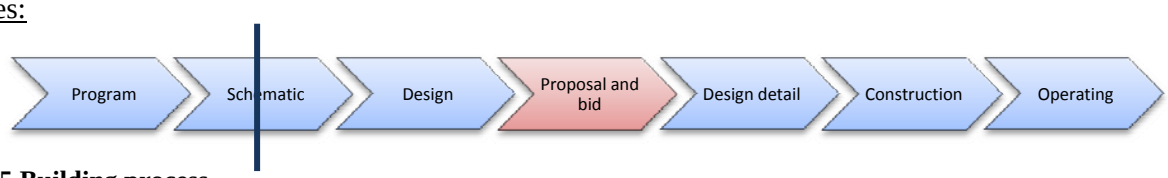


Figure 45 Building process

5. When do you think is the right time, see figure 1, to engage contractors and subcontractors?
   Generally I think in the middle of schematic design. I would say, there is a group of them that would benefit the design sooner, and there is a group where it is a waste of their time to come in too early. So I would say that participation varies per trade but it also varies by complexity. If we bring those people who needs detail in to soon they will have nothing to do. We have to bring in those people that need to make decisions about the general system early. As indicated in the figure above, a few subcontractors should be engaged in the early part of schematic, but most of them not until between schematic and design.

6. **From a contractor's point of view, what advantages do you see by applying BIM?**
   Coordination primarily.
   The tendency is that they can coordinate well with design but they cannot coordinate between trades as well.

7. **How has the application of BIM changed processes in the building industry?**
   The information that it provides is more relevant information.
   If we talk about data imbedded with model, the really questions goes back to "do they really use it" it gives them relevant information. If my BIM data tells them that there is two layers of sheetrock on the wall because the data is there, the data is more relevant ~~to them~~ to a sheet rocker, not to somebody else. If they have to look at it the old way in the schedule that I drew two lines and then they have to go to a schedule and a detailer to figure out does this wall have two layers of sheet rock or not and it is not really reliable and the BIM model is accurate, meaning that if I draw a wall type

he gets that length of two layers of sheet rock. In the old way I just draw one generic line, it could have been one layer or two layers.

8. **What are the advantages of Working in an IPD project? Can an IPD project work without Lean and BIM?**
   "There is a greater chance for the building to be constructed as designed"
   IPD can work without Lean and BIM but it certainly works better with these tools.

9. **How does the coordination of utilities happen in internal wall systems?**
   In a normal process we don't care, I mean nobody coordinates that. But in this project we decided that it is important. The reason why it is not important and why we don't coordinate in a normal process is that there is plenty of room inside walls.
   In 90% of the walls, there are not enough clashes to make it a problem. There is obviously a group of walls that has everything in them, but even in those cases there is still plenty of room in the walls. I don't need to coordinate it, but the trades have to coordinate it, because they don't want to end up with their systems in the same place.

   Today, we make our model in Revit and then we translate it to 2D AutoCad, and the other trades translate it and use it. They may only use it as an underlay, like a graphical representation and work on top of it, and we do the same with other peoples work. With Revit, we don't bring AutoCAD into Revit. We use it as an underlay and then we draw our own model. KHS&S is doing it too; they make their own Revit model and dummying it down and using it only as a background, for what development they are doing.

   Traditionally we zoned the cavities when we did a 2D coordination. We are still doing that today in 3D coordination. The difference is that we have brought everything into the 3D model opposed to the zoning in 2D which only included the larger pieces. We didn't care about things such as IT because they will go wherever was left over.
   In 3D you consider all the systems and the only time it gets messed up is when we forget a system that takes up more real estate than what we planned.

10. **How do you design and sequence interior walls? (Has BIM and Lean construction had an impact?)**
    When we do our modeling we go through a planning exercise first or a design exercise. The planners don't understand wall construction, and they don't care.
    Once they get the first plans done we will assign more specific walls like corridor walls, so we give them another level of detail and replace the generic wall, but even

then it is not the final wall, because there is some other things that is coming in play later like acoustics or what's in the wall that maybe make it bigger. So each time we get a little more detailed. The plan then goes away from the planning side and pretty soon it's owned by the technical people. So, we go through those phases of planning, and rework, but it is better and necessary, as the planners cannot plan if they have to worry about details.

11. **How has the application of BIM and Lean construction influenced the impact of changes late in the process?**
    Changes in general are complicated.
    Lean and BIM make it easier to coordinate and to understand a change, but it does not make it less hard. Change in any form is difficult, but it is more difficult in 3D and BIM.
    BIM is more accurate than what we have ever done, so we care about even small changes. When changes come in you have to do a lot more coordination because you have more details and more complicated drawings. If a change occurred as I was working with sketches, a change would not matter a great deal.
    In AutoCad it got worse and in Revit it got even worse because now I have to care about all kind of things such as what the walls are made out of, not just the thickness. I have to care about the location of it within fraction of inches, etc.
    So BIM has made it more complex to make changes. However the software makes it easier to make a change, so it is kind of that there is a tradeoff that makes it easier to work with. If I had to make a change to a wall, all those walls changes at the same time, so I don't have to go through and find them, so there is a lot of advantages.
    However, the fact that the coordination in BIM is more complicated possibly makes the change a little bit more difficult.

    Lean is really supposed to manage change, so the changes that Lean brings about makes the overall value better. This is where you get in to that whole holistic mindset of Lean.
    Lean embraces the ability to manage change.

Tools for the future:

12. **Does Smith-group take part in any innovation/research projects regarding BIM modelling and Lean Construction?**
    P2SL
    Mostly in-house
    AIA conferences
    We use it to market ourselves more than to teach others what we are doing.

13. **How would you like to see BIM and Lean construction being applied in the future?**

More definitive and more reliable, and what that means is that when we started this project we knew that nobody has done it before, so we had to make it up as we go along, but at the same time we expected that people like Boldt, who were already into Lean, should have brought a process, a working process, with them. Meaning they should have known how to do a certain amount of this, and they did not. We did not expect that they had to invent it all from scratch, which we did. What they came with were certain words and technical terms but not how to implement that. They had an idea of the cluster groups, but they could not tell us how that worked. They had an idea about target value design, but they could not really make it work. So there were a lot of words but not a lot of real process behind it, the process had to be created. So I would like to see a more defined methodology.

