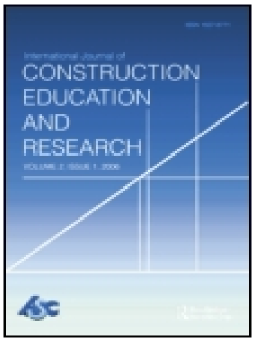

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Learning from the Cathedral Hill Hospital Project during the Design and Preconstruction Phases

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This article explores opportunities and limitations of implementing and experimenting with Lean Product Development ideas and practices in the design and engineering of a complex hospital project. In this environment, new forms of contracts have given rise to new forms of organizing teams to deliver capital projects in which architects, engineers, and contractors are co-located to promote collaboration and deliver projects with a strong focus on clients' needs. The Cathedral Hill Hospital (CHH) project is a 1.2 million square feet urban replacement hospital in San Francisco, California. It is not just designed to be a state-of-the-art hospital but also to break new grounds in multiple areas of design, construction and operations. Since the beginning of project validation in 2007, the Integrated Project Delivery Team has been applying and testing Lean ideas, concepts, tools and processes to develop this very complex project. The article's nurturing proposition is that CHH has implemented most principles related to the Lean product development system at Toyota, and that these principles are the foundation for the evolving operational system that supports its processes on a daily basis. The article contributes to the literature by providing an account of how different processes worked in a co-located environment.

Keywords information flow, Integrated Form of Agreement, leadership, lean, learning, product development

Introduction

The Cathedral Hill Hospital (CHH) project in downtown San Francisco, California, has received considerable attention since its beginning in 2007 due to the implementation of novel ways to develop capital projects in construction (e.g., Parrish, Wong, Tommelein, & Stojadinovic, 2008; Hamzeh, Ballard, & Tommelein, 2009; Nguyen, Lostuvali, & Tommelein, 2009; Rybkowski, 2009; Nguyen, 2010; Heidemann & Gehbauer, 2011; Lee, 2012; Zimina, Ballard, & Pasquire, 2012; AIA, 2012; Hickethier, Tommelein, & Lostuvali, 2013). The project achieved notoriety after the team of professionals designing the project

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was co-located in a single floor of a building and started implementing a host of concepts, processes, and tools proposed by scholars of Toyota's Lean production system. This arrangement was promoted by the innovative contract adopted by the project owner and described by Lichtig (2005) as an Integrated Form of Agreement (IFoA). The IFoA promotes the use of Lean Construction principles and tools to manage the project from the design stage, as well as creates conditions for the teams to share rewards and risks while working together to deliver the best value for the client.

In February 2012 in an event co-promoted by the Project Production Systems Laboratory (P2SL), the Lean Construction Institute, and the American Institute of Architects at U.C. Berkeley, professionals questioned how those involved with the CHH co-located team could return to their organizations and try to change the way projects are designed in the construction industry. The discussion presented in this article is an attempt to document how the product development system at CHH was developed and how its component parts are aligned with principles related to a Lean design process. Much has been written about CHH and the current design and construction of complex hospitals in the strict environment of construction projects in California; however, to the authors' knowledge no article has discussed details related to their product development system as a whole and how their systems relate to Lean principles.

One of the article's nurturing propositions suggests that the operational system to manage a Lean product development in architecture, engineering, and construction (AEC) projects has not been fully developed. This would make it harder to replicate experiences like CHH's and for that reason this paper aims to explore some important yet not properly explored points related to the topic. A phrase attributed to W. Edwards Deming emphasizes that, "If you can't describe what you're doing as a process, you don't know what you're doing" (Morgan & Liker, 2006, p. 336). With that in mind, the authors aim to contribute to this discussion by analyzing the product development process at the CHH project, the challenges facing the team during their implementation, and contrasting the practices used at CHH with those used in the Toyota Product Development System (PDS) as described by Morgan and Liker (2006). It starts with a brief review of the Toyota PDS, followed by the implementation of Lean Construction concepts and processes to the PDS in AEC. To conclude, a discussion is presented of the PDS at the CHH project, their relationship to those in the Toyota PDS, and how they form the basis for the evolving operational system that supports its processes on a daily basis.

Research Method

The article was developed mostly based on the observations of two of the authors who were senior project managers (PMs) at CHH during its preconstruction phase, on a site visit by the academic author, and numerous discussions between the three authors. The senior PMs had direct access to data and examples that are shared herein and no special tools or methods were required to obtain evidence to document practices used. A literature review was conducted to identify peer-reviewed studies that have documented the work at CHH and explored multiple components of its PDS. The published studies were also used as a means to validate the discussion and examples presented, which aim to discuss the entire system as a whole and not only in parts as presented in the existing literature.

The goal was to study and learn about this specific (pre-selected) case due to its intrinsic value without having necessarily to explore a research question (Stake, 1995). Additionally, the intention is not to use the study with the purpose of generalizing the findings, rather it centers on describing how different parts of the case come to life as a whole and how they can be linked to overarching principles related to the Toyota PDS. Stake (1995, p.4) highlights that "*(c)ase study research is not sampling research. We do not study cases primarily to understand other cases. Our first obligation is to understand this one case.*"

Finally, a framework to analyze the numerous innovative methods and tools used to design the project was developed using Morgan and Liker's (2006) work. Other books have addressed Toyota's PDS in broad strokes (Schonberger, 1982; Womack, Jones, & Roos, 1991; Liker, 2003), however, this particular reference was chosen given the importance that it had during the authors' work at CHH and its level of detail regarding the principles exposed. The book was used by the two senior PMs to inform their work and guide how different practices implemented made sense together. It also provided a compass and, to a certain extent, validation for the work they were developing with the entire team. This choice is also supported by at least one other study, which proposes a workshop model to organize design activities to generate value in AEC projects (Thyssen, Emmitt, Bonke, & Kirk-Christoffersen, 2008). Thyssen and colleagues' model uses the Toyota PDS as their basis for discussion and also relies on Morgan and Liker's book extensively. However, their model emphasizes the notion of partnering in the beginning of the process but does not discuss details about how the process is to be managed along the way.

