A Methodology for Collaborative Design Process and Conflict Analysis

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Abstract

The process of collaborative engineering design is relatively complex, and often results in various conflicts due to technical and social factors. Therefore, to understand the relationships between design process and design conflict is critical to improve the collaborative design productivity. This paper provides a methodology for analyzing collaborative design process and conflict based on a new Socio-Technical design framework. The methodology can identify the interdependencies among design tasks, and manipulate the evolution of various design perspectives to facilitate the management of design conflicts. An initial computer implementation of this methodology is presented and its features are discussed.

Keywords: Process, Engineering System, Co-operative Design

1 INTRODUCTION

Collaborative design involves various stakeholders with different intentions, backgrounds and circumstances. The group design activities are influenced not only by technical decisions, but also by social interactions. Conflicts always happen due to various dependencies [1]. Managing design conflict is critical to the successful organization of design process. Therefore, it is necessary to have a methodology to describe, understand and evaluate the relationship between design process and conflicts. Accordingly, a coordination mechanism should be provided to facilitate stakeholders' interactions and hence improve collaborative design.

It is noted that, when applied to collaborative design domain, traditional approaches for design process modeling face difficulties since they do not consider the stakeholder as a critical issue. To overcome this problem, we take a more comprehensive view and introduce a new approach based on a Socio-Technical design framework [2,3]. It addresses the conflict issues in collaborative design, and reveals the relationships between design process and stakeholders' perspective evolution. This paper presents the basics of our methodology for collaborative design process and conflict analysis as a result of the Socio-Technical framework. The outline of the paper is as follows. After reviewing and evaluating the traditional approaches of design process modeling, Section 2 briefly discusses the critical issues of collaborative design process and introduces the collaborative design process architecture. Then the detail methodology is discussed in Section 3. Section 4 presents a prototype collaborative design support system based on this methodology.

2 MODELING COLLABORATIVE DESIGN PROCESS WITH A SOCIO-TECHNICAL FRAMEWORK

2.1 Traditional design process modeling approaches

There are many existing approaches dealing with different elements of engineering design process from various viewpoints. They can be generally classified to three groups. The first group, which is mainly from the engineering discipline, focuses on investigation of how the technical design decisions are made in order to establish systematic design methodologies. Design process models are often implied in these design theories and methodologies, such as Systematic design model [4], Axiomatic design model [5], Quality function deployment [6], General design theory [7], etc. These theories provide the guidelines for designer to make technical decisions more consciously and systematically [8]. The second group comes from the researches of business operation and project management. They view design process as workflow with task dependencies and product information exchange. From this aspect, design is modeled as an information driven process among design activities. Design organization is viewed as a stochastic processing network in which engineering resources are "workstations" and design tasks are "jobs" that flow among them [9]. Accordingly, a set of techniques to manipulate the design activities has been developed, such as design signal flow graphs [10] and design process network [11]. The third group comes from CAD and CAE areas, which view collaborative design as individuals accessing product data and sharing the design information. Design process is accordingly specified as the managing of the product data in different abstraction levels. During this process, the technological, scientific, and interdisciplinary dependencies of the information could be established and maintained to support processing of various types of design data [12,13,14].

Although these approaches provide considerable contributions, their limitations are exposed when applying to collaborative design practices. Even if designers could closely follow these approaches, they still face some failures of coordination due to their perspective differences and various dynamic social factors involved in design process. Therefore, a more comprehensive view is required to account for the relationships among various technical and social factors in collaborative design.