From a BIM perspective on this project we wasted a lot of time, with the expectations and learning how to do it.

BIM should drive the process and Lean should be the tools, Lean should provide the tools for the process, and I think we are getting there. When we started this project Lean was a process and BIM was just a tool that the architect alone used. As we are evolving the BIM model and the BIM data is becoming more and more valuable to the team and more familiar with the rest of the team. Now everything is rotating about the development of that model, and the development of that model needs to be guided by the tools of Lean.

Though you can argue it either way, BIM should only be the tool, has validity, but if BIM is only the tool then what is the process? Lean is not the process it is the process of improvements. So therefore you could say that both are tools for the design and construction process. As we get into design, and trying to make the design process a Lean process, we are trying to evolve that into a Lean process using BIM as a tool. As we get into construction the process is really building the building virtually and translating the virtually model into real life construction.

BIM is the process, but Lean is what keeps people in the right place, and at the right time. So Lean becomes the tool to manage the process. I think that they are interchangeable to some extent.

Processes for the future:

14. **What do you see as the synergies between Lean Construction and BIM?**

In one way one is subservient to the other. So the current synergies between BIM and Lean is that Lean is a process and BIM is a tool. In the future BIM should be more of the process and Lean should be the tool.

15. **How do you see the future for BIM and Lean Construction?**

BIM should be the process and Lean should be the tool.

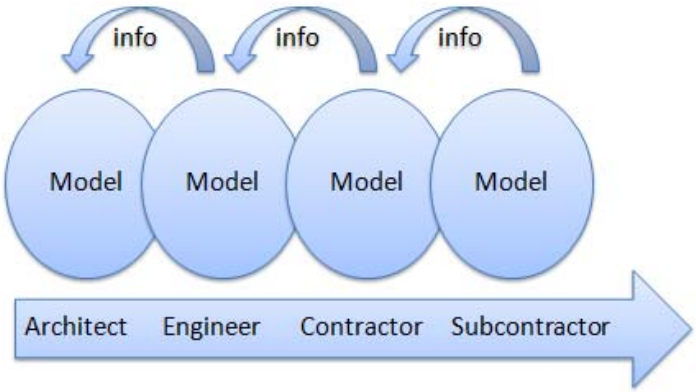


Figure 46 how to create flow

I see that only one model should be in the game as depicted in figure 2, with a standard backflow of information to incrementally improve of the forward moving model.

16. **What are the barriers which keep companies away from applying BIM and Lean construction?**
Cost and commitment, and a component of that is risk, and how risk is being determined according to cost.

Appendix B Interview with John Koga from HerreroBoldt

Question frame regarding:

herreroBoldt Knowledge sharing and communication with their trade partners.

Tools:

17. **Which IT-programs are used by Boldt to handle (drawing material), time schedule, economy and related information's regarding the Cathedral Hill hospital?**

John Mack-will know that

18. **How does HerreroBoldt apply BIM?**

We are applying it to develop 3 dimensional models for coordination purposes primarily but also for field-instruction so that construction workers can look at the model and say that is what they want me to do.

We have not yet taken it to the level of when to install, but I'm aware of BIM's capabilities in that regard. Here on this job as far as my understanding goes, is that it has mostly been about clashes.

19. **How does HerreroBoldt apply Lean construction?**

Many ways!

We have as a goal to develop Lean to develop flow such as product flow in the way Lean talks about it, that is our goal. We have a long way to go to figure that out yet.

The biggest problem right now is that still not everybody understands the concept. Secondly we have not developed the bills of material so that we know what we have to flow and to do value stream maps and things like that to understand the supply chain aspect; I mean there is just a ton of things like that.

Flow in design:

From the beginning of this project we talked about flow in design, especially like one piece flow and we thought that breaking design into OSHPD incremental packages was going to enable flow to occur in a good way. We thought that we were breaking the project down enough to do that, now what has happened is that it is still very much batch and queue. You know you are dealing with a regulatory agency that does not want you to break it down in the first place. So we had broken it down, we had an agreement to break it down to get one piece flow. We really should be breaking it down many times more to get much smaller packages going through, but we don't think that OSHPD would be able to handle that.

And this is not just something that will happen here in California due to OSHPD. Breaking a project down into so many pieces is just not how the inspectors work. Inspectors want to look at total projects in terms of life safety purposes.

The design team has been divided into various cluster groups, and within those cluster groups I believe that they are breaking the design into small pieces. Now I cannot say that we exactly track it through our system that way. But they do work on a patient room design etc, it is small packages.

Processes:

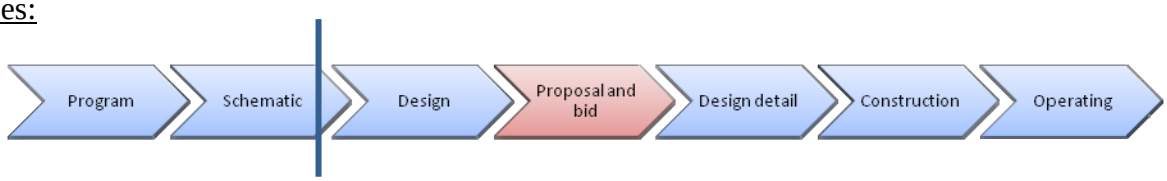


Figure 47 Building process

20. **When do you think is the right time, see figure 1, to engage contractors and subcontractors?**

Regarding this project you have to realize that this project was programmed and designed already once already, I and three other senior advisors got on board as the revised program started.
But in general HerreroBoldt first got on board in the beginning of the schematic design. Some of the subs got on board almost at the same time as us, a few subcontracts like KHS&S first got on board a bit later like in the middle of the design stage.

