MAKING DESIGN PROCESS LEAN

Chien-Ho Ko[1] and Neng-Fu Chung[2]

ABSTRACT

Improper design in the construction industry leads to change orders, rework, decreased constructability, cost overruns, and delays, making it one of the biggest causes of waste. This study aims to develop a Lean Design Process to enhance design reliability by creating a learning environment using the design correctness ratio. Wastage is first identified by analyzing the planning and design processes. A new design workflow is then proposed using lean concepts to smooth design work, reduce unnecessary design errors, and increase design reliability. The proposed process can provide team members with feedback on design status, thus allowing for continuous improvement. The lean process is conceptualized using system dynamics to validate applicability. Analysis shows that the proposed lean design process can enhance design completeness and reliability, thus increasing design correctness. Waste due to improper design could be reduced accordingly.

KEYWORDS

Lean design, design correctness, system dynamics.

INTRODUCTION

Construction projects are increasing in complexity (Gould and Joyce 2009), such that no single designer can claim comprehensive expertise. Thus final designs may include hidden problems that appear only in the construction phase (Abdelsalam et al. 2010). While some minor design defects can be resolved by the general contractor in discussion with the architect, more serious problems require a mandatory change order, which may increase both time and cost (Josephson et al. 2002, Günhan 2007).

Improper design, defined in the study means design error caused by design itself and incurs change order in the construction phase, is potentially one of the biggest sources of waste in the construction industry. From beginning to end, the project life cycle can be roughly divided into phases including conceptual, planning, design, bidding, construction, operation, maintenance, and decommission. After the architect completes the design, design drawings are delivered through the tender process to the construction team. If an improper or unfeasible design is found in the construction phase, the design has to be returned to the architect for correction. This continuously repeated correction process increase both time requirements and cost (Mendelsohn 1997, Kawamura 2000). In the entire project life cycle, planning and design have the

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greatest impact on the whole project (Soibelman et al. 2003) and faulty planning and design can result in significant change orders. Chang et al. (2007) reported that 40% of design changes result from issues arising in the design phase. Therefore, finding ways to reduce design errors and minimize cost overruns and schedule delays resulting from change orders is a serious issue in the construction industry (Nylen 1996), focusing attention on effectively coordinating design with construction to deal with design problems before they occur (Riley 2005, Li et al. 2008).

Lean production concepts were first introduced to the construction industry in the 1990's (Koskela 1992). These so-called lean construction practices can be seen as a means of adopting theories and methods from lean manufacturing to enhance construction management performance (LCI-Taiwan 2013). Several studies have shown that lean construction can break through the traditional trade-off between cost, speed, and quality (Best and de Valence 2000, Ballard 2000, Arayici et al. 2011, Ko and Chen 2012, Ko and Tsai 2013). The objective of this study is to adapt the lean production system to enhance design accuracy.

BACKGROUND INFORMATION

DESIGN CORRECTNESS

*Design correctness can be regarded as a metric to measure the degree to which design meets the needs of the user or application. The concept has been used in construction, software design, hardware design, and knowledge engineering projects to enhance design quality (*Sandecki 1998, Barrow 1984*,* Riet 2008, Ekenberg and Johannesson 2004, Barber et al. 2003*). First Time Pass Ratio was originally proposed as a standard index for evaluating construction quality, and it has the advantages of easy data acquisition, simple calculation of product quality and clear display of product appearance (Lin 2005). Chen (2009) applied FTPR as a design quality control method, converting FTPR construction evaluation items into design projects to calculate the FTPR in design, thus determining the quality of the design process. This allows for defective designs to be immediately improved rather than waiting until the design was completed or in the construction phase. In the FTRP process, first, FTRP requires a detailed planning inspection and work schedule, followed by the selection of key tasks and quality evaluation. Experienced staff members then evaluate the selected tasks to calculate FTRP. Accuracy calculations and statistical analysis results are represented as the quality of product design, which could be used to provide feedback for design correction and revision.*

SYSTEM DYNAMICS

System dynamics, proposed by Forrester (1961), is used to understand the behavior of systems. It explains dynamic behavior of the system using the causal relationships of the factors and their interdependence (Tesfamariam and Lindberg 2005). Due to this characteristic, system dynamics can be used to understand how things change over time (Forrester, 1991). Population growth is frequently used as an example to explain how system dynamics functions. As shown in Figure 1, population is regarded as a tank, whereas birth rate inflows population into the tank and death rate drains the population from the tank. Through the changing of time, dynamic behavior of the population system can be understood, which can be used to develop social strategies.

