REPRESENTATIONS OF BUILDING DESIGN PROCESS WITH ITERATIONS

Tzong-Shiun Liau and Wei-Chih Wang[2]

Graduate Student, [2]Assistant Professor, Department of Civil Engineering, National Chiao-Tung University, Hsin-Chu, Taiwan

Abstract: Design has an inherently iterative nature, especially for multi-disciplinary building design projects. Managing the design process with the consideration of this iterative nature needs to cluster the complex dependencies between design tasks and information delivered between design disciplines and to represent it in a communicable way. This paper uses modified IDEF0v notations to capture the characteristics of design process with iterations between multi-disciplinary design tasks and delivery systems for supporting design management. A framework built on a simulation-based computer implementation strategy and recommendations of future work are also provided.

Keywords: design management, multi-disciplinary design task, design iteration, delivery system, and iterative design cycle

1. INTRODUCTION

Design usually has an inherently iterative nature, especially for some multi-disciplinary building design projects. For example, determining the layout of a clean room of factory for a building design process requires numerous types of design information or data, such as the master plan of building layout, capacities of industrial processing facility, calculations of structural loadings, and specifications of EMP (electrical, mechanical, and piping) facility. These data may come from multiple design disciplines, such as architects, and structural / EMP / industrial processing / mechanical system consultants. A common phenomenon is that the information will be pitched back-and-forth between these disciplines (or between different design tasks) or may flow within a particular discipline for a number of times. These information pitches and flows can be viewed as the iterations of design. And these iterations will not disappear until the requirements of design constraints (e.g., codes and owner's needs) are met.

The iterations of design can be divided into two types: iterations between design tasks and iterations between disciplines (design teams). Although the control of these iterations are critical for a sound design management, the practice's approach is experience-based and does not have a formalized tool for dealing with. As a result, many kinds of design-related problems, such as last minute design, changing design, missing information, gate keeping of information and incomplete design deliverables frequently occur 6. Because of the complex nature of design process, the first step to challenge these iteration-related problems is to research how the iterations can be incorporated into the design process through a representative way.

2. PAST RESEARCH

In 1994, Sanvidor and Norton proposed an Integrated Design Process Model (IDPM) based on an established modeling representation technique, called IDEF0 (Integrated Computer-aided Manufacturing Definition) 6. Based on the capability provided by the IDEF0 techniques, the IDPM allows to set rules to represent different types of information. However, the design iterations and information delivery systems of design disciplines are not considered.

In 1998, Khemlani *et al* developed an intelligent representation scheme for modeling building components 6. The iterative nature of design process is disregarded.

In 1999, Austin *et al* proposed another detailed design process and data model, called Analytical Design Planning Technique (ADePT), by using the modified IDEF0 notation 6. The unique features of this model include (1) The inter-disciplinary design tasks for representing the iterations of multi-disciplines were defined. (2) The model represents design iterations with Dependency Structure matrix Analysis (DSM). (3) The design tasks are assumed to be the Functional Primitive Tasks (FPTs), i.e. a minimum manageable package. Still, however, the number of iterations and information delivery systems are not evaluated.

In addition to these three models, the characteristics of other five current design and data models are also reviewed and summarized in Table 1. Overall speaking, the models, such as Data Flow

Diagrams [1, 3, and 4], that are able to identify the design iterations only view the design process as having a one-iteration nature between design tasks. None of them reflects the design reality of having a N-iteration nature. Also, most existing models do not identify the delivery systems of design disciplines, and assume there are no relationships between design disciplines, [3, 4, 6, 8, 9, and 10]. For some models that do identify the delivery systems of design disciplines, the focus is only on the development of mechanisms for supporting electronic data interchange (EDI) [6, 11]. It is these deficiencies that form a strong need for conducting the research here.