So for a project with a different history, where would it be beneficial for you to be engage?
Well that is a complex question. In a conventional project we would not have been on board before the proposal and bid. When it comes to the Lean aspect then it is different, Lean is primarily focused on production that we could come in somewhere after schematic and still be effective, I like us coming in with the beginning of schematic, because so much of the value of the building gets set early even in the schematic and massing of the building, it is a time when we can look at things like how material is getting handled on the site where the crane and lifts are etc. and sometimes that can influence the design, obviously depending on how complex the design is. There is obviously going to be limitations to what we can do but trying to Lean out the design itself, design effort, is a tough one. I would say that on this job we were all learning to work together, you have so many different partners; we had not worked together before. I would say if we stayed together and worked on a second job, we would do it better and maybe on a third project we might have a Lean system.

One of the problems about creating and Lean environment is to arrange the work packages to a level where the work is really going to flow.
The architects have to bring it down, but they would need at Lean consultant on board to tell them what they need to do, but the architects have to decide that they want to issue it that way, they might feel that it is contrary to the way that their work flows, I suppose it is all a negotiation. But that is what it means to Lean out the design. Of cause you have to know what the work is, and what the work packages are, in order to put them into the right size and right sequence situation. When you are just starting the design, you know that you have phases of work, and that you have to develop a concept and so forth, but when you are talking about work packages that are actually flowing, you are talking about something that is still in the imagination and you want to make packages out of it, it is like trying to put clouds in boxes. So that is hard that part is really difficult, but once the thing does start to take some form, you get some basis blocking and stacking, so you know what you are dealing with. Then absolutely I think you can start to put it in packages as long as everyone is on board. What is going to happen is that when your information cannot flow to the packages, those packages are going to get stopped. As an example, if you are trying to design a patient room and you got some new concept for the headwalls and in general how the room is going to be arranged, and you cannot get the owner's people to sit down for two weeks, because you just cannot they are very busy, that packages stalls. You are trying to get flow but it is getting stopped by these things, so that is just business the way that it is.

4D sequencing in design

- Regarding the time aspect connected to construction and how that can be brought into the design, which is maybe two years before anything is actually happening.
  To be able to do that, we need the designers to have an appreciation of how much time it takes a construction worker to do certain things. The problem is that this is probably one of the most remote things from the designers mind at that point, he is trying to get a room, with features that are pleasing to his client, and he is not so much worried about the construction aspects and the constructability of it. And yet it can be really important to prove out prefabrication which we have tried out with the bathrooms on this project, we spent a lot of time with it. The idea about prefabricating the bathrooms was only construction related and it affected the design of the room, such as how you did certain things regarding the finish of doorframes etc.

- Another aspect of what has to get sequenced in design is the promises that need to get made to get the design done. There is a case of using the Lean weekly work plan.

What is the last responsible moment for the design of a room? If you define it as the time where you start to lose options of alternatives that would have added value or improved the value. Then is that occurring out in the future when you construct it or is it still back here on the drawing board?. It is a thought question because what happens is between all that you have to go through all the regulatory agencies and get permits, you just have to get all this work done with pre construction which has nothing to do with the last responsible moment on a job site and that material is showing up on time. You have this huge wall of regulations you need to go through, so that starts to drive it back to that it is not so much the constructions that drives it as it is to get it through the permitting stage, which is really what you are trying to achieve. So now the last responsible moment for the designer becomes when the designer has to decide which design concept is going to be the final concept.

21. **From a contractor's point of view, what advantages do you see by applying** BIM?

We started many years ago to use BIM to understand underground obstacles. In general exchange adjustments with accuracy, and make things visible, so that errors can be detected early on.

22. **How has the application of BIM changed processes in the building industry?**
See the above answers

23. **What are the advantages of Working in an IPD project? Can an IPD project work without Lean and BIM?**

IPD projects can work without Lean and BIM, because it is about integrating the different disciplines together, and not only from the architecture and engineering side but also for the construction side that is basically all that integrated project delivery IPD means.
Though an IPD project is a whole lot better with the BIM, and it is even better beyond that with Lean. I mean these are all different things, BIM is the tool for the architecture and engineering and not so much for managing it, but for explaining the output. Lean is a philosophy.

24. **How has the application of BIM and Lean construction influenced the impact of changes late in the process?**

Yes! In the millions of dollars of cost avoidance.

We had an example here the other day, if the fire protector guys had detailed their job in the normal way, having piping coming down a certain way in the parking lot of this building, it would have caused problems with the tunnel opening and it would have created problems with the parking.

Because they could model it and everybody could talk about it, and everyone could see what the problems were more clearly, they worked out another solution. Traditionally what would have happened is that you would not even have discovered that problem until you were in construction and down there doing it. You might even have installed all the fire piping, only to have someone coming walking by some month later saying "why is this here?" This is all wrong. You would have had all that expense. So there is a clear example of BIM really saving us a lot of money.

Owner based change:

That is an interesting question, you know Toyota once they go in to production as a rule, they really don't like change. So once it has gone from engineering into production, change is avoided. They really don't like it.

Because they figured everything out in their production system and it is intended to be Lean and flow, and even though you can get custom made cars (from a range of options) and all that stuff they don't want internally changing the design. Everything has been worked out, that is a huge issue. So in a building construction if we have to be Lean, we really need to have commitment from the client not to change things. Now is that realistic? Historically no, but we have to have some talks with our client about that. In our IFOA it says integrated agreement for a Lean project delivery. It is an agreement with owners signature to it as well as the architects and the contractors. We can easily go to them and say "if you start making changes once we have started production then it is not Lean that's not a part of the contract" We would therefore have a basis for that discussion, but we are not going to be hardnosed about this. However we all know that changes happens in the field.

Another change will be an owner instigated change such as wanting the newest MRI, and that really happens and they want to put that in, and you have already roughed in the conduits, the ventilation and you know where the footing is, or whatever is going to support it, and this new magnet just does not fit into all that. To redo such a change could take month, first figuring it out, then reengineer it, go back to OSHPD, because it is a change of large magnitude. But there are obviously both small and large changes and the small insignificant changes you can still handle in the field.

Is it easier today to incorporate the change of a new MRI compared the conventional 2D approach?

I'll tell you what I think; I actually think that it would be easier in 2D, because you don't draw as much in 2D. You'll just work it out in the field. I mean in a plan view you would just move the magnet over, and you would make some general adjustments on how it will work. In 3D there is so much that you have to design.

In the conventional approach you would just do some "as built" drawings.

