PROCESS-PARAMETER-INTERFACE MODEL FOR LEAN DESIGN MANAGEMENT

D.K.H. Chua[1], A. Tyagi [2]

ABSTRACT

Successful management of design is critical to cost-effectiveness, timeliness and quality of the entire project. This paper presents a model for managing the AEC design from a lean perspective. The model, through its constituent components, aims at achieving lean philosophy objectives, such as, reduction in the share of non-value adding activities, increased transparency, process simplification and increased output flexibility. The model has been called Process-Parameter-Interface model. The entities associated with the model include a Design Dictionary, an Interface, the model engine and an information-based design dependency matrix. These entities enable the design management capabilities in the model, with a focus on lean philosophy.

KEYWORDS

Lean, design rework, transparency, process simplification, output flexibility, key design parameter, Interface, Design Dictionary, Information-based design dependency matrix.

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[1] Assoc. Prof., Dept. of Civil Engineering, National University of Singapore, Singapore 119260
email: cvedavid@nus.edu.sg
[2] Research Scholar, Dept. of Civil Engineering, National University of Singapore, Singapore 119260
email: engp9818@nus.edu.sg

INTRODUCTION

Design management is getting lot of attention in the Architecture-Engineering-Construction (AEC) sector due to its strong implications for the entire project. Successful management of design is critical to cost-effectiveness, timeliness and quality of the entire project. According to one study around 20-25% of the total construction period is wasted due to design deficiencies (Undurraga, 1996). Another study suggests that around 78% of quality problems in AEC are design related (Koskela, 1992-a). From cost point of view, as well, design-caused defects form the largest category (Josephson et al, 1996).

Every AEC project has its own requirements with respect to the way of execution, the place of execution and most importantly, what has to be executed. However, amidst all this diversity, all projects have one thing common to them, and that is, the immense complexities that they possess. The majority of this complexity lies in the design phase of the project, wherein a large number of project participants (stakeholders) with different objectives have to derive a consistent design solution, satisfying the constraints imposed by the design requirements. Hence, design management has assumed significance over the years. At the same time, there has been a growing interest in introducing and applying the principles of lean production (World Class Manufacturing) to the various processes in AEC. The lean production philosophy states, "production consists of conversions and flows and the overall efficiency of production is attributable to both the efficiency (level of technology, skill, motivation etc) of the conversion activities performed, as well as the amount and efficiency of the flow activities through which the conversion activities are bound together" (Koskela, 1992-b).

The potential of efficiency gains in the flows in the AEC design processes is promising and there is a need for reducing the wastes related to flows, such as waiting for information, transformation of information and inspection. The model presented in the paper derives its motivation from the potential for improving flows in AEC design processes. The model is called Process-Parameter-Interface model and it facilitates reduction in non-value adding activities (design reworks), increased transparency, process simplification, increase in the design output flexibility. All these features have been incorporated into the model with the help of the various components of the model, discussed in the subsequent sections of the paper.

REVIEW OF RESEARCH IN DESIGN MANAGEMENT

Several design management models have been developed thus far. Some of the more popular models for modeling design are Pugh's 'total design' model, the VDI model of engineering design and the Pahl and Beitz design model (Austin et al, 1999-a). RIBA Plan of Work for Design Team Operation (1973) is another widely used building design model which models the tasks to be carried out by various design players during each stage but does not model the relationships between the tasks (Austin et al, 1999-b).