Table 1. Comparisons of Current Design Process and Data Models

Author(s)	Research focus	Modeling focus	Iterations focus	Disciplines focus	Research method	Design phase studied
Eldin, 1991 6	Electronic data exchange	Modeling data	Not applicable	OBS	Database approach	Multiple phase
Sanvidor and Norton, 1994 6	Multiple phase modeling	Modeling process	IDEF0 notation	OBS	IDEF0	Multiple phase
Austin et al, 1994 6	Information flow modeling	Modeling process	Coupled tasks	FPTs	DFD and DSM	Programming phase
Baldwin et al, 1998 6	Simulation of information flow	Modeling process and data	Coupled tasks	Not applicable	Data Flow Diagram	Multiple phase
Khemlani et al, 1998 6	Building components	Modeling data	Not applicable	Not applicable	Object database	Schematic design phase
Austin et al, 1999 6	Detailed design modeling	Modeling process and data	Interdisciplinary design tasks	FPTs	IDEF0v and DSM	Detailed design phase
Baldwin et al, 1999 6	Information flow modeling	Modeling process	Coupled tasks	Not applicable	Data Flow Diagram	Conceptual and schematic phase

DFD: Data Flow Diagram; DSM: Dependency Structure Matrix;
FPT: Functional Primitive Task; OBS: Organizational Breakdown Structure

3. TERMINOLOGY

Before further discussing the details of representing design process with iterations, it will be beneficial to introduce some terminologies used in this paper first.

(1) Design: to deliver a paper package that consists of drawings, specifications and others that meet the govermental regulations (codes) and owner requirements for designing a project.

(2) Design information: the design data are such as the sketches, drawings, specifications, notices, standards, etc. required to design a specific design element (column, beam, loading, etc.).

(3) Information flow: a flow that contains design data coming in and out between design tasks via design dependencies.

(4) Design dependency: a logical or physical relationship that indicates design information flows through one design task to another. This relationship or dependency can be represented by an arrowed link (→).

(5) Design task: design activity or functional primitive task (FPT), e.g., designing the drawings of a building structure.

(6) Design discipline: a design team or company that performs the design task.

(7) Design iteration: a design interation means a particular type of information coming back and forth bewteen design tasks for one time. This is a special case of design dependency between two tasks. The iteration between two tasks is represented by a connected link with arrows on both sides (<—>). The design iterations frequently exist for providing a fully supportive information design environment.

(8) Discipline iteration: a discipline interation means a particular type of information deliverable coming back and forth bewteen design disciplines for one time. This is a special case of delivery system between two disciplines, and the two disciplines are connected by a link with arrows on both sides (<—>).

(9) Delivery system: a system that defines the way that design information is delivered between design disciplines.

(10) Design process: a process that consists of a series of design tasks, information flows, dependencies, and iterations.

(11) Intra-disciplinary design task: a design task that is performed by varying disciplines in the same company (high-level discipline). In other words, the design iterations between intra-disciplinary design tasks will only occur in the same company.

(12) Inter- or multi-disciplinary design task: a design task that is performed by multiple disciplines in different companies.

4. REPRESENTATIONS OF DESIGN PROCESS WITH ITERATIONS

This section first introduces the research methodology for representing design process. Then, the research results are presented.

4.1 Research Methodology

The methodology of this research include the following steps: (1) modeling design dependency of design tasks, (2) modeling types of design information, (3) using a representation technique to capture design iterations, (4) modeling types of delivery systems between disciplines, (5) incorporating design information into delivery systems, (6) reflecting iterative design cycles, and (7) generating design patterns.

4.2 Design Dependency W/ or W/O Design Iterations

As defined by Eppinger 6 and presented in Figure 2, the possible sequences between two design tasks can be classified as three types: Series, Parallel and Couple. And the tasks in each of these three categories are called as dependent, independent, and interdependent tasks, respectively. Among these three categories, only the coupled tasks can have design iterations.

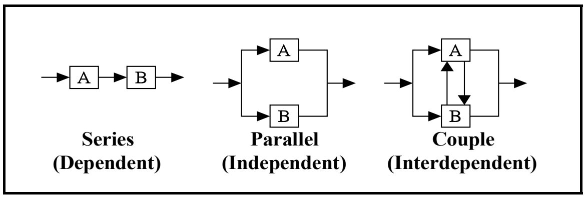

Figure 1. Possible Dependencies between Two Design Tasks (Eppinger, 1991)

By further expanding the concept of dependency stated above, the possible patterns of dependencies with (W/) and without (W/O) design iterations can be derived as shown in Figure 2. The symbols of and O represent different disciplines.