Lean Product Development

The management of the product development process differs from the management of manufacturing in many different ways, which must be addressed when one tries to apply Lean concepts originated in manufacturing to design. In design, the flow of concern is that of data, this flow is often iterative as participants exchange information back and forth before proceeding with their tasks, the product of each process might not be as specific as in manufacturing, and multiple information outputs have to be identified and managed. The temporal measure for the product development stream is weeks, months or years and the group tends to be more diverse than that of a manufacturing value stream (Morgan & Liker, 2006, pp. 314, 322). Additionally, the design process can be understood as a "wicked problem" (Whelton & Ballard, 2002). Stakeholders developing the design have to gain a solid understanding of each other's needs so that value is incorporated in the evolving set of solutions in constant change as professionals work to comprehend problems to be addressed.

In the AEC industry, Lean design has received considerably less attention than production/construction related topics (Koskela, Ballard, & Tanhuanpää, 1997; Alves & Tsao, 2007; Jorgensen & Emmitt, 2009). In fact, the literature lacks a clear definition of what design management entails (Emmitt, 2010), and also what Lean design and Lean design management means (Jorgensen & Emmitt, 2009). Emmitt (2010) reviewed different streams related to design management and emphasized that this is an emerging field where even those with the designation of managers differ in what they do, schools do not teach design management as a discipline, and companies do not usually share what they do.

Given this context, there are some notable exceptions of general contracting companies in the United States that have allowed broad documentation and publication of their design process and management methods including but not limited to Boldt (Ballard & Reiser, 2004), HerreroBoldt—joint venture (Parrish et al., 2008; Nguyen et al., 2009; Rybkowski, 2009; Nguyen, 2010; Zimina et al., 2012; AIA, 2012), and DPR Construction (Alarcón, Christian, & Tommelein, 2011). These publications, like the present one, contribute to enhancing the understanding of what Lean design means in the AEC arena while a formal and definitive definition is not available.

Lean Product Development at Toyota

Morgan and Liker (2006) define the basis of the lean product development at Toyota as a mutually supporting system composed by process, skilled people, and tools and technology. Table 1 presents a list of the 13 principles that guide the product development at Toyota. These elements as presented in their book are discussed in this section.

The Process element is marked by a definition of value from the customer standpoint to guide the entire process. A Chief Engineer (CE) is appointed to guide the team, but before work can commence the CE has to walk in the customers' shoes to gain a deep understanding of their needs. Much effort is put in planning the process and evaluating multiple solutions to deliver the product, "(p)lan carefully and execute exactly" (Morgan & Liker, 2006, p. 40) summarizes that drive. Additionally, module development teams (MDTs) responsible for subsystems work towards developing measurable goals which are communicated to the CE team to assure that all participants understand the project's goals and avoid conflict and confusion. The CE by default has to possess deep knowledge of the process to guide team members and to understand what is needed and when. Along these lines, value stream maps (VSMs) are used to better understand processes, its resulting products and milestones. Another important element is the use of standardization to allow the use of common parts across different cars; to make explicit skill-sets required from team members and major work streams and tasks that support the product development.

In the Skilled People element, it is important to have the "Right Person, Right Work, Right Time." The CE has to understand the complex network of relationships, from beginning to end, and be able to define specific work streams that deliver specific results at the end of the day. This is not an easy task as members of the product development team might perform work independently while at the same time being highly dependent on the work of other team members. Thus, engineers work in a matrix type of organization in which they report to a functional general manager and to the CE managing the development of a specific car.

This organization form combines the focus on the expertise necessary to excel at the function level without compromising the goals of the specific product. Suppliers, chosen based on a long process to demonstrate expertise and ability to meet Toyota's requirements, are integrated into teams and engineers are exchanged between suppliers and Toyota to promote cross-learning. Engineers are selected based on technical expertise, receive extensive training and are mentored by senior engineers in "freshman projects" before being in charge of their own projects. This is in line with an overarching culture of learning based on go and see, reflection, building consensus over time, and learning from failures.

The Tools and Technology element's role goes beyond just a group of tools aiming at waste elimination and value generation. It relies on the complete integration of tools and technology with people and processes in multiple stages of the PDS.

Lean Product Development Concepts Applied to the AEC Industry

"*It is not an exaggeration to say that the management of design and engineering is one of the most neglected areas in construction projects. Findings from research unanimously indicate that planning and control are substituted by chaos and improvising in design*"

Table 1. Product development at Toyota (after Morgan & Liker 2006)

	Principle	Supporting characteristics of the system
Process		
1	Establish Customer-Defined Value to Separate Value-Added from Waste	Establish an emotional connection with the customer, walk in customer's shoes, training to evaluate vehicles and identify opportunities for improvement, Chief Engineer (CE or *Shusa*) concept paper outlining the vision for the product.
2	Front-Load the Product Development (PD) Process to Explore Thoroughly Alternative Solutions while there is Maximum Design Space	"Plan carefully and execute exactly" (p. 40), creation of several study drawings (*Kentouzu*) by Module Development Teams (MDTs) during the *Kentou* phase (study phase of a program), set-based concurrent engineering to evaluate multiple alternatives simultaneously, isolate and minimize variation trough standardization and platform planning.
3	Create a Leveled Product Development Process Flow	Value Stream Mapping (VSM) used to visualize work streams and expose waste. Manage capacity, stabilize value streams. "Process logic determines who will do what and when" (p. 82), defines what PD teams need to deliver in specific milestones creating accountability.
4	Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes	Design standardization (product/component design and architecture). Process standardization (tasks, work instructions, and sequences of tasks). Engineering skill-set standardization (capabilities across teams).
Skilled People		
5	Develop a Chief Engineer (CE) System to Integrate Development from Start to Finish	The CE is viewed as the "Heavyweight Project Manager" . . . "charged with the success of the design, development, and sale of the car."(p. 118) and "the CE is the *voice of the customer*." (p. 137).
6	Organize to Balance Functional Expertise and Cross-functional Integration	Combination of functional and matrix organizations, engineers respond to a functional general manager (e.g., engine, body) and to a product planning CE (families of cars, e.g., Camry, Corolla) The *Obeya* room (big room) to schedule tasks and discuss solutions proposed by different MDTs.
7	Develop Towering Technical Competence in all Engineers	Go and see engineering. "Freshman project" assigned to new engineers to learn the Toyota Way. Engineers must be connected to the user and the products they develop. Detailed selection and mentoring process to develop competencies.

