A DESIGN CASE STUDY: INTEGRATED PRODUCT AND PROCESS MANAGEMENT

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ABSTRACT

Traditional design practices in construction indicate that most of the emphasis appears to be on product design. This may be the result of the traditional process of design-bid-build, where the design team pre-defines means and methods to the contracting team. In contrast, lean design incorporates not only product design, but also process design. Process design is commonly one of the components missing in traditional practices together with the lack of supporting systems, organizational structures, and resources required to obtain a quality design.

This paper presents a case study that describes an integrated approach to manage product and process in design. The case study builds on the design phase for the construction of The Central Bus Station project in the city of Lima, Peru. The case study discusses several topics including working with cross-functional design teams, using pull to prioritize detailed engineering, applying collaborative mapping to identify design constraints so variability is minimized, measuring plan reliability, reasons for non-completion and root cause analysis, and capturing lessons learned as part of a continuous improvement process. The case study describes the use of key tools for product and process management.

Preliminary results are presented including on-time completion of design milestones, customer satisfaction, better understanding of implementation constraints and challenges, and increased transparency in the overall design process. This case study represents the first implementation of lean techniques in design in the Peruvian construction industry.

KEY WORDS

Cross-functional teams, design, digital prototypes, production control, production system, pull, reliability, workflow.

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INTRODUCTION

The Toyota Production System has inspired many industries - including construction - as an example of speed, efficiency, and quality. The construction industry continues its journey towards an understanding of how concepts and principles developed at Toyota can be applied to improve the delivery of capital projects.

Toyota is well known for the development of the Toyota Production System (TPS), however, an area less explored is Toyota's approach to product development. Gaining a better understanding of how Toyota develops new products may be considered a starting point towards improving traditional design management practices in project delivery.

This paper provides a short review of Toyota's product development principles to create some context for the case study presented later. The case study builds on the application of some of these principles to the design phase of The Central Bus Station project in Lima, Peru. This case study represents the first implementation of lean techniques applied to design management in the Peruvian construction industry. It describes the different components of the design management strategy (e.g., processes, supporting system, and organizational structure) incorporating the understanding of stakeholders' needs and wants, which are driving the design and implementation of the strategy. The paper also describes the application of key tools to manage product and process. The paper concludes with a list of lessons learned.

PRODUCT DEVELOPMENT AT TOYOTA

Toyota is well known for the development of the Toyota Production System (TPS), recognized as the most efficient production system in the manufacturing industry. Kanban, 5S, and kaizen are examples of techniques that form TPS.

An area less explored is Toyota's approach to product development. Toyota's product development approach enables them to bring the highest quality products to market faster, and then manufacture more efficiently than most of the industry through TPS. In 2000, Toyota topped seven of sixteen total categories in the J.D. Powers study for Initial Quality while no other car company placed first in more than two categories. Toyota also placed first in four of ten categories for Consumers Reports Top Autos (Morgan 2002).

In their book *The Toyota Product Development System* (2006), Morgan and Liker present a summary of fundamental principles that form the basis of Toyota's approach to product development. These principles are classified in three groups: process, people, and tools and technology. The following is a review of these principles based on the work of Morgan and Liker (2006).

Process:

1. *Establish Customer-defined Value* – This approach results in a deep understanding of customer defined value, which is the first objective on any product development process (the definition phase in terms of lean project delivery). In Toyota, product development must deliver a product design that both meets customer needs and is capable of being manufactured efficiently.
2. *A front-loaded Process* – Toyota is able to minimize downstream process variation crucial to both speed and quality by ensuring early involvement of stakeholders (e.g., designers, suppliers), increasing cross-functional participation, and encouraging early engineering and problem solving.

3. *Create a Leveled Product Development Process Flow* – The product development process can be managed and improved like any other process. Waste elimination is the target.

4. *Rigorous Standardization* – The objective is to create strategic flexibility through three types of standardization: design standardization, process standardization, and engineering skills set standardization.

People:

5. *Chief Engineer as Cross-functional Integrator* – A heavy weight chief engineer or project manager integrates a product development project from start to finish. The unique role of Toyota's chief engineer is to be the glue that holds the whole product development system together.

6. *Balance Functional Expertise and Cross-functional Integration* – Toyota is a functionally-organized company with emphasis on strong functional skills and a skill-based hierarchy. It has integrated the traditional silos through the chief engineer, module development teams, and a big room (or 'obeya' in Japanese) system that enhances functional integration.