In Figure 2, part (a) presents the patterns of design dependency of tasks that have no design iterations in between. Since the tasks for a series or a parallel are executed by one discipline, they are called as W/O-iteration intra-disciplinary design tasks. Similarly, due to the existence of couple dependency, the tasks shown in part (b) are called as W/-iteration intra-disciplinary design tasks. And part (c) shows the W/-iteration inter- or multi-disciplinary design tasks that are executed by different disciplines. These tasks are normally found in multi-disciplinary design projects. Giving different terminologies to design tasks allows management to pay more attention to the W/-iteration design tasks. These developed patterns set a base for modeling the design process considering the design iterations and information flow classifications.

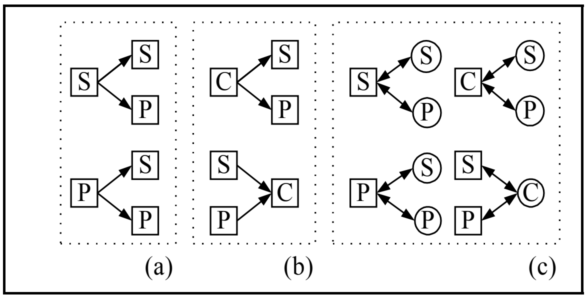

Figure 2. Patterns of Design Dependency W/ and W/O Design Iterations

4.3 Types of Design Information

Representing the design process has to deal with numerous types of design information. In this paper, the design information is divided into four categories, which are described as follows:

(1) Inter-disciplinary design information: The information that flows from one discipline to another that is at the same contractual or the same level of the hierarchical or organizational chart.
(2) Intra-disciplinary design information: The information that flows in a particular high-level discipline (i.e., a company).
(3) Cross-disciplinary design information: The information that flows from one discipline to another that is not at the same level of a hierarchical or organizational chart.
(4) External-disciplinary design information: The information that flows from external disciplines.

Because design information is usually only delivered between disciplines with contractual or logical relationships, classifying the information allows management to identify the disciplines who are responsible for delivering or receiving the required design information.

4.4 Use of Modified IDEF0v Notations to Capture Design Iterations

In order to capture varying types of information flowing through different patterns of design dependency W/ or W/O iterations, a modified IDEF0v notation mechanism is adopted. However, unlike ADePT 6, the information classification used here considers the hierarchical and organizational relationships between design disciplines. Figure 2 shows an example of using IDEF0v to represent how varying types of design information delivered and iterated between three design tasks.

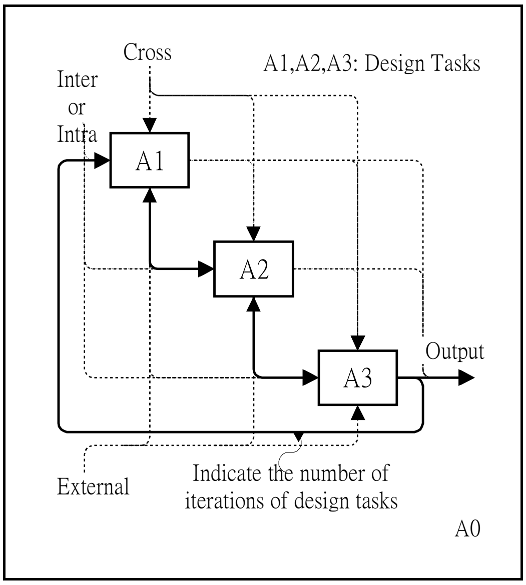

Figure 3. Example of Coupled Dependency W/ iterations for Three Design Tasks

4.5 Delivery Systems between Disciplines

While the design process may be represented for the purpose of controlling design tasks (as presented in previous subsections), more often it would be beneficial to evaluate how information is delivered between people i.e., disciplines. This evaluation provides a way to identify the key disciplines that are responsible for some design-related problems, such as missing information and gate keeping.