Various modeling techniques have been used to model information flow in design. They include data flow diagrams, IDEF techniques (including IDEF0), entity-relationship diagrams, object-oriented modeling techniques, Petri nets and Dependency Matrix (AdePT)

(Austin et al, 2000). Boeing Commercial Airplane Group, in association with MIT, is using Design Structure Matrix (DSM) with Data Driven Approach, for managing its product designs. Design collaboration frameworks like Design Agent based collaboration (Khedro et al, 1994) and Collaborative Construction Agents (Jones et al, 1995) have been developed. The former comprises a collection of *Software Agents*, using which the human designer may perform certain design tasks. The latter comprises numerous agents to enable the various functions of construction management. Change management models like the layer-based model (Krishnamurthy et al, 1995), with capability to manage change at the level of versions, assemblies and configurations and the constraint-checking model (Tiwari et al, 1994) enable the management of design changes. Frameworks, such as, Distributed and Integrated Environment for Computer-aided Engineering (DICE) (Sriram et al, 1993) and the Software Environment to Support Early Phase in Building Design (SEED) (Flemming et al, 1995) leverage information technology advancements for managing design. Information technology is also being used to apply concurrent engineering concepts in AEC (Anumba and Evbuomwan 1997). Hypotheses related to design management have also been proposed (Koskela et al, 1997).

As can be seen from the review of existing work in the field of design management, the existing models focus on a particular aspect, be it transparency, efficient collaboration, design workflow sequencing or passive management of change. However, effective management of design requires a combined focus on all the issues discussed above. Moreover the model must make the design process lean by eliminating or at least reducing the share of non-value adding activities from it and simplifying the design process along with increasing the output flexibility. The proposed Process-Parameter-Interface model provides one such framework for managing design in AEC, wherein the multiple objectives of reducing the share of non-value adding activities (design rework), increasing transparency, process simplification and increased output flexibility, have been addressed. The following section discusses the conventional design process in AEC and is followed by a description of the Process-Parameter-Interface model.

CONVENTIONAL DESIGN PROCESS: LEAN OR FAT

Conventional design processes were studied at a premier AEC design-build organisation of Asia-Pacific, for better appreciation of the need for making the AEC design processes lean.

The design process in AEC is generally led by the architect, who transforms the abstract client requirements into a preliminary project layout. The layout is then used by the engineering design specialists to prepare their designs. There are two levels of information exchange in the design process; broad level and detailed design level. At the broad level of information exchange, two-way interaction is observed between the architect and each of the design specialists for general understanding of the client's intent and the design intent as interpreted by the architect. Decisions such as the type of roof to be adopted are taken at this stage. These decisions take the form of key design parameters and govern the overall design process. After the broad level of information exchange, detailed design begins. During the detailed design stage, each engineering discipline works in isolation, to prepare its designs. The design specialists collaborate with each other, either in case of a potential conflict detected by any design specialist or to confirm their designs with one another. The confirmation of designs is done after the drawings have been prepared by the design specialists. By that time, a lot of resources have gone into preparing the drawings and any change needed in them implies expensive rework.

The design process described above has been shown in Figure 1. Interaction has been shown only among two design processes, namely structural and HVAC, for the sake of clarity.