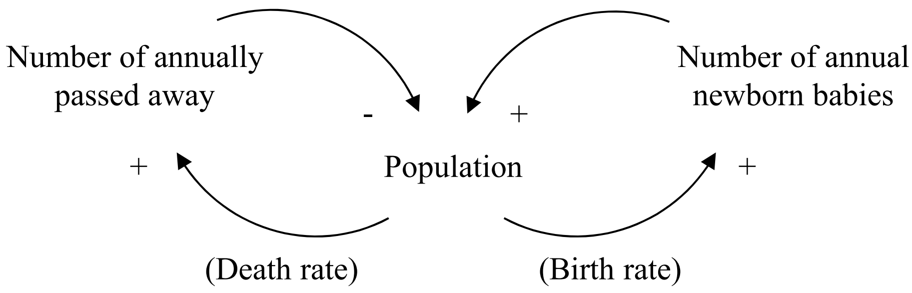

Figure 1: Causal Relationships of Population Growth

CURRENT DESIGN FLOW

Design of construction projects can be largely divided into two stages: preliminary and detailed design. As shown in Figure 2, architectural plans for the preliminary and detailed stages are usually completed independently by architects. Preliminary designs are usually prepared for design competitions, with the winning design plan approved to go to the detailed design stage. Architects make revisions on the winning design plan according to owner's requirements, while the structural portions are handed to structural engineers to generate detailed shop drawings. Once the plans are checked for errors, they are signed and approved. The relevant engineers conduct facility and equipment analysis, after which the plans are again signed and approved after checking for errors. The architect then integrates the prints obtained from these processes. This design workflow may appear smooth on the surface, but it actually hides underlying issues. Failing to uncover these issues in the design phase not only affects the design process, but the actual construction as well.