7. *Develop Technical Competence in All Engineers* - Career paths rewarded technical excellence, which indeed, helped to incentivize cross-functional representation and involvement.

8. *Integrate Suppliers into the Product Development Process* - 'Toyota utilizes a tiered approach to supplier management in which only the top-level suppliers take on black box responsibility including design' (Liker et al. 1995). Toyota maintains close, long-term semi exclusive relationships with these suppliers including very early involvement in product development.

9. *Built-in Learning and Continuous Improvement* – At Toyota, learning and continuous improvement are fundamental components of every job performed, rather than a special corporate initiative. This is achieved through the definition of specific goals for every product development project and by holding both real-time and post-mortem learning events (or Hansai in Japanese).

10. *Build a Culture to Support Excellence and Relentless Improvement* – Toyota's culture supports excellence with explicitly defined values and an unwavering adherence to core beliefs by leaders and team members alike. All of the other principles work because the culture itself makes the principles a living part of how Toyota gets things done.

Tools and Technology:

11. *Adapt Technology to Fit your People and Processes* - People, processes, and technology are integrated, aligned, and designed to be mutually supportive, with technology supporting processes and people, not the other way around.

12. *Align your Organization Through Simple and Visual Communication* – Toyota uses very simple, visual methods for communicating information, often limiting

it to one side of one sheet of paper. This is used to solve problems that naturally occur when things do not go exactly to plan.

13. *Use Powerful Tools for Standardization and Organizational Learning* – A well-known principle of kaizen is that you cannot have continuous improvement without standardization. Sharing learning at all levels of the product development process is also crucial.

These principles form the core of Toyota's product development approach and complement what TPS has been to manufacturing. According to Clark et al. 1991, there is no single practice or characteristic of Toyota's product development process that can be identified as the reason for their success. It is rather the simultaneous use of these practices as a whole. A more recently identified source of competitive advantage at Toyota is their ability to manage multiple product development projects simultaneously. Toyota's reorganization to vehicle development centers is also recognized as key to knowledge, technology, and parts sharing across similar projects, which has resulted in cost and time savings (Cusumano and Nobeoka 1998).

Now that Toyota's product development principles have been reviewed in detail, the question is: how to take advantage of them when managing design during the delivery of capital projects? The following case study proposes an alternative answer to this question.

CASE STUDY

Background

Graña y Montero S.A. (GyM) is the largest contractor in Peru. GyM and its partner ICCGSA formed a Consortium to apply their work experience to design and build The Central Bus Station project in Lima, Peru, owned and financed by The City of Lima.

Amongst other goals, the Consortium envisioned the following for the delivery of this project:

1. Apply Toyota's Product Development principles to design
2. Apply Toyota's Production System principles to construction

The Consortium worked with Strategic Project Solutions to deliver this vision starting with design, which is the focus of this paper. The implementation of TPS principles during construction will be presented in future IGLC papers.

Project Overview

The Central Bus Station project is located in downtown Lima. The overall project duration was estimated to be 18 months (08 for design, 10 for construction). The Central Bus Station is an underground station part of an integrated and new transportation network for the City of Lima.

The station has been conceived with two underground levels. The first level (basement 1) contains the boarding platforms and a large area designated for commercial and retail activities. The second level (basement two) was conceived for underground pedestrian access, and control rooms for all electrical and mechanical systems.

The Design Management Strategy

The development of the design management strategy followed a three-step process: (1) definition, (2) design, and (3) implementation.

Defining the Design Strategy

Getting an understanding of the needs and wants of the stakeholders is a must during any definition process. There are several stakeholders involved in the project. Specifically for the design phase of the project, the main stakeholders were identified as the City of Lima (the owner), the inspectors (a Brazilian/Peruvian Joint Venture), and the Consortium (designers and builders).

The City of Lima requested that the construction phase starts when design is completed. The Consortium proposed to the owner the possibility of overlapping design and construction so total project duration is reduced. The owner rejected this proposal. The reason behind this decision is that the station could not be open to the public unless other concurrent projects (part of Lima's new transportation network) were completed on time. The owner confirmed that these other projects were experiencing delays. The 'voice of the customer' therefore was: *There is no urgency to either increase design speed or reduce total project duration by overlapping design and construction (even though, technically this was possible)*.

The second main stakeholder, the Consortium, expressed the need to make sure design is validated and integrated before construction starts. This will help minimize downstream process variation originating from product sources (e.g., design problems affecting site workflow). This need was incorporated into the design of the strategy presented later on this paper.