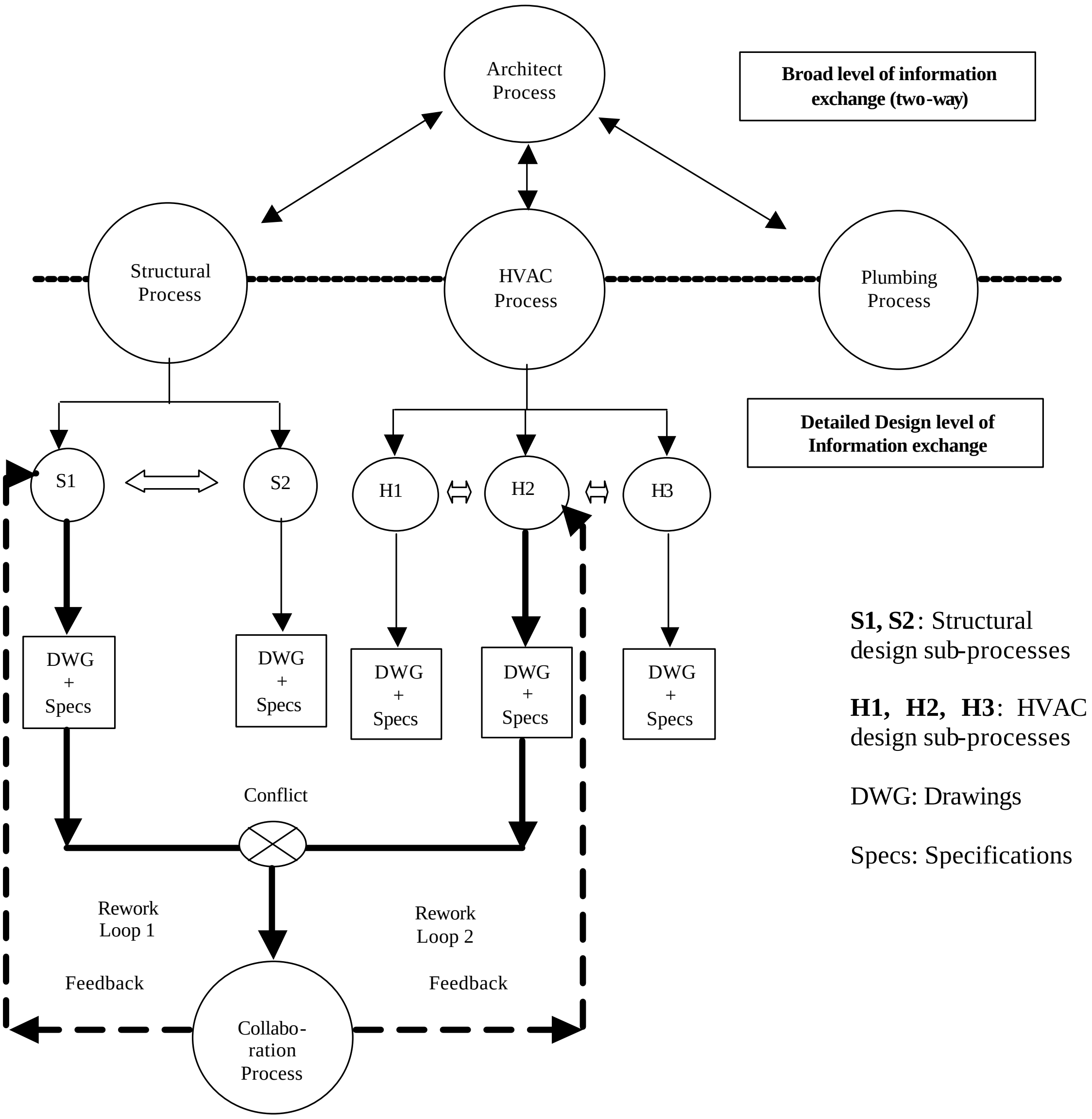

Figure 1: Conventional design process in AEC

Sub-processes within the structural and HVAC design disciplines are all unaware of each other's design parameters, particularly in the detailed design phase, thus leading to an overall design process, that is highly susceptible to conflicts and, consequently, to, numerous rework loops. Moreover, conflict among the structural and HVAC designs is detected after the preparation of design details in the form of drawings/specifications, which leads to long rework loops 1 and 2.

The conventional design process is plagued with long rework loops, although some of these are inevitable. Moreover, the transparency is at the level of drawings whereby a lot of resources have been exhausted till that stage. Collaboration is mainly passive, triggered by a potential conflict foreseen by a design specialist or a conflict discovered during collaboration at the drawings level. These issues motivate the application of lean principles to the design process. The model proposed in this paper is a means to that end.

PROCESS-PARAMETER-INTERFACE (PPI) MODEL

The Process-Parameter-Interface model is a framework for design management, using lean principles. It aims at achieving lean philosophy objectives, such as, reduction in the share of non-value adding activities, increased transparency, process simplification and increased output flexibility. The model is shown in Figure 2 below.