Tools for the future:

25. **Does HerreroBoldt take part in any innovation/research projects regarding BIM modelling and Lean Construction?**

Definitely!

We teach a bachelor level course in Madison Wisconsin University on Lean.

I teach CBA.

On BIM I know we have done a presentation on a 2PSL meeting.

26. **How would you like to see BIM and Lean construction being applied in the future?**

I don't think that we have completely figured out Lean for construction, I think it is a big challenge yet. I thing we owe a lot to Glenn Ballard and Greg Howell. I think the Last Planner is a true adaptation of lean in construction, it has so many of the elements in there, it is all about the promising and improving the flow so that is one aspect. I think what I see happening is if you are in a Toyota environment, a company that is focused on doing Lean and they have been doing it for decades and their suppliers do now also have the philosophy and culture things work. In the construction situation you have so many transient personalities and the projects break up these teams, I mean this project is going to go on for years, but most construction projects are not like that. They are much shorter duration, and teams constantly get broken up, now it would be good if all those teams were trying to do Lean, like Boldt is trying to. Boldt believes that by moving round between jobs you actually get better at Lean.

, I think it is pretty tough to get Lean into construction. You go from being on a Lean job site to a non lean job site, which make it hard to have continuity about it.

One of the things that you learn by applying Lean is that the hierarchy is flipped from traditional; we are all here to support the guy who is doing the final installation. So it requires a different type of project managers, the traditional manager is a very strong minded type who wants things to be done in his way – giving orders.

The Lean manager is different, you still need to have the vision and the authority and the foresight to know how you want it done, but the way you implement it is through gemba walks, and asking Socratic questions, help people making them feel good about the things that they do and the way that they are doing them, and just support how everyone does their job, it is just a different philosophy. The leadership is there to support. Secondly you need a lot more Lean leaders because the leaders are there to answer questions and make them (the workers) solve problems. You don't have that in a traditional construction project.

Processes for the future:

27. **What do you see as the synergies between Lean Construction and BIM?**

If BIM helps produce better flow, then there is a very strong potential synergy there, so that is BIM helping Lean.

What is interesting is that Lean is a philosophy and BIM actually has an output, BIM produces drawings that you build from, so during the design stage Lean is supporting BIM, which is then supporting Lean production later on. It is kind of a cycle or maybe it is two different Lean systems, one of design and one for construction and the BIM's come in the middle.

I would say that the most important synergy between Lean and BIM is the flow. Lean construction enables you to organize the flow, compare to the conventional flow where things just happens

28. **How do you see the future for BIM and Lean Construction?**

We have a vision that a construction worker can go over to a screen and pull up a drawing in a 3D model that tells him what to build. What I don't know yet is whether that really will be better. I have a lot of hope for it because I have watched superintendent many times taking the 2D drawings making his own hand sketches of what it says, and then carrying his own sketch out in the field to do the work.

29. **What are the barriers which keep companies away from applying BIM and Lean construction?**

The biggest barrier is simply to believe that it is better, than the conventional way.

Appendix C Interview with John Mack from HerreroBoldt

Question frame regarding:

HerreroBoldt Knowledge sharing and communication with their trade partners.

Tools:

1. **Which IT-programs are used by Herrero to handle (drawing material), time schedule, economy and related information's regarding the Cathedral Hill hospital?**
   AutoDesk products, Naviswork, Bozzer, Office.
   Revit Architectural, Revit MEP, AutoCAD Architectural, AutoCAD MEP, AutoCAD, NavisWorks Manage, NavisWorks Freedom, Autodesk Design Review, Autodesk DWG TrueView, Google Sketchup, Autodesk Buzzsaw, Primavera, Solibri, FreeMind and Gotomeeting

2. **How does HerreroBoldt apply BIM?**
   When I think of BIM, I think more of the information than building and modeling. We are not using a lot of the information in the BIM model because it is coming in too late for us.

   In the beginning of this project we sat down and brainstormed our ambitions for this project, we talked about 3D special coordination, 4D production planning and schedule planning, 5D putting cost into it and we talked about Lean tools in our vision.
   We thought that we were going to do it all, as we made the vision. When we started to bring team members on, we realized that a lot of the teams were lacking the expertise that we had expected and we realized that if we went after everything we would fail in all of them. So we kind of stepped back and said well 3D is the low hanging fruit that has the best return of investment so let's really concentrate of spatial coordination. We have the information to do the spatial coordination and it is actually working quite well so this is where our emphasis is right now on CHH.

   Regarding 4D we are still struggling where everybody is using different software. It will therefore be a very time consuming job to attach each of these models to line in a sketch up. I don't believe that I could put down a crew big enough to stay up with the changes from all the models.

I don't see a Master schedule being put together, but I see us doing it for congested areas such as simulation for instance. I see 4D helping our productivity but at this time I don't see an entire master schedule in this project.

5D we are using the information in the 5D to take quantity takeoffs. Meaning that we are in the trade partner agreement IFOA, where each company is responsible for putting together their own numbers. It is not a typical job where the general contractor is gathering all the information and doing check numbers. HerreroBoldt is not checking the sheet metal numbers, the sheet metal guys gives us their numbers and we just trust it and compile the numbers and keep track of them. We were looking at walls early on, and then KHS&S came on and now they are taking care of the walls. So the only thing that HerreroBoldt does regarding costing is when we don't have a trade partner on board and assembly of all of the trades to produce the combined budget.
We can get schedules and quantities out of the model but, we don't have an automated 5D program that is reading directly to the model. We have an intrum where we take a schedule and we are doing handins where we are using On-Screen Takeoff, (http://www.oncenter.com/products/ost/).
We are actually taken lessons learned from this project regarding the wall with us to the St. Lukes project. So that they can build the wall families correct earlier on, and we are hoping to leverage the model sooner than what we did at CHH. In our first models in CHH, all the walls were the same no matter what they were according to thickness and height. They were all listed as the same so when you did a schedule takeoff you got the quantities you had of however many liners feet's of one type of wall. The model is different now they have it all broken down and have families for each wall type.