8	Fully integrate Suppliers into the Product Development System	Partnering with *Keiretsu* members. Careful selection and development of suppliers through a detailed process. Guest engineer program to promote integration.
9	Build in Learning and Continuous Improvement	*Hansei* (reflection) events: personal, real-time (at major milestones), post-mortem. Held frequently, close to the events, open dialog. Resident engineers exchange between partners in the PD, supplier demonstrations, competitor teardown analysis, checklists (organize knowledge from experienced members), know-how database (e.g., standards, design data and tools) maintained by users.
10	Build a Culture to Support Excellence and Relentless Improvement	*Kaizen* (continuous improvement). Customer first, Contribute to the society and the community. Defective parts are sent back to the plant to learn from failure. Managers share key activities daily with superiors, who also manage by walking around.
Tools & Technology		
11	Adapt Technology to fit your People and Process	Technologies support processes and enhance people's capabilities, are tailored to specific purposes and should be seamlessly integrated.
12	Align your Organization through Simple, Visual Communication	Visual management. Travelling *obeya* moves closer to production as the PD process evolves. *Nemawashi* (slowly build consensus), share problems with those involved in the process, prepare A3s, obtain feedback, adjust before meetings. *Hoshin* (policy deployment in different levels).
13	Use Powerful Tools for Standardization and Organizational Learning	"The focus must be on tools that help the organization change the way things actually get done" (p. 279). Checklists, know-how database, decision matrices to evaluate alternatives, *Senzu* (stamping engineering drawing with requirements marked next to the parts)

(Koskela et al., 1997). Over the past 15 years, Lean practitioners and scholars have joined forces to advance the management of design in the AEC industry and alleviate the problems pointed out by Koskela et al. in 1997. Examples of changes that occurred over this period of time include efforts to use the Last Planner® System (LPS®) of production control to manage design (Tzortzopoulos, Formoso, & Betts, 2001; Ballard, 2002, Ballard et al., 2009; Hamzeh et al., 2009), target value design (Ballard & Reiser, 2004; Rybkowski, 2009; Nguyen, 2010; Lee, 2012; Zimina et al., 2012), set-based design to evaluate alternatives (Parrish et al., 2008), design structure matrix to visualize and streamline the exchange of information (Tuholski & Tommelein, 2008), choosing by advantages (Nguyen et al., 2009; Nguyen, 2010), creative workshops (Emmitt et al., 2004; Thyssen et al., 2008), and methodologies to improve design (Freire & Alarcón, 2002) to name a few. And more recently, the advancement of design development and management has also been related to the use of Building Information Modeling (BIM) and a host of capabilities provided by this new process (Sacks, Koskela, Dave, & Owen, 2010).

Despite recent advances in the field of design management, questions remain about how to use concepts, principles, tools, and processes discussed in previous publications in an integrated fashion. These issues are at the core of the present article and the authors expect to contribute to this discussion through their own analysis of what was implemented at the CHH project and how that supported its PDS. To put this discussion in perspective, the authors reviewed the principles outlined by Morgan and Liker (2006) for the Toyota PDS in the previous section. The next section briefly discusses the LPS® and attempts to use it to manage product development in AEC.

Last Planner® System (LPS®) Applied to Product Development in AEC

In this section the authors do not attempt to cover all details that pertain to the LPS®. The goals are to expose basic tenets of the system, which was developed to manage field operations, along the same lines of the Toyota Production System (TPS), which was developed to manage production (e.g., see Nahmens & Mullens (2011) for an example of the use of the TPS to manage production activities related to precast concrete fabrication). It is worth noting that the TPS and its related product development system evolved separately, and product development stakeholders did not have detailed knowledge about how to implement its tenets to design new products (Morgan & Liker, 2006).

The LPS® was originally developed to manage site activities through the management of commitments made by those involved with construction tasks and stabilization of the flow of inputs necessary to develop these tasks (Ballard & Howell, 1994). The LPS® elegantly mimics the teachings of Taichii Ohno (1988) and Shigeo Shingo (1989), the architects of the TPS. These teachings suggest that: workers should be directly involved with the design and planning of the work; information about the production system should be accessible to those performing the tasks; "the production line" should be stopped so that problems are analyzed in detail and their root causes eliminated; variation in the flow of inputs to production should be minimized through careful planning; the work should be balanced throughout the production line; only work that is necessary to advance production should be done; and go slow to go fast, amongst others.

However, Ohno and Shingo's teachings, and later their translation to AEC were born out of shop/field operations, which are more likely to have a linear progression of tasks and obey the laws of physics and creation of space so that new tasks can be completed, that is, a slab cannot be built without placing the columns and walls cannot be built if the slab is not in place. This is in sharp contrast to activities developed as part of the design process, which are often interdependent and have constraints that cannot be resolved in an isolated fashion (Ballard, 2002; Whelton & Ballard, 2002). In one of the first implementations of LPS® to design (Ballard, 2002), practitioners pointed that the system helped them to only select assignments that would help work progress, and measured the reliability of the system with the percent plan complete indicator and the causes of problems. However, they also indicated points that have to be improved which include the need for participants to come prepared to the meetings, the need to control workflow and better define assignments, and act on the causes of problems (Ballard, 2002). Similar issues and other challenges were faced by participants when they tried to implement LPS® to CHH's design process and are discussed later in this article.