In summary, the design management strategy needed to accomplish two objectives:

- To ensure a quality product design rather than to increase the speed of the design phase, and
- To deliver the product design within a certain time frame with very specific milestones and deliverables associated with each milestone

Designing the Design Strategy

This phase focuses primarily on identifying the processes, supporting systems, organizational structure, people and performance metrics necessary to deliver the two objectives outlined during the definition of the strategy.

The final design of the strategy included the following:

Processes

1. Define construction sequence in advance (at a macro level) so the development of detailed engineering is pulled (prioritized) based on this sequence.
2. Establish weekly integration meetings for product and process where agreements are recorded and actions are incorporated into weekly production plans to monitor design progress.

Tools and Technology (supporting systems)

3. Use SPS|PM3 to (1) introduce process into a product world supporting the creation of weekly production plans, (2) manage and control design workflow so design milestones are delivered on time, (3) balance workload and resources,

and (4) allow real-time learning and improvement by measuring production plan reliability and capturing reasons for task non-completion and related root causes.

4. Use process mapping as a tool to collaboratively capture design workflow and its constraints.
5. Generate digital prototypes to (1) integrate and validate 2D design, and (2) create digital builds to show design progress.
6. Use an ftp server shared by all team members as a repository for design information.

Organizational Structure and People

7. Define a cross-functional team to produce product design and control design progress.
8. Define the role of design integrator.
9. Ensure new skills are developed amongst selected members of the cross-functional team for (1) the use of the supporting systems described above, and (2) meeting facilitation and collaborative leadership.

Figure 1 presents a graphical representation of the production system focused on producing product design. It includes the overall process including pulling signals, and the supporting systems for the process and people.

Implementing the Design Strategy

Implementation represents the delivery of the design strategy presented above. The first step was to configure the weekly design meetings to ensure a discussion about process and product occur using SPS|PM and digital prototypes as support systems. Figure 2 shows a graphical representation of this configuration.

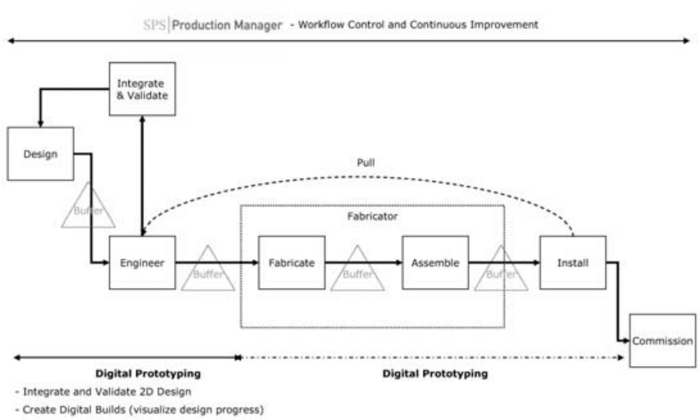


Figure 1: Production System Design to Produce Design

[3] SPS|Production Manager is an integrated suite of web-based modules that enables better control of cost, time and associated use of capital, enhanced quality and reduced health and safety risk for the delivery of capital projects.

Training on facilitation and collaborative leadership was delivered to selected members of the cross-functional team. This started with actions to re-arrange the layout of the meeting room used for the weekly meetings in order to enhance collaboration amongst team members and increase focus on topics being discussed. Figure 3 shows the changes in room layout. Pictures of the team working with the new layout can be seen in Figure 2.

The Consortium subcontracted all design and detailed engineering to different specialists. This approach was agreed with the designers themselves before submitting the budget to the owner. This way of working created an integration challenge for the team and the Project Manager when trying to align all specialists to change their normal and traditional way of designing into a more collaborative environment focused on delivering value to the owner. This integration challenge was in both product and process. The Project Manager needed to perform more than just a project management role - he was the design integrator from start to end of the design phase using SPS|PM to enable process integration, and digital prototypes for product integration.