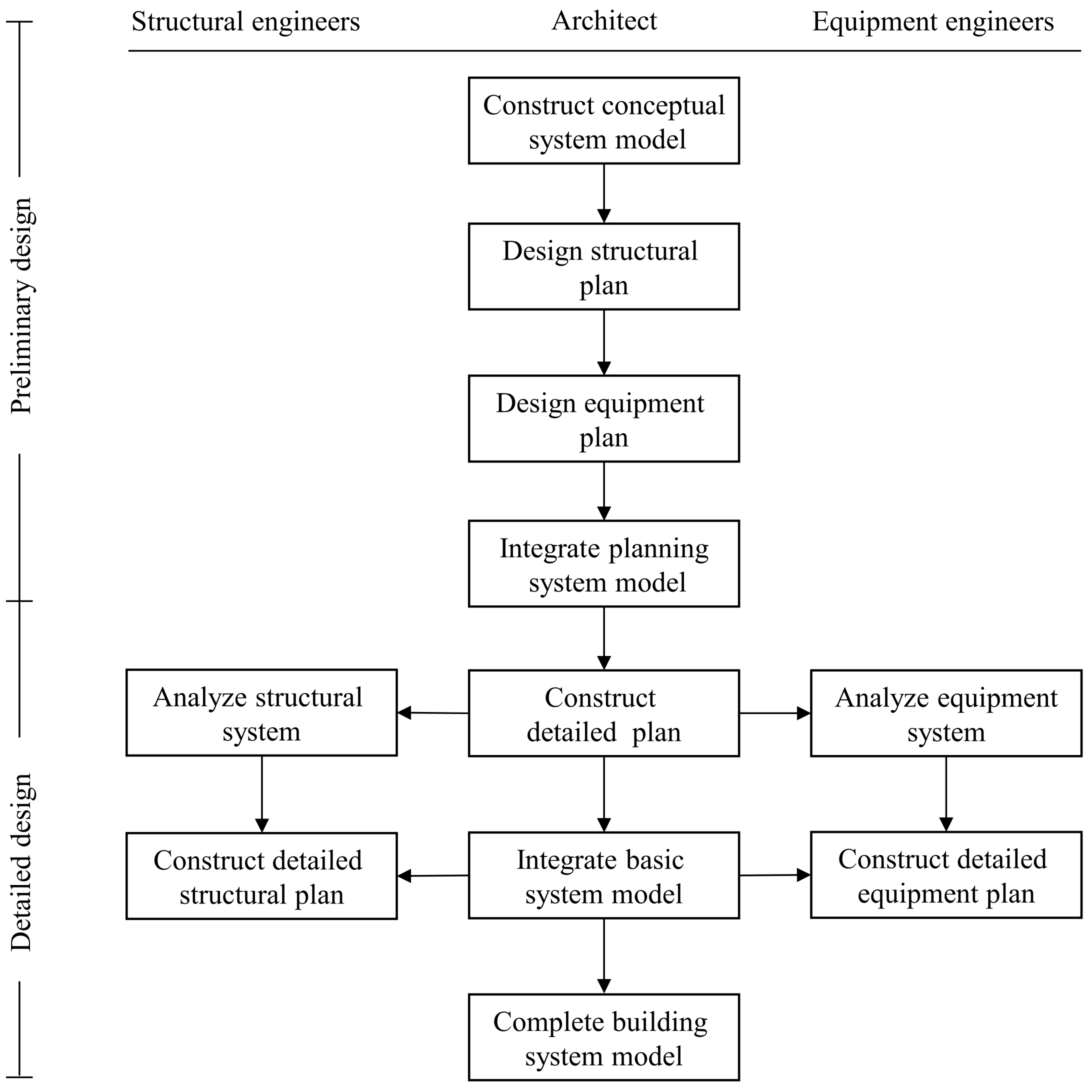

Figure 2: Current Design Workflow

Figure 2 shows the current design and planning workflow. With the exception of the structural and equipment designs which were delegated to structural and equipment engineers, every stage of the design plan is the responsibility of the architect. To analyze issues in the current design process, this research illustrates the current-state value steam mapping of design processes. As shown in Figure 3, the owner first tasks the project design to the architect who would then independently complete each part of the design plan. Structural and equipment engineers must wait until the upstream design work had been finished before analyzing, illustrating and inspecting the designs. The completed work is then handed over to the construction firm to initiate construction. The completed building is then turned over to the owner. If work is obstructed by design errors or construction issues, the design is returned to the architect for corrections.