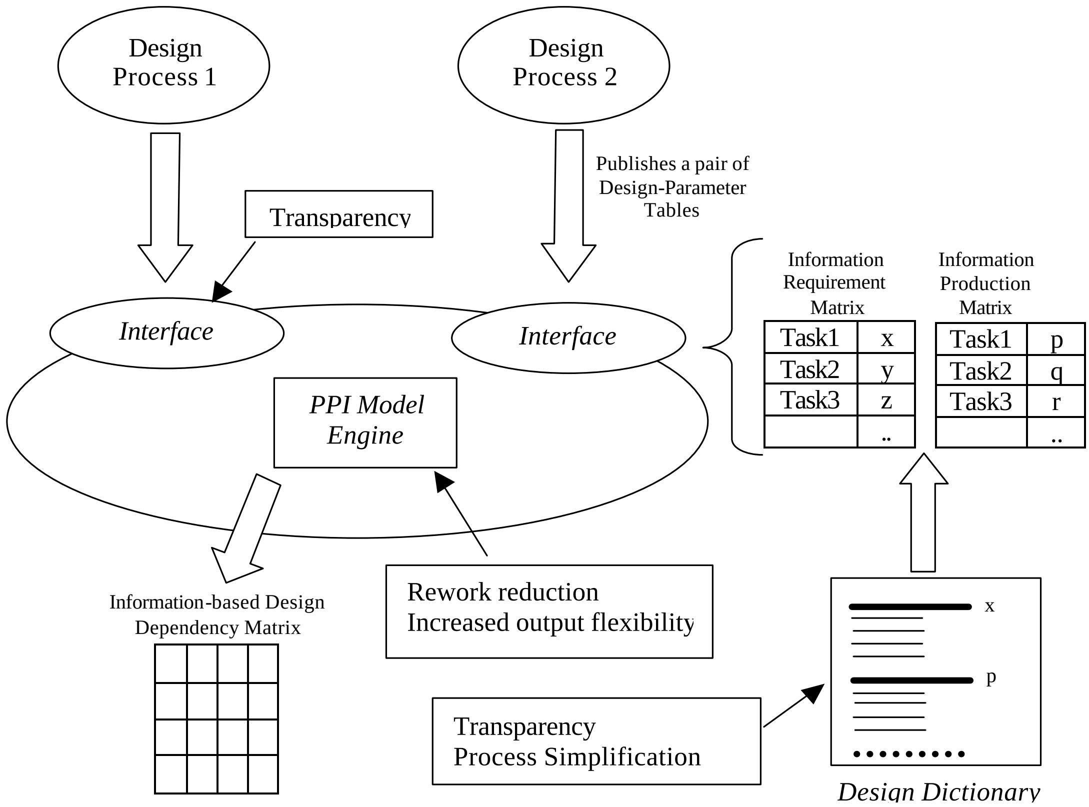

Figure 2: Process-Parameter-Interface Model

Design reworks form a major part of non-value adding activities in the AEC design processes. These design reworks can be avoided by active collaboration among the design specialists over key design parameters. This is facilitated by the model engine, which generates a sequence, optimised with respect to the number and length of rework loops. Besides, the engine also prompts the appropriate design specialists at appropriate times for the design parameters that they need to produce. The model comprises a design dictionary, which imparts transparency. Transparency is further facilitated by means of Interfaces. Process simplification is achieved through the use of the design dictionary while output flexibility is increased by frequent proactive collaboration among the design specialists facilitated by the model engine. Each of these components, along with their relevance is discussed in the following paragraphs.

DESIGN DICTIONARY

Design Dictionary is a vocabulary of the key design parameters being used in the design process by the different design specialists. These design parameters have attributes associated with them, which yield a better insight to the design process. The design dictionary adds transparency to the entire design process in terms of each design specialist's awareness of the key design parameters used by other design specialists. Besides transparency, the defining of design parameters in the Design Dictionary, also contributes to simplification of the processes through standardization of design parameters, used across the entire design process, which helps to avoid misinterpretation of the design parameters.