Integrated Project Delivery (IPD) and Product Development in AEC

The term IPD has gained popularity in the United States after the development of the Integrated Form of Agreement (IFOA), by Will Lichtig (2005), for Health Care owner Sutter Health. However, caution should be taken when using the term IPD as many understand it as "Integrated Project Design" with the support of processes such as Building Information Modeling (BIM). The IPD and the IFoA discussed in this article are forms of contracts, and have very distinct characteristics which promote collaboration in AEC beyond the product development phase. For a detailed discussion on IPD and its variations the reader can refer to Darrington, Dunne, and Lichtig (2009), Heidemann and Gehbauer (2011), and NASFA and coworkers (2009), a detailed description of projects that have implemented different levels of IPD in the United States can be found at AIA (2012).

The IFoA is a multi-party contract in which the project's core team (usually the owner, architect, general contractors, and major specialty contractors and designers) sign the same contract and share risks and rewards (Lichtig, 2005). Stakeholders are involved early in the conceptual stages to define targets for the project and to deliver the best value for the client. Previous research has underscored the importance of early involvement of contractors and suppliers during the design phase (Gil, 2001; Song, Mohammed, & AbouRizk, 2009; Gane & Haymaker, 2010) as they bring their knowledge regarding installation, procurement, and integration to other systems to the design process. Additionally, research suggests a strong correlation between owner influence and innovation (Gambatese & Hallowell, 2011). At CHH the owner played an important role in the way the team was assembled and the product was developed due to the adoption of a multi-party contract (IFoA) which required the teams to start working together very early in the product development.

In this environment, stakeholders contribute part of their profit to a contingency pool shared by the team, that is, when problems happen the fix is "financed" by the contingency pool and everyone loses. By having "skin" in the game, that is, risking their profits, companies are encouraged to collaborate early on to avoid problems, even if that means crossing organizational boundaries to find solutions with partners in the team. Another distinctive characteristic of the IFoA is that it attempts to take care of the *organization*, the *commercial terms*, and the *operational system* of the project. Other forms of contract (e.g., design-bid-build, design-build, construction management) spell out commercial terms and the organization of the project, but do not work on the operational system of the project, e.g., using the LPS®, organizing the work of the trades (Darrington et al. 2009). The present article focuses on discussing the principles that are behind the operational system that guides the Lean product development system at CHH.

PDS at CHH and its Relationship with Toyota PDS

This section presents characteristics of the PDS at CHH in broad strokes while comparing them to the PDS at Toyota as discussed by Morgan and Liker (2006), summarized in Table 1. The discussion attempts to highlight principles that appear to be well implemented based on the point of view of this article's authors and other principles that merit further discussion and development. Table 2 at the end of this section summarizes how the PDS principles were applied by the CHH project team and indicates peer-reviewed studies that also discuss the practices.

The Project

CHH is a large 1.2 million square feet urban replacement hospital. The project like other hospitals in California has undergone reviews by California's Office of Statewide Health Planning and Development (OSHPD). The project faced strong oversight and a lengthy discussion process with the hospital neighbors. To overcome these and other challenges related to designing and building a major hospital in California, the team resorted to Lean concepts, principles, processes, and tools.

The Team and Main Partners in the IFOA

CHH was the first project to use a full-fledged IFOA and might remain as one of the few projects to have attempted such a broad implementation of the IPD concept (AIA, 2012). A detailed description of how the project was organized from a contractual standpoint can be found in the works of Nguyen (2010), AIA (2012), and Lee (2012). The cornerstone of CHH's IFOA is to share risks and rewards between the partners, having them co-located to foster collaboration, and have all customers of the value chain integrated from the very beginning. In short, the contract lays the basis for a cooperative relationship, one that is fundamentally different from the relatively adversarial relationships between suppliers and assemblers in the West. Similar contracts have also been commonplace between first- and second tier suppliers in Japan since the 1960s (Womack et al., 1990) and have also been used in US (Matthews, Howell, & Mitropoulos, 2003).

The use of an IFOA supports principle 8 "*Fully integrate Suppliers into the Product Development System*" in that the main stakeholders designing and building the project work in an integrated fashion. This new form of contract brings teams to a whole different level of collaboration, as evidenced at CHH (Nguyen, 2010). Thus, the environment promoted by the IFOA begs for a strong leader, along the lines of the chief engineer (CE) at Toyota, who would be well experienced in all fields of a design, fabrication, construction and operation of the project and empowered by the owner and all the other members of the team to lead the project. This leader needs to have in-depth experience of the project areas, as well as hands on experience in the different phases of design, engineering, manufacturing, and construction.

At Toyota, the CE's intimate understanding of the project's goals helps him/her lead the team to meet nearly impossible targets, to deal with trade-offs and serve as a the element that links all parts of the PDS together (Morgan & Liker, 2006); this idea was born with Toyota when its founders led by getting their hands dirty while the TPS was developed (Liker, 2003). However, one can say that this well-versed leader profile might not exist (yet) in the construction industry, which is much broader in its range of products than the manufacturing industry. Thus, the authors of the present article believe that principle 5

Table 2. Comparison between principles adopted at Toyota PDS and their adaptation at CHH