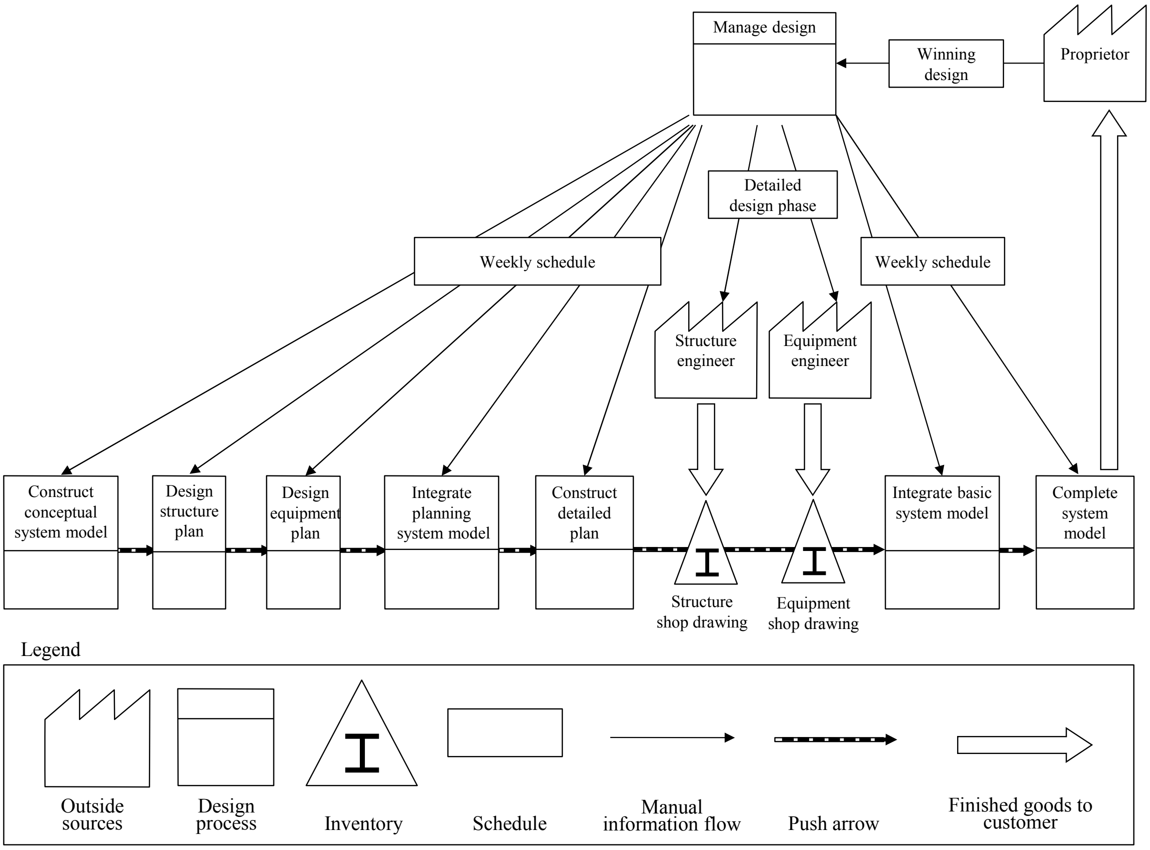

Figure 3: Current-State Value Steam Mapping

LEAN DESIGN PROCESS

Product designs undergo numerous reviews and are subjected to continuous brainstorming sessions by designers before they are actually manufactured. These processes are also applied in construction. Simply put, architectural designs are organizations of space for using material technologies to construct a living environment for people. Hence, architectural designs are by nature multi-disciplinary efforts, requiring consideration of many aspects including structural composition, aesthetics, pipes and cables, water drainage, overall environment, and more. Over its lifespan, from construction through maintenance, a building experiences many problems. As in the automobile industry, even a single oversight in the design process can require design corrections and reviews during manufacture, or time- and cost-intensive repair work (Ko and Chung 2014).

In the proposed design process, as shown in Figure 4, the architect leads the entire design process and is responsible for communicating with the owner. The architect translates the owner's ideas and requirements into an architectural model. The design flow is divided into three stages preliminary design, basic design, and detailed design.