The attributes associated with each key design parameter in the Design Dictionary have been discussed below:

Estimability: It is the measure of ease with which the value of a parameter can be assumed or estimated, incase the parameter value is unavailable. If the parameter has a well-defined and narrow range of values, it is supposed to have high estimability. Estimability has been graded as Low, Medium and High. This attribute can give a fair idea as to the whether a particular design process can be started even before all the parameters required by it are available.

Volatility: This is the degree of potential of change of the design parameter due to an external environment like building authorities or other agencies. If the parameter has a high chance of being changed by an external authority, it is supposed to be highly volatile. Volatility has also been graded as Low, Medium and High.

Owner: Refers to the design specialist who owns a particular parameter. By owning a parameter, the specialist has the freezing command over it. A parameter can have only one owner. However a design specialist may own more than one parameter. Generally, the parameter owner shall initiate any negotiation process to resolve the conflict involving the parameter.

Judging the Estimability and the Volatility of a design parameter requires design experience. However, at times, the external factors affecting the design are completely unpredictable which makes volatility difficult to measure. Ownership, on the other hand, is easy to determine because the design responsibilities are generally fixed at the start of the design and the design specialists are well aware of the design outputs that have to be generated by them.

INTERFACE

As a result of increasing specialisation in AEC design, multi-disciplinary design teams, often from different organisations, are becoming increasingly common. Most of these design specialists have their own proprietary design processes. Although they interact with each other to resolve conflicts or to improve the design, they are not always at ease, sharing their design process with other specialists. Moreover, the design processes are generally irrelevant when it comes to collaboration because the design specialists mainly seek information that they require as inputs to their design processes, while preparing their designs. The Interface addresses both these issues.

Each design specialist publishes his/her parameter requirements as well as the parameters generated by him/her, corresponding to the design processes he/she is responsible for, through the interface. These requirements are in the form of a set of matrices, called Information Requirement matrix and Information Production matrix. Each of the design processes in the model has an interface attached to it. The Interface facilitates transparency among the design processes at the level of information exchange, without requiring the revelation of design processes, at the process level.

Besides increasing the transparency, publishing the parameter data through the interface also helps to avoid non-value adding activities, such as, data collection and verification, which are generally scattered over the entire design.

The idea of the interface is illustrated with the help of a design case for a conference room. Structural, HVAC and Lighting design processes are involved the design. Figure 3 shows the Information Requirement Matrix and Information Production Matrix for each of these processes.

PPI MODEL ENGINE

The PPI Model Engine generates a sequence, in which the key design parameters involved in the design processes, must be produced. This sequence is such that the rework loops are as short as possible and as few as possible. Such optimised scheduling of the design process information facilitates reduction in the share of a major non-value adding activity, namely the rework.

The engine prompts the appropriate design specialists at appropriate time for the design parameters that they need to produce, on the basis of the schedule that it generates, thus facilitating a lean design workflow. The lean design workflow enabled by the engine also offers an opportunity for restructuring the processes, that is, process re-engineering.

Structural Process

Information Requirement Matrix

Task	Task description	Parameters Required
T_{s1}	Determination of free height, based on architectural requirement, depth of beam and space requirements for lighting and HVAC ducting.	Beam Depth (H_b), Duct Size (D)

Information Production Matrix

Task	Task description	Parameters Produced
T_{s1}	Determination of free height, based on architectural requirement, depth of beam and space requirements for lighting and HVAC ducting.	Free height (H_f)

HVAC Process

Information Requirement Matrix

Task	Task description	Parameters Required
T_{h1}	Heating Loads determination	Heating load (Q), Free height (H_f)
T_{h2}	Layout determination	Length (L), Room width (B)

Information Production Matrix

Task	Task description	Parameters Produced
T_{h1}	Heating Loads determination	Duct Size (D)
T_{h2}	Layout determination	Duct Spacing (S)

Lighting Process

Information Requirement Matrix

Task	Task description	Parameters Required
T_{l1}	Lighting Requirement determination	Illumination Required (I)
T_{l2}	Lighting Layout determination	Length (L), Room width (B), Duct Size (D)