	Principle	Principle adaptation at CHH
Process		
1	Establish Customer-Defined Value to Separate Value-Added from Waste	Definition of a "True North" as the "Five Big Ideas" developed by the project owner: collaborate really collaborate; increase relatedness among all project participants; treat projects as networks of commitments; optimize the project not the pieces; tightly couple action with learning (Lichtig, 2009). Use of evidence-based design and root cause analysis to support target value design (Rybkowski, 2009). Use of choosing by advantages to define systems that are more advantageous to the owner and its clients (Nguyen et al., 2009; Nguyen, 2010), target value design (Nguyen, 2010; Lee, 2012).
2	Front-Load the Product Development (PD) Process to Explore Thoroughly Alternative Solutions while there is Maximum Design Space	Work in process. Basic structure for systems clusters (attempt to mimic the MDTs at Toyota). Use of swimlane diagrams to depict the exchange of information necessary to deliver the design. Use of LPS® to manage design (Hamzeh et al., 2009). Set-based design (Parrish et al., 2008).
3	Create a Leveled Product Development Process Flow	The use of VSMs and swimlane diagrams for process mapping allowed the team to visualize the tasks and the work load involved in different processes, and attempt to balance work among different specialties. Use of LPS® to manage design (Hamzeh et al., 2009).
4	Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes	The use of visual tools, especially swimlane diagrams, provides the basis for continuous improvement as processes are mapped, analyzed, feedback is provided, and adjustments are made to improve their performance.
Skilled People		
5	Develop a Chief Engineer (CE) System to Integrate Development from Start to Finish	Work in process
6	Organize to Balance Functional Expertise and Cross-functional Integration	Use of a Big Room (*Obeya*) for weekly meetings with project stakeholders (Rybkowski, 2009; Hamzeh et al., 2009; Nguyen, 2010). Stand up meetings with system leaders. Special task engineers assigned to work in cross functional teams.

(*Continued*)

Table 2. (*Continued*)

Principle		Principle adaptation at CHH
7	Develop Towering Technical Competence in all Engineers	Work in process. A structured policy to foster mentoring activities is not yet part of the IFoA
8	Fully integrate Suppliers into the Product Development System	Use of an IFoA (Lichtig, 2009; Heidemann & Gehbauer, 2011), use of a co-located environment where cluster teams develop the product together (Nguyen, 2010; Lee, 2012).
9	Build in Learning and Continuous Improvement	Definition of a "True North" as the "Five Big Ideas" developed by the project owner (Lichtig, 2009). Designation of a 'value and Lean process manager' to educate the team on Lean delivery of projects (AIA, 2012).
10	Build a Culture to Support Excellence and Relentless Improvement	Definition of a "True North" as the "Five Big Ideas" developed by the project owner (Lichtig, 2009). Designation of a 'value and Lean process manager' to educate the team on Lean delivery of projects (AIA, 2012).
Tools & Technology		
11	Adapt Technology to fit your People and Process	All trades are required to use BIM software to prevent clashes and make changes visible through the use of parametric models that quickly incorporate and display changes (AIA, 2012). 4D simulations enable workability studies and the study of multiple alternatives for assembling components at the project site ((Nguyen et al., 2009; Nguyen, 2010).
12	Align your Organization through Simple, Visual Communication	Use of VSMs and swimlane diagrams (Nguyen et al., 2009; Nguyen, 2010), A3s indicators, boards at the co-located office to collect and disseminate information and manage interfaces between trades.
13	Use Powerful Tools for Standardization and Organizational Learning	Use of VSMs and swimlane diagrams for process mapping, analysis of these documents aiming at standardization of processes and learning about basic routines and new design alternatives (Nguyen et al., 2009; Nguyen, 2010).

"*Develop a Chief Engineer (CE) System to Integrate Development from Start to Finish*" is still a work in progress in the AEC industry as there might not be many CE leaders who are fully knowledgeable about the construction process from start to finish, especially when a much broader range of project types are considered.

Closely related to the need to have a strong CE to manage the process is the need to "*Develop Towering Technical Competence in all Engineers*" (Principle 7). At Toyota, and in countries like Germany, technical competence is gained through hands-on experience and a strong mentoring process that supports the building of skills necessary to climb the corporate ladder (Morgan & Liker, 2006). Principle 7 was not fully implemented at CHH due to the challenge to devise and implement a policy (or multiple policies for the IFOA signatories) to encourage engineering mentoring programs to support towering technical competence. Looking at the corporate policies of the major contractors and the two companies that form the general contractor enterprise (joint venture) for the project, they do not have any formal technical mentorship or technical/engineering training programs. Nevertheless, there is support for technical trainings on managerial routines and sharing information from *gemba* walks on the project level.

Another principle related to the Skilled People category depicted in Table 1, and observed at CHH, is Principle 6 "*Organize to Balance Functional Expertise and Cross-functional Integration.*" At CHH a "Big Room" exists where every Tuesday all project participants meet and discuss design, engineering, estimates, and milestones. Once a week the main system leaders meet in a stand-up meeting and exchange the work in progress and interdisciplinary constraints. Special task engineers for cross-functional engineering coordination have been assigned to coordinate rated wall tie-ins of interior rated walls transitioning to exterior walls. Involved parties include: interior wall structural engineer, fire protection engineer, interior architect exterior envelope architect, contractor for interior walls and the contractors for the three different systems is led by the cross-functional engineer to agree on solutions.

The Origins—Using Lean Concepts to Manage the PDS at CHH

The product development phase started with book reading meetings in which 10 to 15 professionals read The Toyota Way (Liker, 2003) and discussed how its teachings could be applied to the project. At that stage, the intention was to translate the concepts presented at The Toyota Way book to the environment at CHH, and some concepts were very much applicable (e.g., co-location) and others were not as much. For example, the book talks about the 14 principles of the TPS and various examples of how to apply them in manufacturing and production of cars, it only talks in very small portions about the product development (design/engineering) phase of a car. Most examples provided are geared towards production, and therefore hard or difficult to apply in design, especially design in the AEC industry.

Although it is difficult to find a way to apply those ideas without any guidance, the different tools that are part of the TPS can be adapted and are well applicable to any industry or phase of a project, as observed in much of the literature reviewed for this article. Take for example the use of 5S to organize the work environment, visual management, the use of A3 to communicate ideas and document the decision-making process, and the idea of streamlining the flow of information and driving waste out of the process at CHH while working to increase value to the end user (Nguyen, 2010).