Six delivery systems between multiple disciplines are developed and presented in Figure 4. Each of these delivery systems is described as follows:

(1) P2 must receive information from P1 before he can proceed.
(2) P1 delivers information to P2 and P3, but P3 must also receive the information from P2 before he can proceed.
(3) P1 delivers the same information to P2 AND P3 simultaneously.
(4) P1 delivers information to P2 OR P3.
(5) P1 delivers the same information to P2 AND P3 simultaneously; P2 and P3 have information iterated in between; and P4 must receive information from P2 and P3 before proceeding.
(6) P1 delivers the same information to P2 OR P3; P2 and P3 have information iterated in between; and P4 must receive information from P2 and P3 before proceeding.

In Figures 4(5) and (6), the information should be delivered between P2 and P3 until the design needs are met. These delivery systems with iterations deserve management to pay special attention.

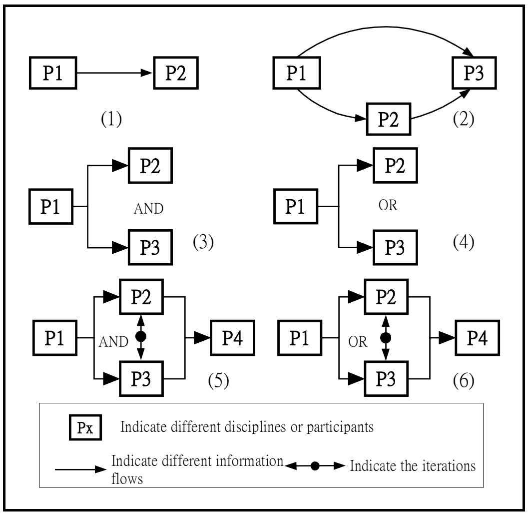

Figure 4. Possible Types of Delivery Systems

4.6 Delivery Systems with Information Types

Note that the representation of different delivery systems shown in Figure 4 does not capture the types of information delivered between disciplines. Figures 5 and 6 show two examples of W-iteration delivery systems with the representation of classified information. While Figure 5 represents the information flow by IDEF0v notations, Figure 6 is by a hierarchical organization structure.

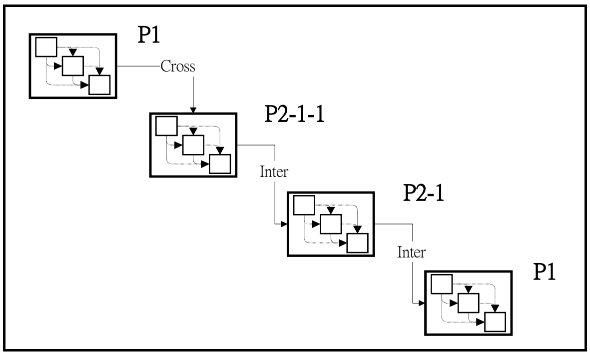

Figure 5. Example of W/ iteration Delivery System by IDEF0v Notations

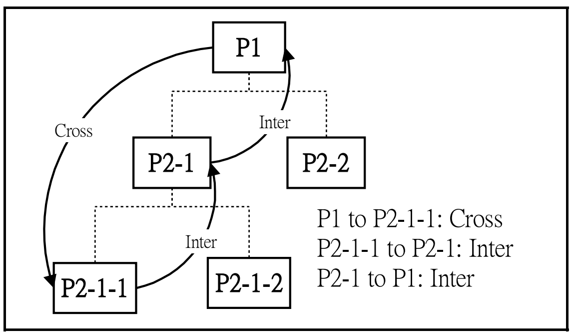

Figure 6. Example of W/ iteration Delivery System in Hierarchical Representation

4.7 Iterative Design Cycle

The iterative design cycles exist in both intra-disciplinary and inter-disciplinary iterative design tasks. Figure 7 shows an example of describing how design information is iteratively delivered between two design tasks. In the figure, the symbol "N" (number of iterative design cycles) indicates the number of iterations that the information will be iteratively delivered between two tasks. That is, the design process will proceed to the next design stage or initiate the design tasks followed by A2 only when the information delivered between A1 and A2 is iteratively delivered for N times.