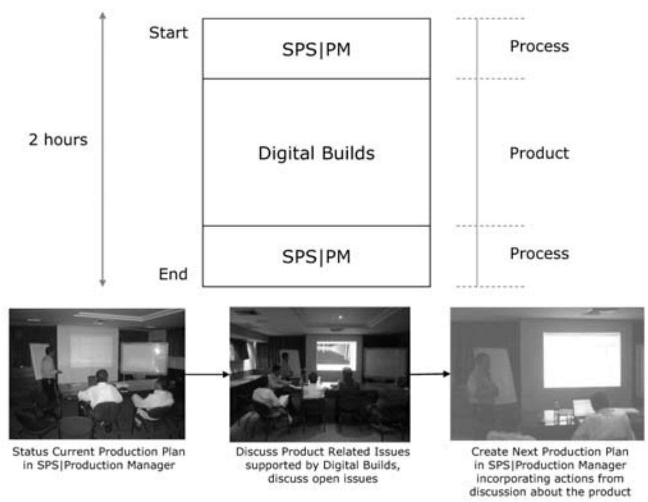
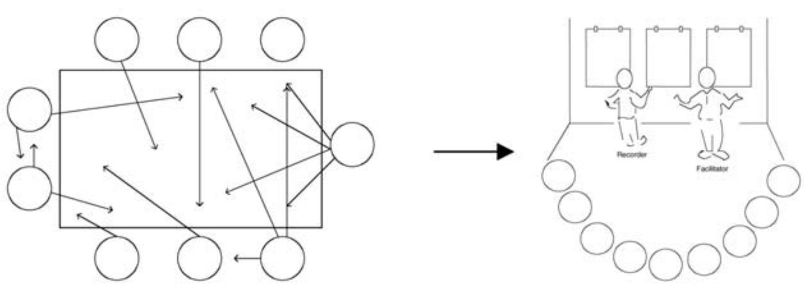


Figure 2: Integrated Product and Process Management



Before After (facilitator and recorder roles made explicit)

Figure 3: Room Layout Configuration for Better Team Collaboration

Although the team developed a CPM schedule for contractual reasons, the schedule was not used to integrate all team members in the design process. The team identified 4 main design milestones with very specific contractual deliverables for each milestone and realized that the design phase was driven by these four milestones. For each milestone, the team worked collaborately to identify 'mini' milestones behind the main milestone using post-it4 notes. Then, more detailed processes were mapped collaborately (also using post-it notes) until executable tasks were identified. These processes were then entered in SPS|PM for control, resource management, and continuous improvement. Figure 4 presents a graphical representation of this approach.

Work structuring played a key role to determine construction sequence. Although construction was not overlapped with design, the definition of the work structure for construction helped to define priorities for the creation of digital prototypes for integration and validation (the digital prototype was created sector by sector according to construction sequence). Figure 5 presents the macro work structure for the entire project (section 1 to 13).

As stated, the creation of digital prototypes followed the construction sequence; however, digital prototyping was overlapped with design. Design and digital prototyping were almost in fast-track mode. The goal was to virtually build the project before construction starts. Figure 6 presents the transition between 2D and 3D following the construction sequence defined as part of the macro work structure.