3. **How does herreroBoldt apply Lean construction?**
   I'll tell you when we get to construction.
   Here during the design we are using aspects of Lean. We are using Last Planner and reliable promises' that is probably the most widely used tool. The behavior of Lean I believe is on this project from almost everybody that I have talked to.
   We are studying The Toyota Way in study action groups. Bringing people in from the 2PSL. Lab. The philosophy of open sharing is here with incomplete information and all that type of stuff.
   We are doing value stream mapping etc.

4. **How is the communication between and their trade partners?**
   On this project it is good, and through collaboration we have cut various obstacles, such as noise problems regarding the design of the waste pipe lines. Initially I think that it was cut due to the BIM design but it was brought forward in the Lean implementation, because the Lean implementation allows them to speak forth and get an issue addressed and BIM backed up that thought. When we get into our weekly work plans and meetings and someone says we have a problem, something is not working, you have to revisit this part of the building, With the visualisation that BIM can provide they will understand the issue easier.
   The problem with the waste pipe line I believe would also have been cut, if only BIM would have been applied, but not until later and then the cost of changing the problem would have been much higher, and in worst case it would have been too late to do anything about it.
   This is where Lean comes in and this is also how I look at Lean. Lean brings in the contractors earlier on board as compared to a conventional project.

Processes:

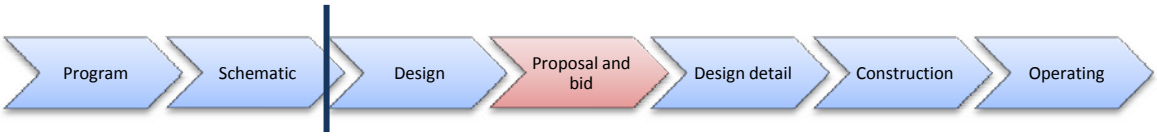


Figure 48 Building process

5. **When do you think is the right time, see figure 1, to engage contractors and subcontractors**?
   I would say bring them on sometime between the middle and beginning of design, but only for constructability review not to draw anything just to make sure that the designers are designing something that can be actually build. And are drawn or modelled the way that they want to build it.

6. **From a contractor's point of view, what advantages do you see by applying BIM?**
   Predictable planning, consistent workflows, reliability, commitment, safety and better scheduling.
   As a contractor we want to minimize our time on the floor, which depends on predictable flow of people and material. We actually tracked that on a previous job. We had each contractor to say the amount of work that they were going to do, during the week. The superintendant for each trade would come into the office each day to mark what they actually installed.

7. **How has the application of BIM changed processes in the building industry?**
   I believe that the contract can influence the BIM process and help it. BIM is still a benefit if the contract does not have it in there. My most successfull job in the past was a project that was supposed to be one of the first IFOA's contracts but it never happened. Everybody however behaved in a manner of working together in a very Lean environment and that was a very fruitful and productive job for everybody. Everybody came in under budget, the entire job came in 10.000.000$ under budget and 6 month ahead of schedule and that was not an IFOA contract or an IPD contract. I therefore believe that behavior of the team can have just as much or more influence than a contract. People use a contract as an escape gate.
   The opposite can also happen that you have an IFOA contract but the people involved just do not have the right spirit.

8. **What are the advantages of Working in an IPD project? Can an IPD project work without Lean and BIM? What do you see as the best way to contractual facilitate a BIM project?**
   The advantage of working in an IPD project is the collaborative environment.
   IPD projects can work without Lean and BIM but they definitely add to the success of it, I still think that having a collaborative environment in a traditional contract with 2D drawings in an IPD world would still have a positive impact. I have never been involved in one, but I just imaging that just having the job setup for communication, is going to make it better. And I believe that because it is setup for communication. What is probably going to fall out from such a project is a Lean and BIM environment anyways.

   I think that collaboration software needs to be stated in the contract and that everybody needs to have it.

   Regarding the management it depends on the expertise in the team, who is going to manage the team. Traditional it has been the mechanical contractors who have managed the BIM, just because they have had the most experience, they have been doing it the longest, so they that usually led the BIM type stuff, while now the contractor is seeing it and starting to take vent of that and now they are coming to lead, which I think is right.

9. **How does the coordination of utilities happen in interior wall systems?**
   Coordination of utilities happens when the time is right. The trades will draw the drops into the walls. A good example is the headwalls in the patient rooms which has

different connection that needs to happen there such as electrically, gasses, and stuff like that for the patient. So we draw the unit in the wall, and we are actually drawing the utilities that are coming down that wall, and we put all the studs in the wall, and make sure that things are not conflicting with each other. We are doing coordination and clash detection in a wall no different than what we would do above ceiling. The matter is drawing it, and drawing the outlets on the wall in the correct location. Looking back at The Camino Medical Center we did not draw the things on the wall, and it was a huge dollar impact back to us, because what happened was as we came to the electrical outlets on the walls they were behind pieces of equipment or pieces of furniture. If it would have been drawn or in their scan of the model it would have been caught, but being that they were not drawn they were not caught being in the wrong location until after installation. So everything had to come out, and it was costly to fix that, so lessons learned as we move forward was that we have to coordinate things around the walls such as switches, thermostats, and outlets etc.

10. **How do you design and sequence interior walls? (Has BIM and Lean construction had an impact?)**
Sequence of interior walls, what we did a Camino was that we used the NavisWorks to sequence the walls.
We had the drywall contractor come in, in stages. We would not allow him to keep material on the floor. On a typical project floor, you would see piles on the floor of sheetrock and studs and they would get in everybody's way and constantly making everybody having to move around them. All the material for the wall construction were delivered using the "Just in Time" method where material are delivered the day they are to be installed. So instead of that we sequenced the walls for installation, they came in and did what we called out as tier 1 priority walls.
The drywall contractor build the walls in three batches during construction; tier 1, tier 2 and tier 3. A tier 1 wall wall is a full height wall that has MEPF located close to it. Too close to sheet rock if the MEP was installed. These walls are framed, sheet rocked at the top 4 feet and fire taped before the MEP installation. A tier 2 wall is a full height wall that would be in a main hallway or lobby area. Tier 2 walls are done after the first wave of MEP and are just framed. Tier 3 walls are any remaining wall and are done after the MEP overhead is complete. The cost for the drywall contractor is higher than normal, but the accumulated cost for the MEP trades on the installation was almost 5 over with what the extra cost was for the drywall contractor. It allowed the MEP trades to work on lifts longer not transferring over to ladder's. this combined with "just in time" delivery of materials keeps the floor cleaner. So there were a lot of advantages to it, so wall sequencing to me is very major.