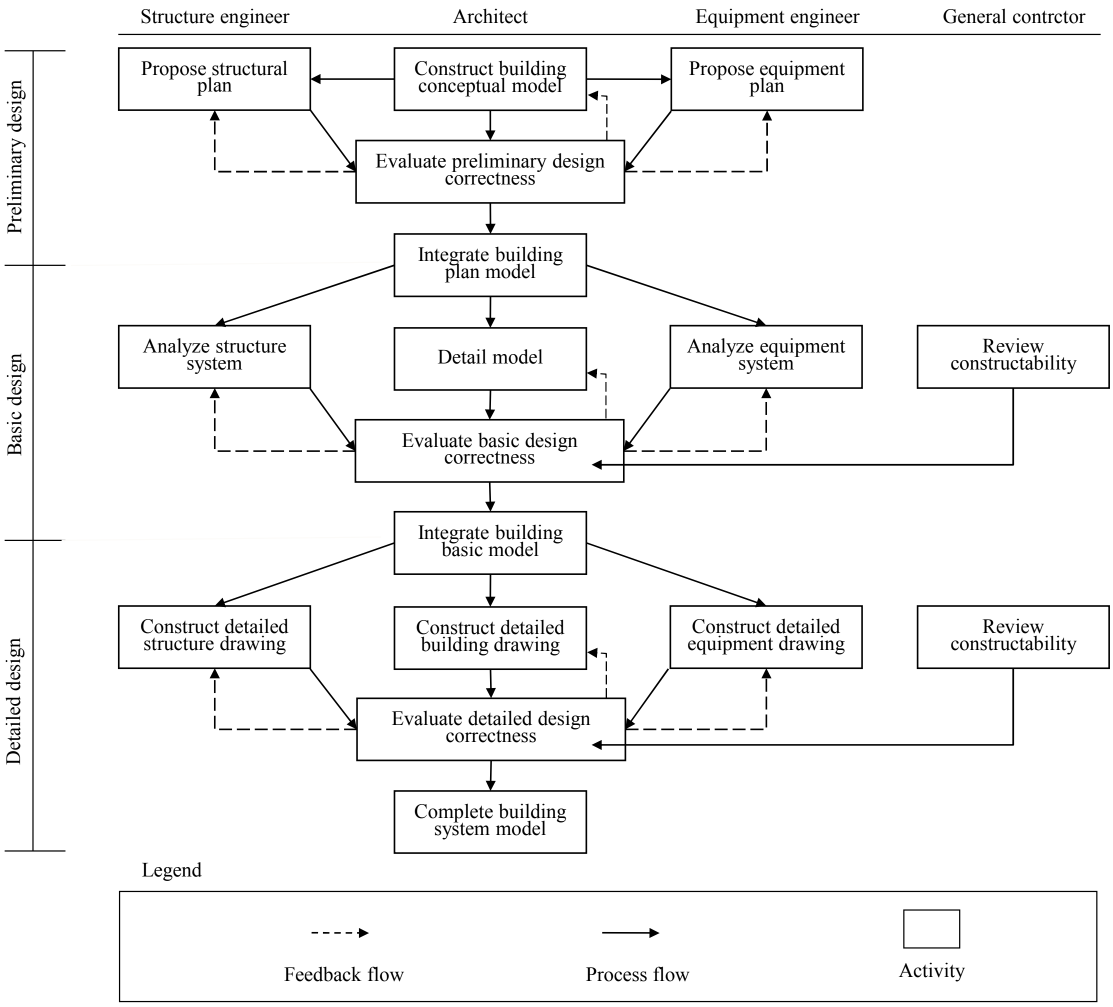

Figure 4: Lean Construction Design Process

PRELIMINARY DESIGN PHASE

The main purpose of the preliminary design phase is to prepare the necessary documents and illustrations for a design competition. These include the exterior perspective, interior perspective, floor plans, sectional plan, elevation plan, and design report. This phase of the design process is led by the architect in close consultation with the owner.

BASIC DESIGN PHASE

This stage focuses on the detailed analysis of the building plan model for the design competition's winning entry, including the planning for structural reinforcements, structural strength and load analysis, water pipe and electrical layout, and emergency evacuation routes.

DETAILED DESIGN PHASE

The aim of this stage is to compile all documentation following three inspections to reduce design errors. Components and equipment in the basic design plan are marked and represented in the design plans. The architect determines the brand, model, and style of the equipment, such as doors, windows, elevators, and air conditioners.

VERIFICATION

System dynamics was used to validate the feasibility of the proposed Lean Design Process, converting the workflow into conceptual causal loop diagrams to analyze possible results when implementing the process. The design flow is divided into three phases: preliminary design, basic design, and detailed design.

PRELIMINARY DESIGN SYSTEM

The aim of the preliminary design system is to understand whether the collected information and building concept can meet the owner's requirements. The architect creates a conceptual building system after inspecting on-site conditions and obtaining design requirements. Information from the design concepts then is sent to the structural and equipment engineers for structural and equipment planning. The preliminary design correctness ratio represents the degree of correctness of the system's design. Failure to achieve 100% correctness triggers successive rounds of corrections until the correctness reaches 100%. Figure 5 shows the preliminary design causal loop. The next design stage is only implemented when the current stage reaches 100%, thus eliminating the need for redesign, which would idle other team members and delay work schedules.