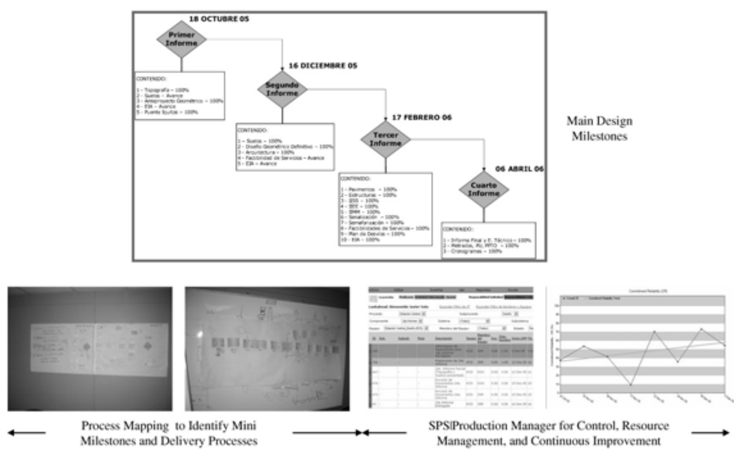


Figure 4: Detailed Process Management Approach

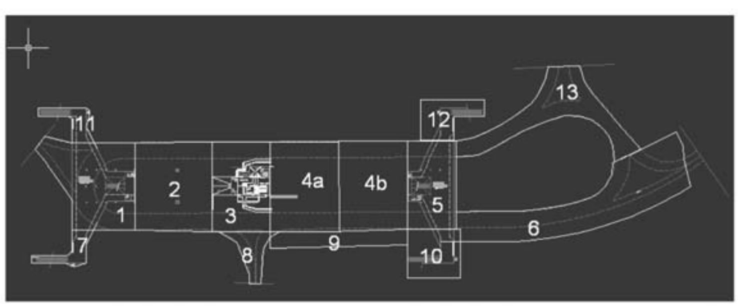


Figure 5: Work Structuring at the Macro Level

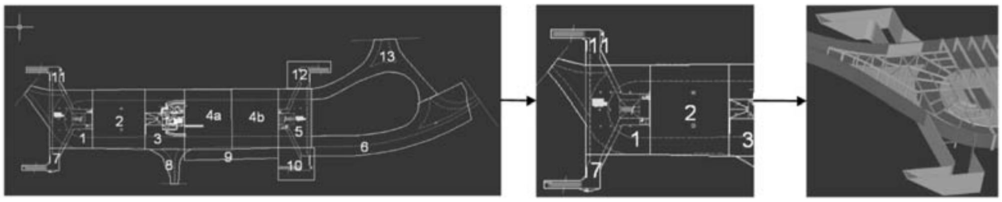


Figure 6: Use of Digital Prototypes According to Work Structuring

The Results

The integrated approach to process and product management presented in this paper delivered the following results:

- On-time delivery of design milestones. The owner requested additional time to review the existing design and look for opportunities to reduce the budget due to their funds restriction. This affected the delivery of the last milestone. Target costing was not implemented in this project however would have benefit from its application in order to avoid budget revisions when design is pretty much completed.
- SPS|PM recorded the average weekly plan reliability for the entire cross-functional team as 48.3%. The main reason for task non-completion was categorized as 'design/engineering'. The two main root causes behind this reason were: (1) late delivery of information, and (2) information submitted but not completed (a quality problem). Figure 7 shows outputs from SPS|PM: plan reliability on the left, and reasons for non-completion on the right.

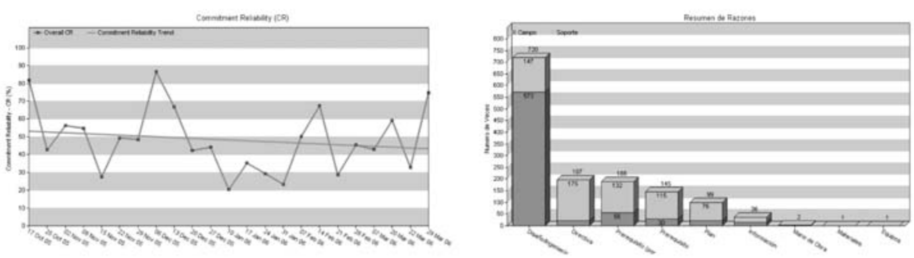


Figure 7: Process Metrics

One of the main constraints was to ensure specialists followed the consortium pulling system using SPS|PM. The trend was that specialists were more comfortable delivering their work in the old and traditional way, causing work overloads to the consortium team and augmenting the integration challenge.

- The team worked towards product standardization. Some results include:
  - Air Handling System – Used digital prototypes to define standard routing, dimensions, and shapes.
  - Pre-cast Slabs – In coordination with the structural engineer, the team managed to define a unique shape for pre-cast slabs. Due to variations in loads and location, this unique shape was properly reinforced resulting in three different types.
  - Concrete Elements – the majority of columns, beams, and retention walls to be poured in-situ were standardized
  - Acoustic panels – the team worked with the acoustic engineer to define standard dimensions for acoustic panels resulting in standard acoustic modules.
  - Light Fixtures – the team worked with the electrical engineer to define standard light fixtures to minimize complexity during detailed engineering, procurement, and site installation
- In addition to product standardization, design incorporated specific constructability details such as the use of specific construction equipment (e.g., concrete sliding paver), and the use of pre-cast elements for all underground electrical and mechanical systems.
- Process wise, standardization was also achieved for the management processes. Management processes are those where the members of the Consortium are responsible for performing all process steps. Figure 8 shows a standard process (in Spanish) as an output from SPS|PM.

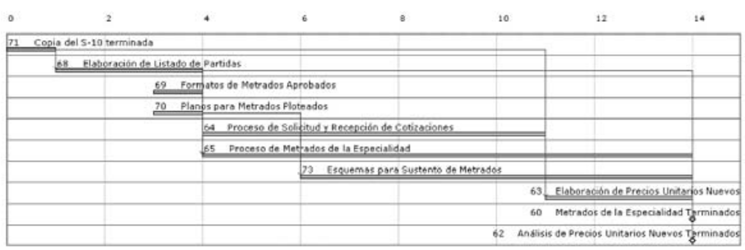


Figure 8: Standard Processes

- The use of digital prototypes enabled a better quality design through the identification of design errors, missing information, interferences between systems, and changes in design for better constructability. Figure 9 shows samples of these results.