11. **How has the application of BIM and Lean construction influenced the impact of changes late in the process?**
    Well we are still getting changes, but BIM and Lean are allowing people that are receiving the changes to say and show and explain what the impact to them is before any work on the change happens.

Tools for the future:

12. **Does HerreroBoldt take part in any innovation/research projects regarding BIM modelling and Lean Construction?**
    2PSL
    Lean Construction Institute
    NorCal Virtual Builders (aka Virtual Builders Roundtable).
    San Francisco Digital Design
    Center for Integrated Engineering (CIFE)
    Teaching a various universities.
    Multiple things
13. **How would you like to see BIM and Lean construction being applied in the future?**
    I think as we move forward more tools will become available and the programs are going to get easier to use. And more interoperability among the different platforms.

Processes for the future:

14. **What do you see as the synergies between Lean Construction and BIM?**
    I think that they are tools of each other; BIM is a tool of Lean and Lean is a tool of BIM. I think that they actually help each other along.
    One of the main principles of Lean is to removing waste, and if you think of the waste that are out there then BIM actually helps eliminate some of those wastes. So it stream-lines your process, it allows people to think better and quicker. The visual aspect of BIM allows you to make better decisions on you design as you move forward to construction. In the return, as we are doing this things giving promises to each other the tools of Lean allows us to track those promises and making sure that people are staying on track with the things that have been delivered on time. We have checks and balances, so we know when we are slipping in schedule; we know when we don't have enough information available to make a decision.

If you look at Revit as an example, you can carry multiple design sets in one model and drop one of as you go forward. So the tools are definitely a help there so you don't have to do 5 separate models you are doing one model with 5 options so that you can do correct comparisons.

15. **What are the barriers which keep companies away from applying BIM and Lean construction?**

Revit is a great design tool, it is probably one of the better ones but it is still not good for construction it is still lacking a lot of information. On the construction side they are still using what is known and proven, which is the AutoCad platform. They are throwing 3rd party programs on top of AutoCAD, such as CadMech and CadDuct and all that stuff. They are using what is known and proven. These software have customizable libraries in them. They also have estimating and automation of part cutting in them, which allows the companies to get their whole production planning out of them.

I don't see in the immediate future jumping up to Revit on the construction side even if Revit solves the problems and gets the contracting tool in there. There is so much money spent by the larger companies, with what they got in databases and libraries and years of putting the stuff together using the 3rd party AutoCAD software. I mean I'm thinking of the two companies that I use to work in for how many millions of dollars each company invested in the software. It is going to be very hard for them to jump to a new piece of software, when what they have work's fine for them.

Appendix D Interview with David Lim from KHS&S

Question frame regarding:
KHS&S's Knowledge sharing and communication with their trade partners.

Tools:

1. **Which IT-programs are used by KHS&S to handle drawing material, time schedule, economy and related information's regarding the Cathedral Hill hospital?**
   AutoCad, Revit, strucsoft, Navis, Excel, Word, Outlook, Onscreen take off, Penta (project management)

2. **How does KHS&S apply BIM?**

   It is still evolving for us; while a lot of the other trade detailers, especially the MEP guys have been using similar processes for a while now. As a framer or a framing company we have come into it and we have hit the ground running and luckily we are staffed by mostly architects, which means that we are coming in(to this digital world) and looking at the whole thing and are positive about what we see. The tool is actually much more than just coordination as we thought as we looked at it in the beginning.
   Now it is evolving into a lot more powerful tool, as we see a lot of the programs starting to overlap and even integrate.
   We do want to grow into 4D and 5D with all this applications which go down into reduce waste by having cut length defined, increased productivity, having kits established etc. all seems very appealing to us.
   Also, the opportunity to monitor productivity from the distance is considered an advantage. Tags can enable the monitor to see how the installation is progressing.
   Another side effect, but very effective side effect is that the IOR (the inspector) can come to such a tag, slide his phone over the tag, and it will bring up locations of all the associated information UL, EG and hilty information details. We can even show proofed documentation from OSHPD right on the spot into his phone, so it eliminates the hassle of having to go somewhere to make a phone call etc.

3. **How does KHS&S apply Lean construction?**

   Various ways I suppose, like looking into productivity mechanisms that we can extract. All this coordination work that we do, make us end up with a boat load full of information's and then it is like "how can we best use it"?

I think the way we use Lean is the way we are trying to fully utilize the capabilities that we have, compared to just use bits and pieces.

Processes:

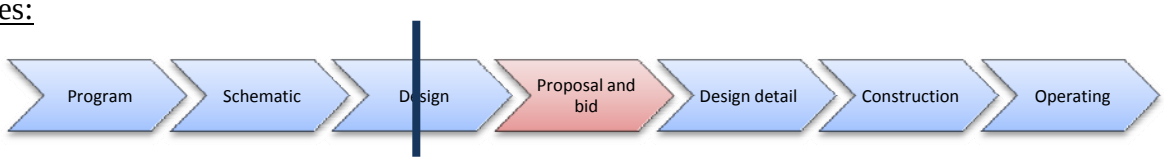


Figure 49. Building process.

4. **When do you think is the right time, see figure 1, to engage contractor and subcontractors?**

   I think the right time to engage subcontractors is at the end of schematic design, just before design development. In the design development the architects begin to do the detailed design, where they might not know all the construction details, and therefore unintended incorporate design errors, that we, with our knowledge can catch and do right.

   In this project we were engaged in the middle of the design development, so we were engaged at an appropriate time I suppose, but a little earlier would have been fine too. Specially with our particular trade, because we have so much to do with the design and the architectures that it is good to have our knowledge up-front, because you could alleviate a lot of rework down the line for things like seismic joints etc.

5. **From a contractor's point of view, what advantages do you see by applying BIM?**

   Rework, but that comes down to **money** and **time**.. BUT **MONEY** is the key word. Reliability and quality are also positive advantages.
   When 4D becomes a reality I can see how BIM also will have an influence on safety, but as things are working today, I don't see BIM having a huge influence on safety.