The true north of the project was given by the five big ideas developed by Sutter Health (the owner) with the assistance of Lean Project Consulting (Lichtig, 2005): collaborate really collaborate; increase relatedness among all project participants; treat projects as networks of commitments; optimize the project not the pieces; tightly couple action with learning. The true north provided guidance to implement Principles 1 "*Establish Customer-Defined Value to Separate Value-Added from Waste,*" 9 "*Build in Learning and Continuous Improvement,*" and 10 "*Build a Culture to Support Excellence and Relentless Improvement.*" The use of evidence-based design and root cause analysis to support the development of the product with the characteristics and value expected by the client and its major stakeholders (e.g., patients, doctors, nurses, staff, vendors) while meeting cost goals set during target value design process (Rybkowski, 2009; Nguyen, 2010; Lee, 2012) exemplifies the practical side of Principle 1. Along the same lines, the use of choosing by advantages to analyze multiple sets of alternatives (e.g., viscous damping walls installation), their benefits and costs for the owner and its clients also support Principle 1 (Nguyen, 2010). Principles 9 and 10 were supported by the definition of a value and Lean process manager to promote learning about Lean implementation and project delivery and continuous learning (AIA, 2012). Despite having a true north in terms of how the Lean deployment should occur, the practical roadmap or the framework for implementation was not there and the team was set to sail into uncharted territories.

At the beginning of the product development at CHH, there was some structure for the clusters (the MDTs at Toyota) (Nguyen, 2010), and some implementation of the LPS® (Hamzeh et al., 2009), which matched the concepts outlined on Principle 2 "*Front-Load the Product Development (PD) Process to Explore Thoroughly Alternative Solutions while there is Maximum Design Space.*" However, this was all organized at a very high level and did not have enough detail to make the system move on a daily basis. The operational model to manage the work, and called for in the IFOA, was not in place in the early phases. There was no "how to" indicated in the IFOA. To be fair, there were academic papers discussing this new type of contract and its implications but to the practitioners at CHH they looked fuzzy, and the project managers at CHH had to develop their own "how to operational model book" as the project unfolded.

Simple tools that helped the project managers to organize the operational system to manage the teams at CHH are the swim lane diagrams and VSMs. Although VSMs were used, they can become very cumbersome when managing information flows coming from multiple stakeholders who collaborate in a very iterative fashion. The simplicity of the swim-lane diagrams provided a clear way to depict the exchange of information over time (Figure 1). Swim lane diagrams are a clear visual display of how the information flows and with that CHH stakeholders could make sense of the processes to learn, capture, and visualize the information flow. Once managers and participants perceived that the process adequately captured the information flows and the routines involved, efforts were made to standardize the process or adjust it to improve its results. These efforts matched what is called for in Principle 12 "*Align your Organization through Simple, Visual Communication*" and Principle 13 "*Use Powerful Tools for Standardization and Organizational Learning.*"

By mapping the processes and exposing their details to participants, the team improved how to:

- Design and perform effective pull planning sections,
- Collect and disseminate information to the right people at the right time,
- Manage interfaces between disciplines and trades,
- Define what is a workable backlog in design,

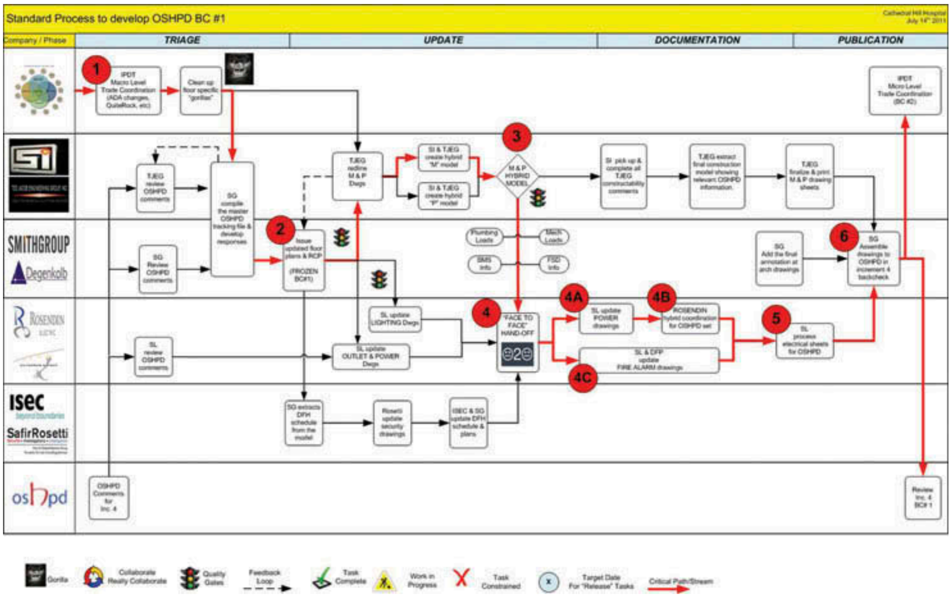

Figure 1. Example of swim lane diagram at CHH (color figure available online).

- Decide when to stop the line in design (to deal with what they call "the gorillas" which represent constraints), and
- Decide when the information is "good enough for now" so that it can go to the next station.

The last bullet point is an extremely important one: when is the time to call it a good/acceptable solution? The Integrated Project Delivery Team (IPDT) has to know when to stop and say it is "good enough for now" and pass the information to the next stakeholder in the line. Additionally, the mapping process ties into Principle 3 "*Create a Leveled Product Development Process Flow*" as it allowed a better management of the workflow between different stakeholders. In design and engineering of construction projects it is difficult to have the workload leveled for all involved parties. At CHH basic tenets of the LPS® are followed and three-week-lookahead schedules are pulled from major milestones defined by the project's phase schedule. The goal of this system is to have the workload leveled for design and engineering tasks. However, many regulatory agencies and companies multi-tasking between different projects are involved, which makes it difficult to have a consistent amount of people developing the same amount of work.