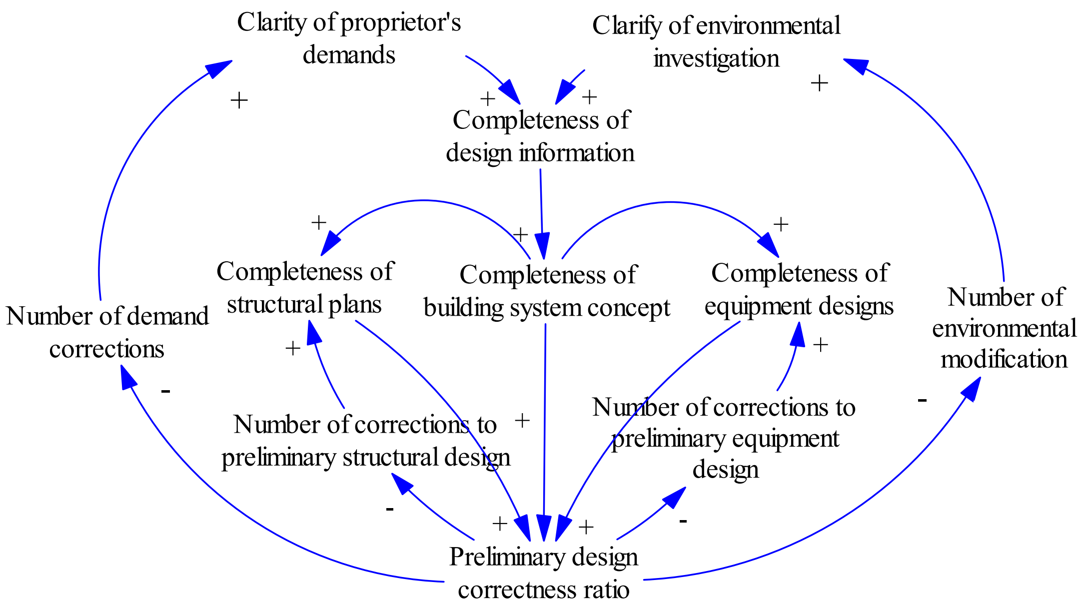

Figure 5: Preliminary Design Causal Loops

BASIC DESIGN SYSTEM

Figure 6 shows the basic design causal loop. Changes to the building model, structural and equipment plans are carried out based on the design correctness results. With the participation of the general contractor, the first round of corrections is able to cover the constructability analysis, structural analyses, model detailing, and equipment analyses. When the basic design correctness ratio has reached 100%, these documents are then sent to the next phase to complete the detailed designs.