Information Production Matrix

Task	Task description	Parameters Produced
T_{l1}	Lighting Requirement determination	Lighting Equip. Size (H_l)
T_{l2}	Lighting Layout determination	Lighting Spacing (S_l)

Figure 3: Information Requirement and Production Matrices for Structural, HVAC and Lighting processes

The engine also facilitates frequent proactive collaboration among the design specialists, which helps to make the design process highly flexible in terms of the output. Since the collaboration is more frequent, the potential design conflicts can be known earlier and changes can be made, as compared to the conventional design process where generally conflicts are resolved after the drawings have been prepared. However, at times the design conflict can only be discovered after the details have been prepared. In a design process, where the cost of late changes is very high (Reinertsen, 1997), it is important to restrict changes to the upstream of the design process. The engine facilitates this function by enabling the collaboration, as discussed above.

The sequencing done by the engine is through generation of an information-based design dependency matrix, based on the information contained in the interfaces in form of Information Requirement Matrix and Information Production Matrix. The information-based design dependency matrix is a square matrix showing the information dependencies among the design parameters of the processes being considered. The matrix has been shown in Figure 4 for the design case illustrated in Figure 3. The design parameters involved in the three processes, namely, structural, HVAC and lighting, are written on the left and top of the

	Q	B	L	I	H_b	D	H_f	S	H_l	S_l
Q										
B										
L										
I										
H_b										
D	*						*			
H_f					*	*				
S		*								
H_l				*						
S_l		*	*			*				

'*' implies dependency of row parameter on the column parameter

Feedback/rework loop

Figure 4: Information-based Design Dependency Matrix

matrix. The asterisk marks in the cells of the matrix denote the dependency of the corresponding row parameter on the column parameter, that is, the generation of the row parameter depends on the column parameter(s). The design parameters are sequenced using the Dependency Structure Matrix (DSM) approach (Steward, 1981) based on their information dependency such that the rework loops can be curtailed with respect to size and number.

The PPI model adopts information-based sequencing instead of process-based sequencing, that is, it sequences the information rather than sequencing the processes directly. This is motivated primarily by two factors; smaller size rework loops as brought out by information-based sequencing and greater transparency in information-based sequencing. For the purpose of illustration, an Information-based Design Dependency Network has been developed (Figure 5) from the Information-based Design Dependency Matrix shown in Figure 4.