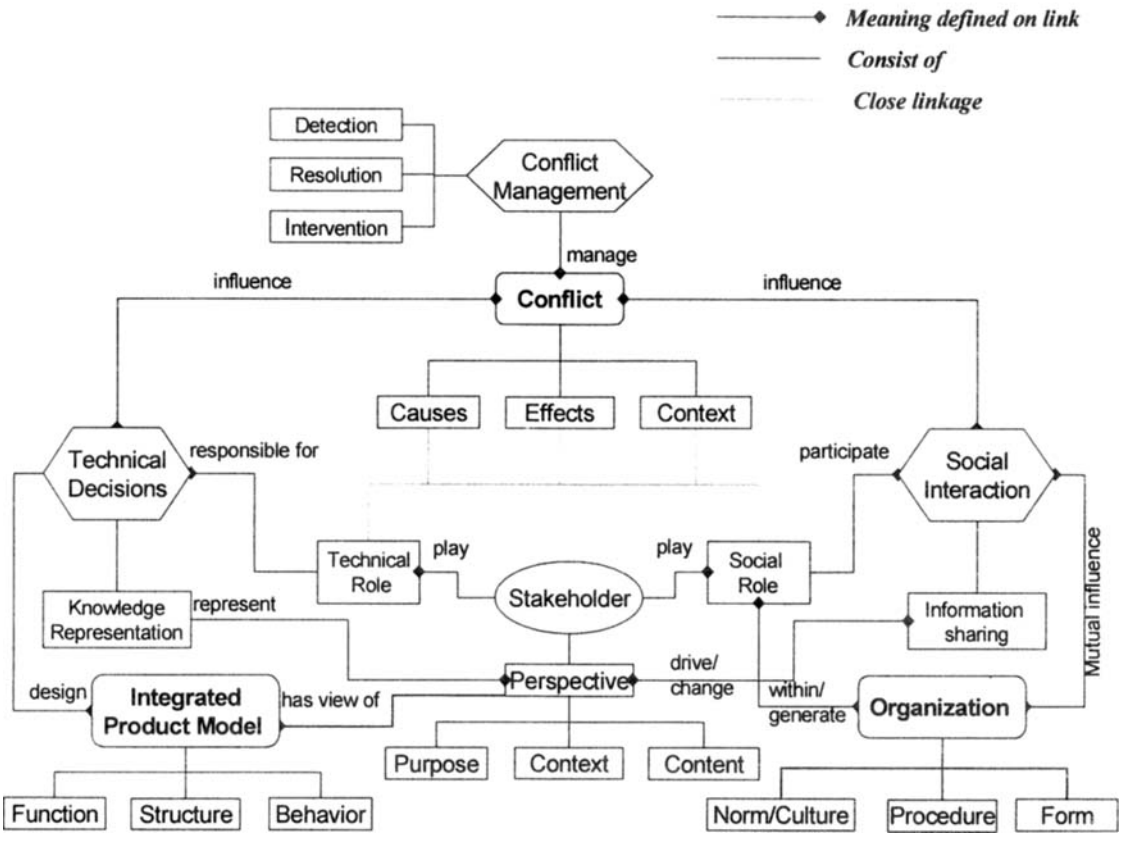

Figure 1: The Socio-Technical design process architecture

The Socio-Technical framework is built based on the acceptance that collaborative engineering design is a human-based, interdisciplinary, and socio-technical activity, and must be accordingly modeled as a co-construction process within design environment (i.e. the infrastructure in which a specific design campaign is to take place). During design interactions, the meaning and institutions are a joint, negotiated, agreed construction of those participating in an endeavor [15]. Initiated by a design objective, the design campaign evolves whose outputs constitute not only design result (e.g., the final product), but also feedback to the evolution of the design environment and to the design campaign itself. The co-construction which occurs in the design campaign is relevant at the product and process level, while that occurs in the environment may be envisioned is relevant at the system level.