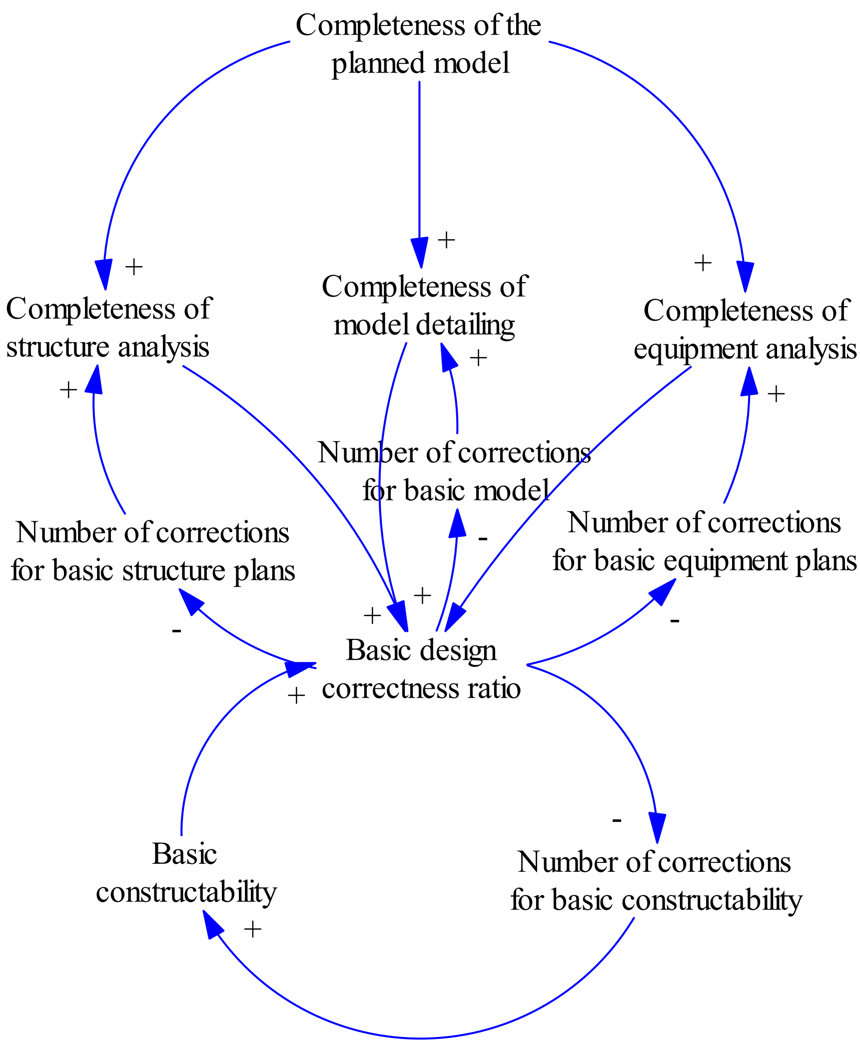

Figure 6: Basic Design Causal Loops

DETAILED DESIGN SYSTEM

As in the previous system, this phase begins with a basic design model with a 100% correctness ratio. Once compiled by the architect, the basic design plans are sent to the structural and equipment engineers to illustrate the detailed plans. The architect also makes detailed changes to the model and assesses design correctness at this stage in consultation with the general contractor regarding constructability analyses. In Figure 7, the general contractor conducts a feasibility analysis while the architect and structural, and equipment engineers reference the design correctness ratio to conduct a first round of corrections to the relevant design prints. Subsequent rounds of corrections are conducted until the finished design is assessed as being 100% correct.