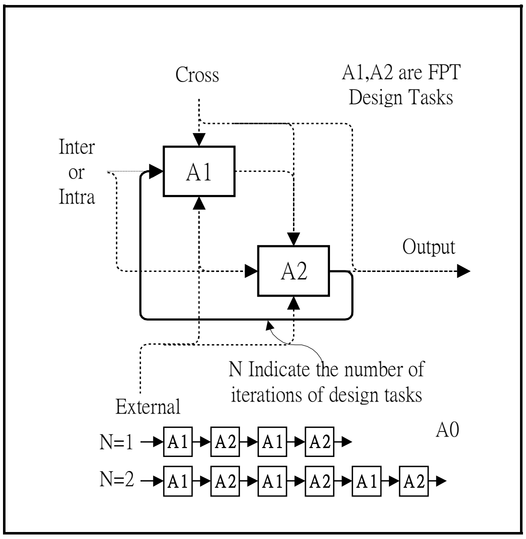

Figure 7. Example of Iterative Design Cycles between Two Design Tasks

4.8 Generation of Design Patterns

Built on the IDEF0v notations, the varying types of design patterns may be generated by incorporating the representation approaches proposed in sections 4.2~4.7. By starting with three types of dependency (i.e., series, parallel, and couple) and considering the W/ & W/O iterations, types of design information, etc., Figure 8 shows an example of the logic for generating the design patterns. Each of the generated design patterns will then be libraried and represented by IDEF0v notations.

5. IMPLEMENTATION STRATEGIES

The framework of computer implementation strategies of the proposed representation mechanisms is shown in Figure 9. The core strategy is the use of future-selected simulation software. Based on the cyclic nature of simulation, the iterative nature of design process may be easily captured. And the use of uncertainty in simulation further allows to model the uncertainty in design process (e.g., uncertain number of iterations between disciplines). Also by incorporating the productivity rates of the design disciplines into a simulation-based model, expected outcomes of design duration and cost can be calculated for measuring design performance. Other special features provided by simulation, such as Combi activities (for representing design tasks), queues (for storing design patterns, and disciplines), and links (for carrying varying types of design information), make these implementation strategies feasible. More details of this simulation-based implementation framework can be found in Figure 9.

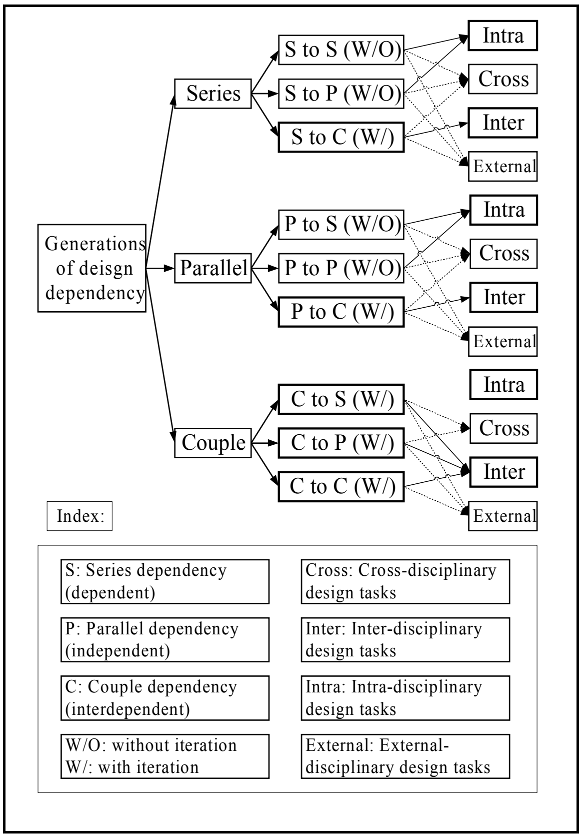

Figure 8. Example of the Logic for Generating Design Patterns

6. CONCLUSIONS AND FUTURE WORK

The major contribution of this paper is the representation of design process with the consideration of iterations (i.e., design iterations and discipline iteration). However, the research results shown here are developed only based on the evaluation of two or three design tasks. Therefore, future work is required to expand to a larger pool of design tasks for modification and verification. Two other on-going research jobs are to computerize the representation mechanisms and to test the mechanisms via a case study.