2.2 Socio-Technical design process architecture

The above Socio-Technical framework results in a design process architecture, which expressively depicts various elements and their relationships in collaborative design [3]. As shown in Figure1, **technical decisions**, **social interaction**, and **conflict management** are three critical components within the collaborative design process. Based on our Socio-Technical framework, collaborative design process is modeled as a social-technical construction process. In a design campaign, stakeholders perform both technical roles and social roles based on their unique perspectives. The former is conducted in the technical decision-making process while the latter is represented as social interactions. Stakeholders' perspectives can be visualized as different "lenses" they wearing during different stages of design. They are formed when stakeholders become part of a community undertaking a design campaign and begin to interact with other members of the community. A perspective is defined as the combination of a purpose, a content and a context [2]. It is adaptive and evolving while stakeholder exchanging and sharing the meaning with others. By making technical decisions based on their technical roles, design stakeholders create, modify, and evaluate the product features. Since the involvement of social roles, which are normally influenced by the organization structure, norm, and culture, technical decisions are coupled with the social-interactions during the design cooperation. Knowledge representation is critical for designers to capture the understanding and reasoning behind technical decisions. Effective information sharing mechanisms accelerate the process of achieving shared reality. During technical decision and social interaction, various conflicts will occur due to task interdependencies and perspective differences. When treating engineering design as a purely technical process, conflicts are usually regarded as being abnormal and to be avoided as soon as possible. To resolve design conflict, different approaches have been proposed by building utility functions for designers [16], by categorizing conflict resolution knowledge [17], or by capturing design rationale [18]. However, when treating engineering design as a socio-technical process, conflicts must be systematically and explicitly dealt with as a resource to drive the social construction process and design innovations. To manage conflict near its source and root, social interaction should be considered as a controllable parameter to affect and change the design perspectives. In the early design stage, conflicts are treated as a motivation to identify the deficiencies among design team and to generate creative ideas, while at the late stage conflicts should be prevented or resolved to achieve high efficiency.

3 A METHODOLOGY FOR ANALYZING COLLABORATIVE DESIGN PROCESS AND CONFLICT

3.1 Overview of methodology

Based on the above architecture, a methodology is developed to analyze collaborative design process and design conflict. The basic question to be addressed by this methodology is how to understand and manage the relationships between design process and design conflicts for a given design problem.

Figure 2 illustrates the five basic steps in the methodology:

1. Analyze the collaborative design scripts and formalize design problem;
2. Build design process database;
3. Automatically generate Design Process Diagram (DPD);
4. Meanwhile, create Perspective State Diagrams (PSDs);
5. Manage Perspective State Diagrams and Design Process Diagram to achieve satisfied conflict strategy.

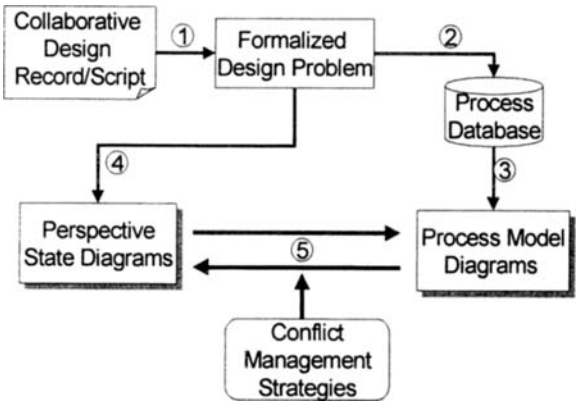

Figure 2: Steps of design process and conflict analysis

The following section describes the detail of these steps.

3.2 Analysis steps

Step 1: Analyze design scripts and formalize design problem

To transfer the informal design script to more structured forms is the first step. The principle objective of this step is the explication of the stakeholder perspectives and the identification of the means by which they interact. Consulting to the design group about detail information is sometime necessary during this step. Important issues should be clarified to reveal the information about the elementary elements in collaborative design process architecture, such as stakeholder, perspective, design campaign, conflicts, and design environment. After this step, a formalized description of design problem is obtained.

Step 2: Build design process database

The process model database is an entity-relational database that holds a record of a process defined by a sequence of tasks assigned to various stakeholders. The entire process model database can be built based on the formalized design description. Design activities, decision events, and their sequential relations are explicitly captured in the database schema.