The use of swim lane diagrams also supported Principle 4 "*Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes.*" At CHH the diagrams are used as a basis for continuous improvement (Plan-Do-Check-Act), that is, the processes are mapped, implemented, feedback is gathered from participants, and changes are made as necessary to improve their performance. Some examples are: integrating architectural design changes into the project; integrating additional miscellaneous steel structures into the project; coordinating transitional details between different trades; coordinating the detailing process on a micro/shop drawing level.

Another element that supports the product development at CHH is the use of Building Information Model (BIM) (Nguyen, 2010; AIA, 2012). It is a basic requirement of the CHH project that all trades, architects, and engineers design and draw in BIM software, which opens the opportunity to see adjacent scope and changes, and adjust systems/components before they create clashes (clash avoidance early on in design). The use of BIM is related to Principle 11 "*Adapt Technology to Fit Your People and Process.*" The BIM software on the project is parametric which makes changes directly visible. The use of 4D simulations at CHH (equivalent to Toyota's Digital Assembly) enables the study of how individual building components will be built/assembled. Workability studies provide details on the effects of a certain design and the impact it will have on ergonomic issues involved in building certain parts of a building, e.g., fire-prevention installation in locations that have difficult access. Virtual first-run studies, coupled with VSMs, BIM, and choosing by advantages, were also used to simulate and analyze the installation of structural systems for the project (Nguyen et al., 2009; Nguyen, 2010).

Management of the Information Flow at CHH

The management of information in a project like CHH is a major challenge. Communication and information dissemination is a challenge for projects with this size and complexity. Hickethier and colleagues (2013) analyzed the information flows at CHH and concluded that the chief engineer and leaders of cross-functional teams (clusters) play major roles in the management of information in an IPD environment. Their study also found that the IPD environment fosters collaboration resulting in a large number of people involved during the design, and that even those who are not assigned coordination tasks take upon themselves the role of coordinators (i.e., they become information hubs). The study of the information flows at CHH and how it materialized among team members supported the notion that the IFOA's triad (organization, commercial terms, and operational system) works in unity to promote what is best for the project (Hickethier et al., 2013).

Along these lines, two of the most broadcasted characteristics of the product development process at CHH are the co-location of its team in the same floor of a building in downtown San Francisco and its intense sharing information using visual systems throughout the floor. While co-location fosters collaboration and *promotes* communication it may not necessarily *improve* communication as there might be an overload of information in the environment. Morgan and Liker underscore the importance of managing and sharing information in a lean system:

> "*In product development, knowledge and information are the materials that are required by the downstream activity. However, not all information is equal to all people. The lean PD System uses 'pull' to sort through this mass of data to get the right information to the right engineer at the right time. Knowledge is the fundamental element (material) in product development. Toyota does very little "information broadcasting" to the masses. Instead, it is up to the individual engineer to know what he or she is responsible for, to pull what is needed, and to know where to get it.*" (Morgan & Liker, 2006, p. 96)

As suggested above, information is not equal to all people. It is the task of the cluster leaders (MDT leaders at Toyota) to make sure information is available to those who need it, but information should not be broadcasted to all people in the team. This can avoid confusion or extra coordination efforts that arise when team members have to sort through an overload of information and define who is responsible for what, or what information is relevant for their work. Product development in AEC involves a great deal of complexity and it is very important for the product development team to "embrace" and "appreciate" the complexity in all aspects of the product. This is probably the most challenging part of the process where you continuously work on the "mental models" that align the team. Having leaders who understand the complexity of the project and see the whole is crucial to define how the information is coordinated and distributed within the team (Hickethier et al., 2013).

Work in Process and Lessons Learned

One of the nurturing propositions is that (so far) CHH has implemented most principles related to the Lean product development system at Toyota, as described by Morgan and Liker (2006), and that these principles are the foundation for the evolving operational system that supports its processes on a daily basis. The previous section compared and contrasted Morgan and Liker's 13 principles about Toyota's PDS to what can be found at CHH's PDS and indicated a few areas in which the principles are not fully implemented (Principles 2, 5, and 7 still need more work to be fully implemented). This section points out to some lessons learned about the journey to define the operational system of CHH's PDS.

"*Our knowledge of its details was actually very limited. After all, we were academics, not hands-on product development engineers, and our access to Toyota was limited*" (Morgan and Liker, 2006, p.xv). The previous quote illustrates a reflection by Morgan and Liker about their understanding of the product development system at Toyota. In a very similar fashion, this quote reflects the views of the co-authors of the present article. They started reading Morgan and Liker's book independently and to some extent independently started applying some of the book's teachings. Most principles listed by Morgan and Liker were implemented by the team at CHH and others are still work in process. However, some of the ideas presented in some Lean Production books, as well as in some Lean Construction papers, were too far off from CHH practitioners' reality and at times considered too academic. There was no benchmark for what the CHH team was trying to do in the beginning of the project as CHH was the first project to use a full-fledged IFOA with co-located teams and ambitious goals for collaboration to develop the project. Based on the experience gained at CHH, it is believed that there are two elements that should be at the core of a Lean PDS: role of leadership during the transformation to a Lean enterprise and the effective management of the information flow.

Moreover, to implement the necessary changes and devise an appropriate operational system to manage the product development phase it is recommended that organizations take a serious and honest look at their current processes by using a VSM workshop (Morgan & Liker, 2006, p.345). The VSM should be assembled by a multi-functional team, and no blame should be assigned if broken processes/tasks are identified. Future state maps for the processes investigated should be defined, people empowered to make the necessary changes should be identified, and the leadership should support the changes and lead by example. At CHH, the team's ability to constantly map/design processes, implement changes, and track their results using feedback from participants promoted the continuous improvement of processes.