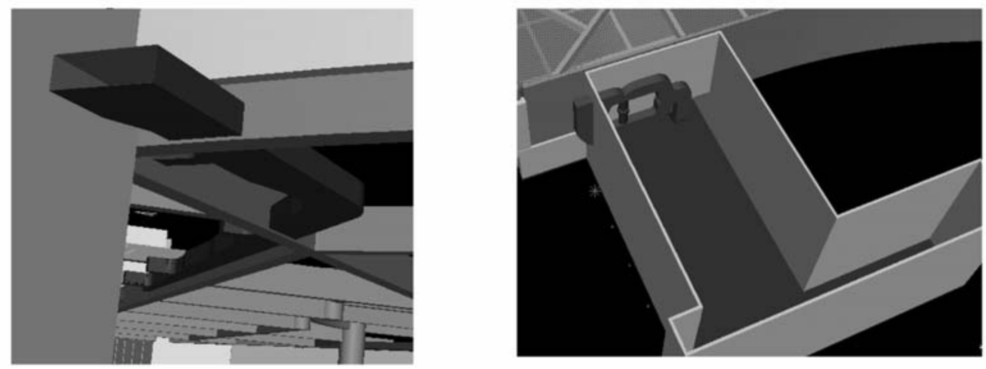


Figure 9: Examples of Interferences captured using Digital Prototypes

- Finally, the fact that stakeholders worked cross functionally contributed to obtaining the results presented in this section. The cross-functional team included members with design and engineering management experience as well as members with extensive construction experience that will be directly involved during the construction phase. This approach will enable a smooth start of the construction phase with full project knowledge and main construction-related constraints already identified.

Even though construction is not manufacturing, this paper considers as part of the results the fact that the applicability of principles of Toyota's product development approach to design management in project delivery is possible. Some principles were explicitly implemented as shown in Table 1.

Toyota's Product Development Principles	Proposed Design Management Approach
Establish Customer-defined Value	Design strategy designed around customer needs and wants (e.g., client's desire to avoid overlapping of design and construction – no need to fast track!)
A front-loaded Process	Proposed design management approach is problem-solving driven. Identify and eliminate problems up front using SPS|PM (e.g., need for more design resources) and digital prototypes (e.g., interferences between systems)
Rigorous Standardization	Use of digital prototypes to enable stakeholders to identify opportunities for product standardization. Use of SPS|PM to generate a library of standard processes.
Chief Engineer as Cross-functional Integrator	Support from leadership and direct involvement of the Project Manager as design integrator were crucial to achieve final results – 'desire to do it'.
Develop Technical Competences in All Engineers	Capability development was a key component of the design strategy
Integrate Suppliers into the Product Development Process	Design team formed for one-time event (the project). Use technical expertise of the members of the Consortium during product design. . Key suppliers and subcontractors were identified during tendering process. Contractor continued working with them during the design process to ease design internal review and comments.
Built-in learning and continuous improvement	Real-time learning through the use of SPS|PM (e.g., reasons for non-completion and related root causes) and 3D modelling. Execution of post-mortem learning events with main stakeholders.
dapt technology to fit your people and processes	Process-driven design management approach supported by SPS|PM and digital prototypes to integrate and align stakeholders.
Align your Organization Through Simple and Visual Communication	Digital prototypes utilized as tools to align stakeholders during design
Use powerful tools for Standardization and Organizational Learning	Use of digital prototypes, SPS|PM, dedicated ftp sever, and collaborative process mapping

Table 1: Proposed Design Management Approach

CONCLUSIONS

This paper has demonstrated the applicability of Toyota's product development principles to design management in construction. The paper has presented a series of tools that can be implemented to increase value delivered throughout the design phase of a project. These tools support a design management approach with three pillars: (1) integrated product and process management, (2) collaborative and cross-functional teams, and (3) leadership.

Key lessons learned are: (1) a combination of the inability of some design specialists to balance their own internal resources in order to perform actions previously discussed, agreed, and included in weekly production plans, and their negative response towards collaboration and cross-functional work were the main root causes for plan reliability levels of approximately 50%, (2) need to evaluate the possibility of having a designer from each speciality fully dedicated to the project, and physically integrated in order to enhance process and product integration, and (3) the fact that core team members dedicated time to fix design deficiencies (e.g., quality problems during the release of 2D drawings) did not leave enough time to focus more on the optimization of design based on construction processes.

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