6. **How has the application of BIM changed processes in the building industry?**

   It is pretty significant, but again still evolving for us.
   Traditionally the coordination was done in construction.
   We did our layout drawings, basically a dimensioned floor plan, that the trades would use to slive into cavities and things like that, which is also what is going to happen here. All the trades are going to use our drawings, because where we are drawing the walls are where we are going to build the walls. When they have embedded stuff into the cavities, it just make sense that they are using our drawings.

In the 2D world, drawings were used for this kind of documentation, and only in those areas (an issue point) the architect would have indicated as zones requiring more attention would be at the level possible coordinated during the design stage (it was done with overlaying overheads).

7. **What are the advantages of Working in an IPD project? Can an IPD project work without Lean and BIM?**
   It is an integral strategy; I mean how and why was IPD developed? The core concept for the development of IPD is based on the Lean philosophy.

8. **How does the coordination of utilities happen in internal wall systems?**
   Architects do the first sketches and then we apply MWF, and then we input the 3D information and then put it into the Navis model and then we go through coordination, and make adjustments. This is the same process for all trades, they are originally making their drawings based on the architect's drawings and then when we go into coordination they change to our drawings.
   On this job there is no fixed time for coordination iterations, which means that clash detection is happening when someone want to see whether they clash with someone else who might be in that certain area.
   You need a strong facilitator on behalf of the owner or the GC to say "what's the most economical in a broad sense for the projects and force the different trades to do clash detection more often I think".

9. **How do you design and sequence interior walls? (Has BIM and Lean construction had an impact?)**

   We have been working with strucsoft for well over a year now to develop their product. They have created a program, and we are testing it and coming across all these intricacies that they cannot see, because they are not framing.
   We looked at Tekla as an alternative to strucsoft, but Tekla, was too detailed, to what we need for our purposes here. Strucsoft gives us just the right amount of tools and flexibility that we need to implement this BIM concept, and we are actually maybe only using 20-30 % of strucsofts capabilities. We can get information on each individual stud and sheetrock, and through that do material count etc. The information about each individual stud can be sent directly to a milling machine, and then that machine produces exactly that stud. So the software is already there, it is the mentality in the building industry that is holding the development back, so to speak.

   We can take the strucsoft model and get individual panels, so we can create individual panel layouts, cut length, and penetration locations. Basically what strucsoft does is that once we frame out a wall (including studs) it reads the profile

and then we can actually export that into our rolling machine/a milling machine that looks at that and determines that this is a 14 feet and and then that would split the corresponding amount of studs out.

The backing issue is still not solved, but it has certainly been discussed. What has happened is that they have taken the tool they use to do the headers and they have tweaked it to allow us to place a horizontal member within the field of the wall. It is a little awkward right now because we do not have a lot of control over length stopping and starting of pieces in a wall. Right now you can only do like one piece one length independent whether it is the whole wall or if it is a piece of the wall, you can only do one piece.

Strucsoft recognizes a certain wall in the architectural model that it connects to a tag that KHS&S has designed for their specific wall types. That connection has to be manually mapped between the wall types that the architect is designing and our own wall types. So every time that we click on a wall it reads the family name, and recognizes that this type of wall is connected to a certain type of structure and that this type of structure needs those particular studs to frame that wall. And then the studs can be precut. This approach is almost actuating itself to 50% pre-manufacturing, and that does not quite happen yet, but that is our goal, which we would like to eventually reach. We would like to use such a penalized system. A kit basically for every wall where it comes pre-packaged, comes cut to certain length with all the bits and pieces that you need to assemble a wall, it's raped it's labelled, tracked, delivered and ready to get installed.
The reason why we are not there yet is not software limitations it is a mental limitations, it is like the IPD process, there is a lot of buzz, things are happening, but before any of this projects really got kicked off and really experimented with, people don't really want to try out new things and especially in construction – New is not good in construction.
It comes down to a management issues, we do not know whether we are going to fall flat on our faces and we do not want to risk it.

The next major issue with the BIM world is that a lot of data has to be put into the system; it is no longer so much about developing the programs, it's more about getting the right information in there.

10. **How has the application of BIM and Lean construction influenced the impact of changes late in the process?**

They are more heavily scrutinised, because everybody is under that impression that you should have caught that earlier like a year ago, so that's one aspect, and another aspect is that you should have significantly less change orders.
I think that owner related changes (scope change) also can be embraced easily, but that has more to do with the environment of change that we are currently working in. I mean we are in this whole IPD process, we are more used to changes and we are definitely more flexible. In the conventional approach everybody designed to an architectural plan, and as long as the changes were small; no problem, but larger changes would just make the hands go up(stop the process, no one would listen).
It is this kind of mentality that the IPD process is changing, the feeling of not really wanting to change does still exist, but it is much easier on this job.
Secondly, before you signed up for this particular contract you signed up for this certain level of flexibility with coordination of work and rework. I think that this approach opens everybody up to be susceptible to change.

Tools for the future:

11. **Does KHS&S take part in any innovation/research projects regarding BIM modelling and Lean Construction?**
    We work with Strucsoft, on the development of their software.

12. **How would you like to see BIM and Lean construction being applied in the future**?
    I would like to see it more going in the direction of a production manufacturing style, with the 4D and 5D, that is really uncharted territory, where I think the biggest gain are going to be made. During the current process we are saving money, we are doing what we need to do, but at the end, if you look at it as a whole, we are going to get more out of that back end of the process that you are at this up front process. Obviously, we lay the foundation up here in the front and that is extremely important, but to take everything that we are doing and put it and translate it into this other idea of construction habits. I think when that starts to happen, you are really going to see leaps in our industry.

Processes for the future:

13. **What do you see as the synergies between Lean Construction and BIM?**
    Coordination in BIM really holds a lot of Lean values.
    Decreasing error rates/minimizing waste.

    I think it is a bit choppy right now; the BIM technology is somewhat to that level where 3D,4D and 5D can be applied which puts itself into the Lean category of processes, sequences, and activities and things like that.

Last Planner works fairly well up to a certain point, because coordination is not quite as an immediate thing where you wait to the last minute, and then all of a sudden everything is wrong and then you have to go back and change everything.