Feedback from CHH Participants—Lessons Learned and Comments on Improved Collaboration

The discussion presented was mostly based on the experience of the structural cluster which was in charge of a number of activities including design and engineering, design and trade coordination, design optimization and constructability, target costing, modeling and simulation, and production planning. In the Summer 2012, one of the authors (a senior PM in the project) asked the team: "*What made this a different experience for you individually?*" The goal of this exercise was to capture some of the tacit knowledge created by the team members along the way and their perception regarding how the system in place worked for them. A summary of the lessons learned during the 5 years the team worked together, as indicated by team members, is provided below. It is worth noting that this project had a long preconstruction phase when compared to other projects, and that this might have been a very important factor on how this team worked together.

This summary supports the discussion presented and, to some extent, validates the effectiveness of the processes and tools used by the structural cluster to develop their work. Quotes provided by team members were reviewed to identify key lessons learned presented here in a summarized format. A few generic quotes provided were transcribed without identifiers to protect the anonymity of those who participated in this exercise. In the CHH environment, participants learned about and valued the following aspects:

- Practicing the concepts discussed in the Toyota Way and experiencing the changes. The transition from a hard-bid to a Lean and IPD environment took time and allowed participants to adapt to the new system. The GC's leadership was instrumental in bringing the team together during the transition. As stated by a team member: "*That made the transition easy and fostered a non-combative team work environment.*"
- Teamwork, collaboration, and going through the experience of applying Lean concepts in a collective way opened people's mind about possibilities that they had not explored in their industries. One of the team members highlighted that "*collaboration on this project has been unprecedented.*"
- Trust and commitment from participants to get issues discussed, documented, and developed as promised.
- Openly sharing ideas and knowledge among team members to achieve the best for the project and the client (optimizing the whole), and also to reduce risks. Breaking down barriers between team members and their specialties. One participant expressed that "*Excellent communication allows team members see constraints/issues of others to get a better understanding of issue at hand.*" Another added: "*Scope of work review, discussion, and collaboration resulted in the most cost effective scope assignment for the overall project and a detailed definition with no "grey area".*"
- Developing a solid network/community of trade partners, designers, and the general contractor and being able to benchmark and learn from other projects developed by the network.
- Frequent collaboration meetings resulted in issues being resolved by participants during the meetings instead of through requests for information (RFIs).
- Great learning experience provided by the project and its team members. Participants value the intense exchange of information which allowed them to learn from other trades, and about the state of the art in healthcare design and construction.
- Putting in practice Sutter Health's 5 Big Ideas: collaborate really collaborate; increase relatedness among all project participants; treat projects as networks of commitments; optimize the project not the pieces; tightly couple action with learning (Lichtig, 2005). These 5 Big Ideas draw from concepts discussed in the Lean literature and can be found throughout the principles discussed Toyota's PDS.

- Mentorship and leadership skills of the PM, which were also praised extensively by team members. The PM was able to focus on project's goals without losing sight of individual trade's needs.

Conclusions

Morgan and Liker's 13 principles related to the product development system (PDS) at Toyota were used to analyze the PDS at CHH. Some details were shared about the journey the CHH team went through as these principles were used as a basis to develop the operational system that supported the PDS at this project. According to the discussion, most principles have been implemented to some extent, and a few still need to be worked on (Principles 2, 5, and 7).

Lessons learned from the journey to develop a Lean PDS at CHH were presented and indicated that leadership and the management of information are essential elements of a Lean PDS. Additionally, the importance of running the Plan-Do-Check-Act cycle in different formats and continuously using the resources available to improve the processes to deliver more value to the final client was highlighted. With this spirit in mind, at the time this article was written, the CHH team had been meeting every Friday morning to share their stories of success, alignment and breakdown, and trying to learn from their successes and their failures.

Practical implications include informing architecture, engineering, and construction practitioners, as well as owners, about the potential benefits achieved when Lean principles are applied to the development of building projects. Additionally, these principles support the vision of a sophisticated owner in terms of what needs to be done to change how healthcare projects are delivered. The PDS principles at Toyota, when transplanted to CHH supported the achievement of the 5 Big Ideas proposed by Sutter Health and promoted unprecedented levels of collaboration as indicated by team members of the structural cluster.

Morgan and Liker (2006) place a very strong emphasis on the importance of leadership at Toyota, leaders lead by example and get to know their projects inside-out. The leaders are directly responsible for the success of their projects, how tools are used, and how implementing Lean Thinking can be a continuous journey in projects. Senior leaders have to be committed and involved with the process and foster a learning environment. An IFOA contract promotes the exchange of knowledge and the leader can be a champion to promote learning and continuous improvement. Leaders and the team members have to recognize the complexity of using Lean concepts to change the PDS, and take an honest look at current practices while empowering team members to make changes. Continuously working on the integration of people, processes, tools and technology by promoting alignment is essential to keep the team focused on doing what is best for the project.

To conclude, suggestions of future work and implications to the academic community are presented. Research on IPD projects is still in its infancy, relevant topics that merit further investigation and discussion include:

- Gathering evidence on how the practices implemented during the preconstruction phase of IPD projects improve construction and ultimately the built environment's performance.
- Analyzing the return on investment (ROI) of the investments made during the preconstruction and construction phases of IPD projects.

- Understanding how learning takes place in the highly cross-functional environment of co-located teams. IPD contracts foster information exchange and learning but it does not mean that people actually learn from this exchange. This topic deserves a separate study to discuss this issue, as much has to be done to manage the data and the knowledge created by such teams and how it is disseminated across organizations and their projects.
- How to prepare the next generation of AEC practitioners to operate in IPD environments and to push for changes in the industry towards more collaborative forms of contracts, when most current textbooks do not focus on Lean practices, with one of the notable exceptions being Forbes and Ahmed's (2011) book.
- How to effectively incorporate the different methods and tools used to support the operating system of IPD projects in classroom activities.

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