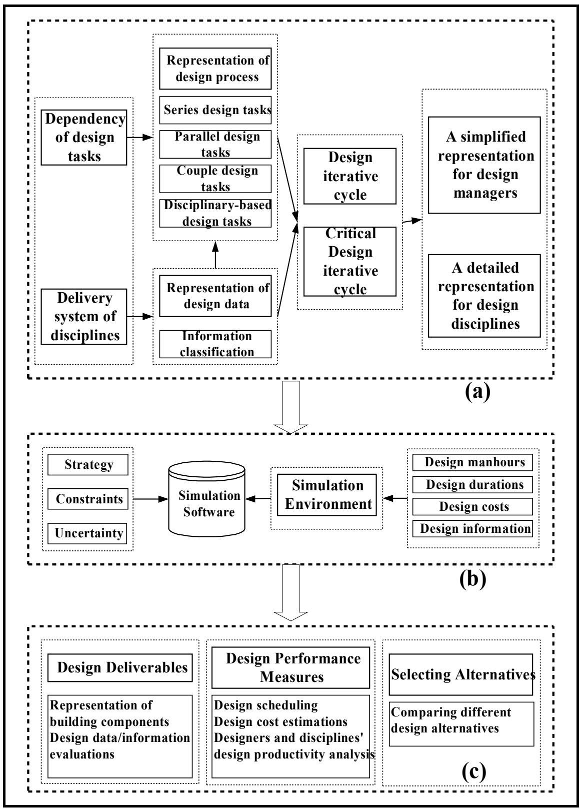

Figure 9. Framework of Implementation Strategies

REFERENCES

[1] Austin, S., Baldwin, A., and Newton, A., "Manipulating the Flow of Design Information to improving the Programming of Building Design," *Construction Management and Economic*, Vol.12, pp.445-455, 1994.

[2] Austin, S., Baldwin, A., Li B. and Waskett, P., "Analytical Design Planning Technique: a model of the detailed building design process," *Design Studies*, Vol.20, pp.279-296, 1999.

[3] Baldwin, A., Austin S., Hassan, T., Thorpe, A., "Planning building design by simulating information flow," *Automation In Construction*, Vol.8, pp.149-163, 1998.

[4] Baldwin, A., Austin, S., Hassan, T. and Thorpe, A., "Modeling Information Flow During the Conceptual and Schematic Stages of Building Design," *Construction Management and Economic*, Vol.13, pp.127-136, 1995.

[5] Glavan, J. R. and Tucker, R. L., "Forecasting Design-Related Problems-Case Study," *J. of Construction Engineering and Management*, ASCE, Vol.117, No. 1, March, pp.47-65, 1991.

[6] Eldin N.," Management of Engineering/Design Phase," *J. of Construction Engineering and Management*, ASCE, Vol.117, No.1, March, pp.163-175, 1991.

[7] Eppinger, S., "Model-based approach to managing the concurrent engineering," Journal of Engineering Design, Vol2, No. 4, pp.283-290, 1991.

[8] Kashiwagi, D., "The construction delivery system of the information age," *Automation In Construction,* Vol.8, pp.417-425, 1999.

[9] Khemlani, L., Timerman, A., Benne, B., and Kalay, Y., "Intelligent representation for computer-aided building design," *Automation in Construction*, Vol.8, pp.49-71, 1998.

[10] Sanvidor, V., and Norton, K., "Integrated Design-Process Model," *Journal of Management in Engineering*, Vol.10, No.5, pp.55-62, 1994.

[11] Vries, B., and Somers, L., "Message exchange in the building industry," *Automation in Construction,*" Vol.4, pp.91-100, 1995.