Did you do point based or set based design?
In some perspective we did set based design, but when it comes to several alternative solutions for the 10th floor, then we did not. We are so tightly connected with the architects that we become reactionary we are not really designing in that respect we are waiting for issues to happen, and then we take it and then we model it.

I think that BIM and Lean Construction are integral, I don't know if one can do without the other or if one really exist without the other. I mean you can do BIM without being Lean about it; you can just do a model and be done with it. Then you just would not get the most out of it. The Lean concept it is almost a broader look at BIM, because it was conceived of as a tool to simplify and increase productivity and that is basically Lean. So it must be germinated from a Lean philosophy, and that is why I say that I don't really know if one exists without the other. You can use it however you want to, but really to use the strategy and the development of BIM not just as a tool but as a process, then that comes from Lean.

Maybe those who invented BIM did not know about the Lean philosophy itself, but the two concepts certainly have overlapping philosophies.

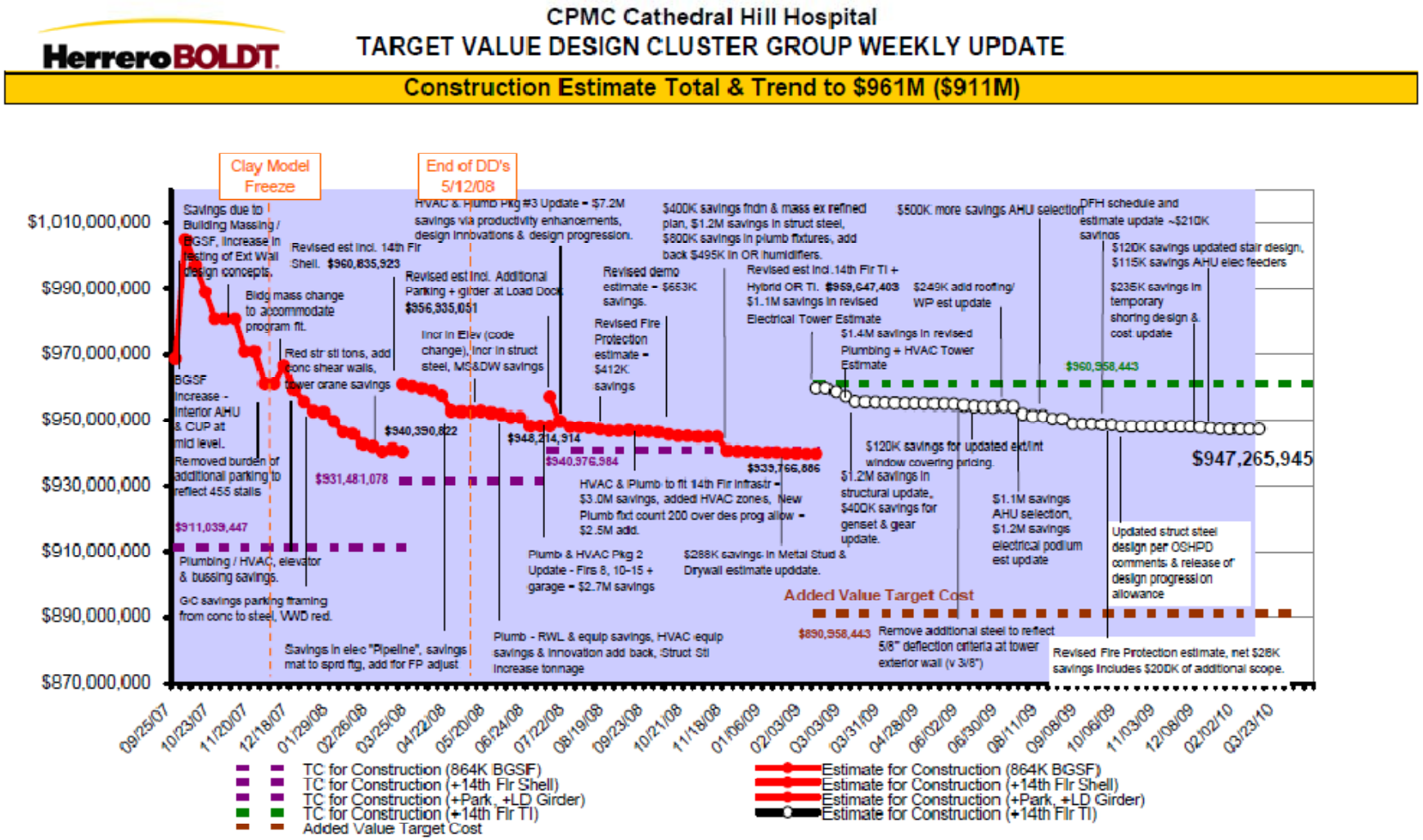
It is an interesting perspective to use the Lean philosophy as a guideline for better integration and implementation of BIM.

14. **What are the barriers which keep companies away from applying BIM and Lean construction?**

Fear for the unknown, the theory is proven in manufacturing but not in construction. The theory has not been vetted for construction. So people are afraid and I see this from border to border in the US, there is a lot of resistance to change.

15. **What would be the optimal way to design and sequence interior walls?**
Like a blink with the eye. No really 4D and 5D are going to be the killing aps. You will be able to do real estimates on the lifecycle on a project.

Appendix E Target Value Design at CHH



Appendix F Companies involved in the Cathedral Hill Hospital

IFOA Team
CPMC
SmithGroup
HerreroBoldt.

Consultants
DagenKolb Engineers
Silverman and light
Ted Jacobs Engineering group
Treadwell and Rollo
Orange Blade Consulting

Trade partners
Pankow builders
Malcolm General engineer
Ferma Corporation
Ryan Engineering
Rosedin Electric
Southland Industries
Bagatelos Architectural Glass
Herrick Steel
Olson Steel

KHS&S contractors
ISEC
Otis
Pacific Erectors
RLH Fire Protection
DIS
Fuel Oil Systems
Advanced Pneumatic Tube
Rescue Air
Ad-In Inc
Capital Engineering
The Lawson roofing
Tractel Inc.
MRI Corporation