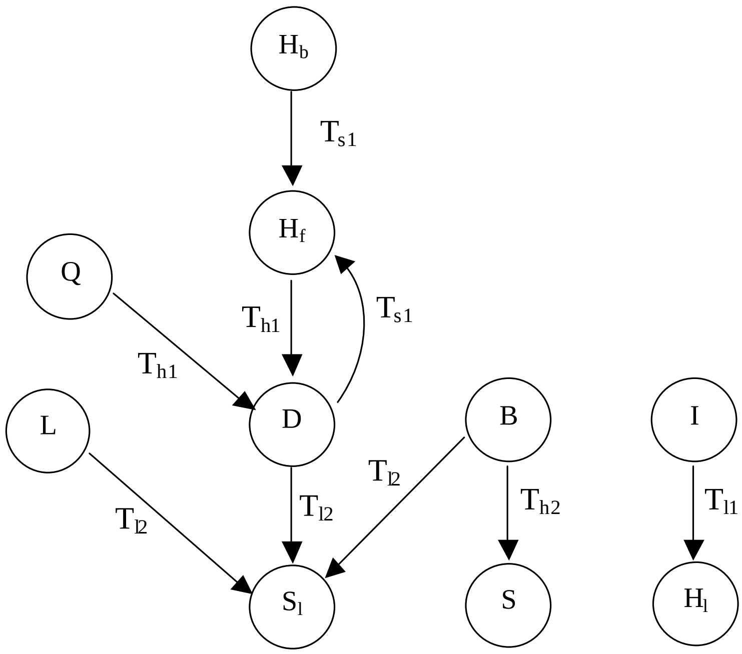

Figure 5: Information-based Design Dependency Network for matrix in Figure 4

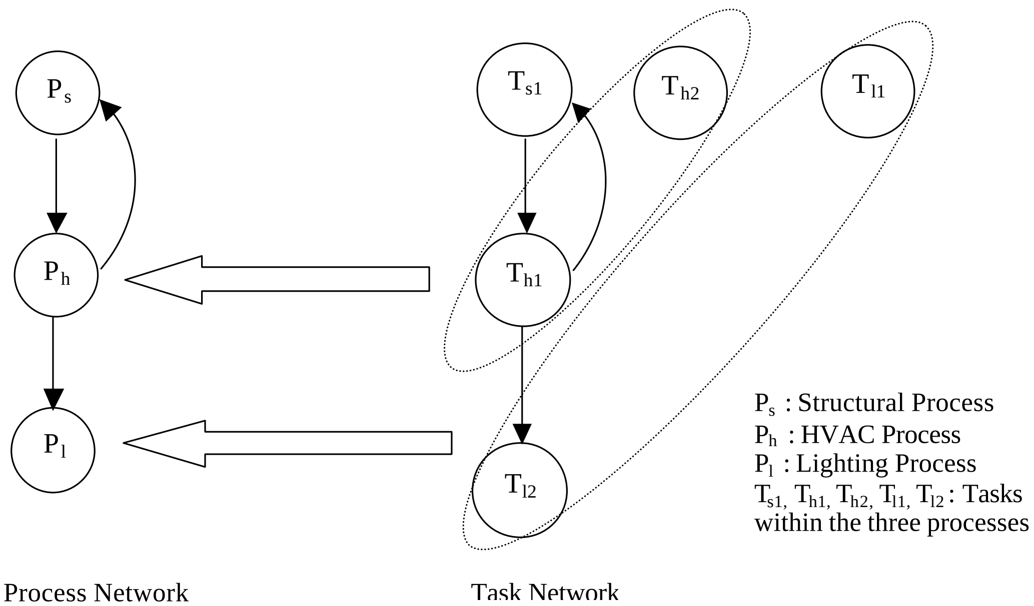

Figure 6: Process and Task Networks

The network has been mapped to process and task networks, which are depicted in Figure 6. It is observed from the comparison of process and task networks, that the non-involvement of the task, T_{h2}, belonging to process P_h, with the feedback loop P_s-P_h-P_s, is encapsulated. The task network on the other hand is capable of overcoming this. It can be seen from the task network that the task $T_{l1,}$ belonging to the Lighting process, can be started even before the Structural and HVAC processes have finished. For complex processes, the gains in transparency and the shortening of rework loops, achieved through the information-based sequencing, will be, intuitively, more appreciable.

An important point that deserves attention is that, in the information-based sequencing, the information dependencies are expressed explicitly thus enabling a better understanding of the design process. The model uses the information-flow, which is the life-line of processes, for managing the design process.

CONCLUSIONS

The model presented in the paper is an effort in the direction of making the AEC design processes lean. The model, through its constituent components, facilitates reduction in the share of non-value adding activities, increases transparency, simplifies design processes and increases the output flexibility. Design reworks constitute a major portion of non-value adding activities in the AEC design processes. The model's engine through its information-based scheduling capability and by enabling active collaboration, helps to reduce the reworks, both in number and the length. Moreover, output flexibility is increased by frequent proactive collaboration among the design specialists facilitated by the model engine. This is because frequent proactive collaboration makes the design process more responsive of any changes made during the design, instead of resolution of changes after the preparation of drawings. Thus the flexibility in the design output, with respect to making changes, is increased. The Design Dictionary and the Interface help to achieve process transparency. Design Dictionary also facilitates process simplification.

Validation and implementation of the model, using information technology, is the next exercise that we look forward to.

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