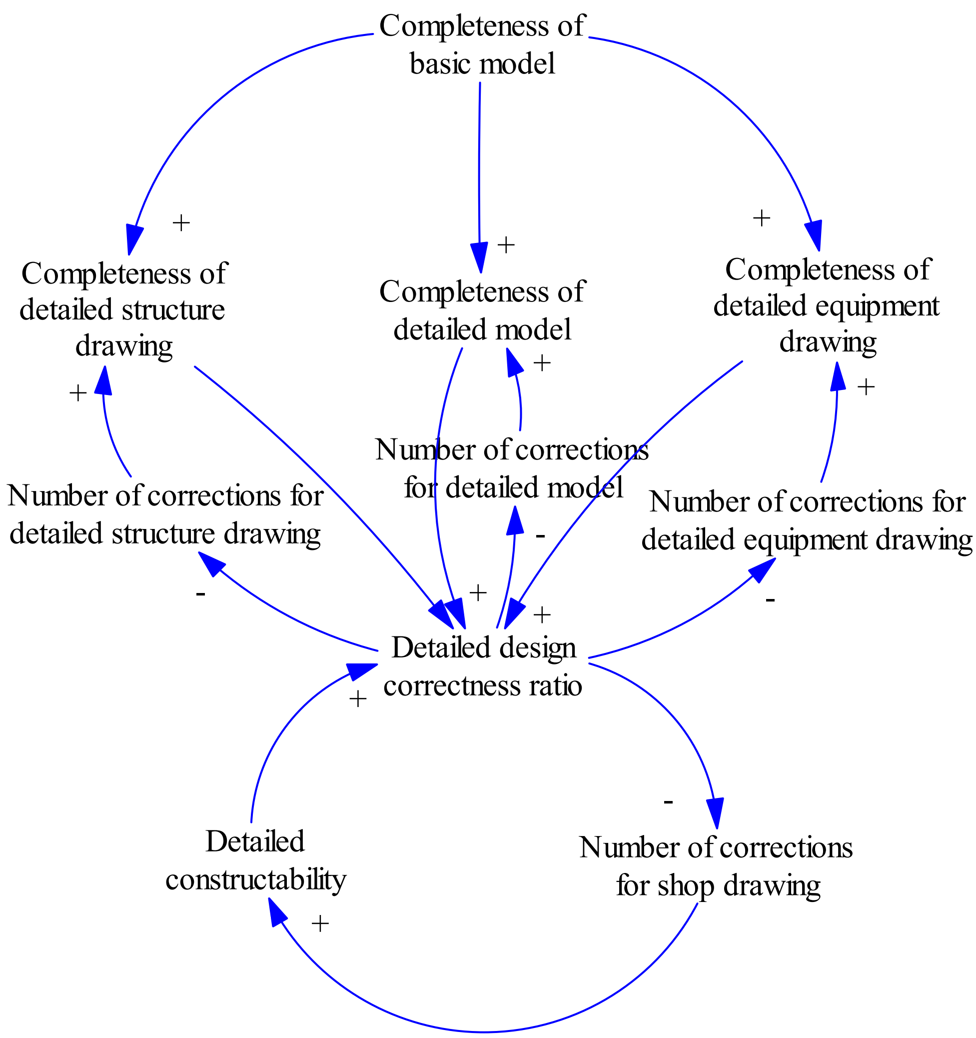

Figure 7: Detailed Design Causal Loops

Design Correctness Analysis

The design correctness ratio is analyzed using system dynamics. Basic design phase can only be launched while design correctness in preliminary design phase achieves 100%. Likewise, when basic design achieves 100% correctness, detailed design phase can be carried out. Experimental results of detailed design phase are displayed in Figure 8. Based on the results shown in line A, model detailing, the detailed structure plan, and the detailed equipment plan attain 100% completeness in the 1st week. The reduced time required for the design period points to the benefits of creating an organizational learning environment for the design team. However, as shown in line B in the figure, the design correctness ratio is affected by detailed constructability, thus the entire design project is completed by the 5th day of the 2nd week, as shown in line C in Figure 8.

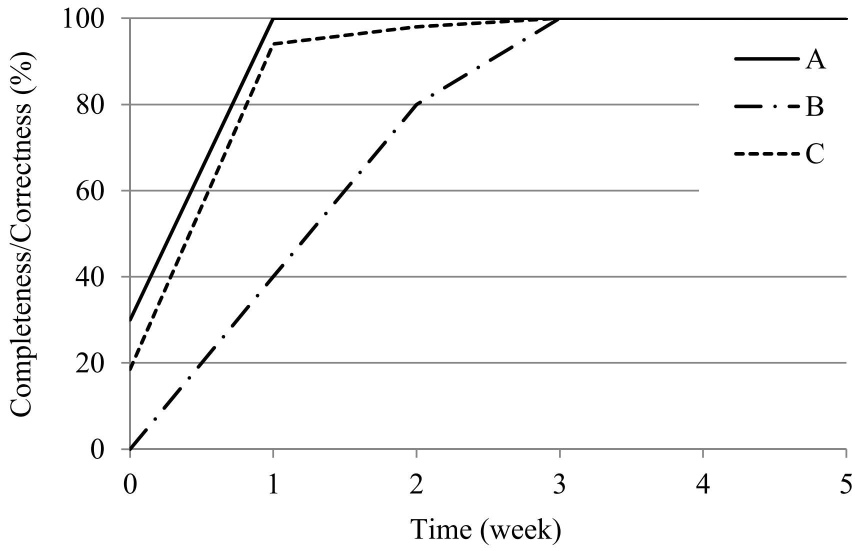

Figure 8: Analyzed Results in Detailed Design System

CONCLUSIONS

This research uses Lean Production perspectives to review traditional planning processes in construction projects. Value streaming is applied to ascertain hidden sources of waste in traditional workflows. A Lean Design Process is then developed using lean concepts to make the process more pliable to owner's needs, i.e. customer's value. System dynamics is used to validate the feasibility of the proposed process, and analysis results show that it can increase design correctness and reliability, thus increasing value to the owner.

Construction projects require the joint effort of professionals from different fields. Currently, design plans tend to be completed independently by the architect, who is responsible for resolving design errors discovered in the design phase or change orders made in the construction phase. Current practice frequently results in schedule delays or budget overruns. This research establishes an organizational learning environment within the design workflow. The root cause of design errors can be identified though systematic inspections of design correctness. This approach not only helps correct the design itself, but allows design team members to learn from errors. In addition, while traditional design processes are divided into two stages (i.e., preliminary and detailed planning), this research seeks to provide project participants with the opportunity to inspect actual design contents by dividing the design process into three phases: preliminary, basic, and detailed designs. This three stage approach, coupled with multiple design feedback cycles, builds team consensus, and allows for the early detection of errors, thus optimizing the resulting design plans.

ACKNOWLEDGMENTS

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