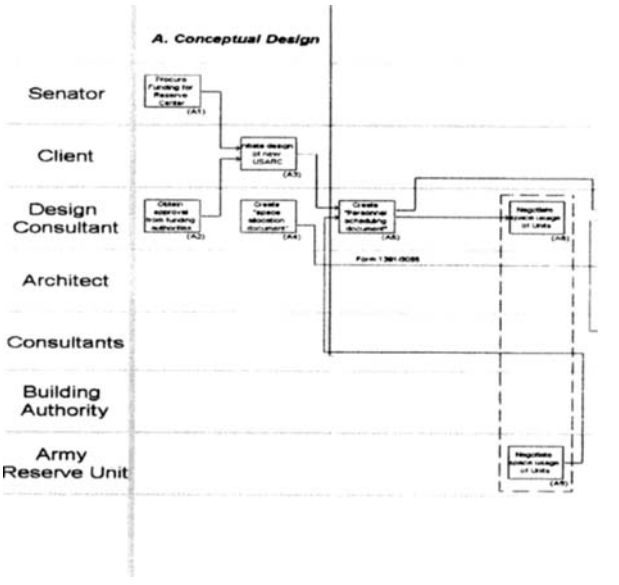

Figure 3: A PROOF diagram (partial view)

Step 3: Generate design process diagram

From the previous database, a PROOF (Process Representation Oriented toward Organization and Function) diagram can be automatically generated by a special program (Figure 3) [2]. This process model diagram shows the sequence of activities and the corresponding responsible stakeholder(s), represented as horizontal bands on the diagram. The sequence of activities on the diagram represents a chronological execution of the activities while the vertical axis showing stakeholders. The PROOF process model presents a structured view of the activities occurring in a partial scenario that is amenable to a detailed analysis of the process. This model has three salient features. First, the sequences of precedence-ordered activities are represented by linkages between IDEF0 boxes. Second, each horizontal band corresponds to a given stakeholder playing a particular role in the design campaign. By assigning an activity to a stakeholder, the relationship among stakeholders in the process becomes very apparent. Third, the horizontal axis presents the progress of time and the major design phases of the design process.

Step 4: Create perspective state diagrams

To analyze the evolution of design perspectives, we applied a systematic approach to capture the purposes, contexts and contents of the different stakeholders. Our method is to describe the perspectives of each stakeholder by using "perspective state diagrams". A Perspective State Diagram (PSD) (Figure 4) is a picture of the perspective status of one stakeholder at a given time. It has related information from design description shown in "boxes". Each box captures the view (i.e. purpose, context, content) of one stakeholder to one element in the collaborative design process architecture, such as product, organization, knowledge representation, etc. These views are further decomposed to perspectives toward more specific design objets. For example, the product view of a stakeholder consists of his/her purpose, content and context related to the product function, structure, and behavior at a certain time. In the collaborative design process, each stakeholder has a series of state diagrams, which describes the adaptation and evolution of their perspectives during design process.

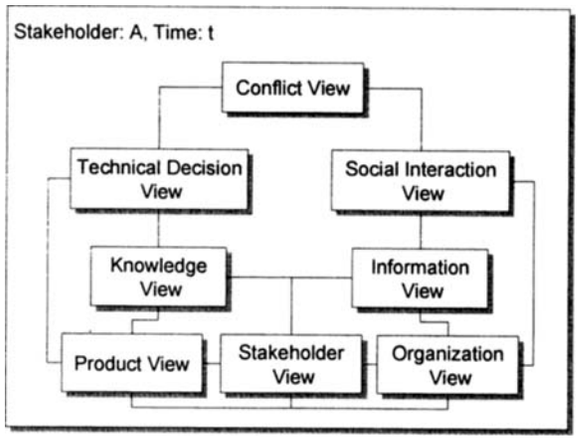

Figure 4: Structure of a design perspective state diagram

However, due to the limitation of the information that can be derived from the script, it is sometime difficult to get information for less-familiar stakeholders. That, in fact, reveals some coordination problems within the design team. By comparing the information within boxes in the PSDs of stakeholders, the relationships and differences of their design purpose, content and context can be easily detected. The related concepts of perspectives reveal the dependencies among stakeholders, while their inconsistencies indicate conflicts. The dependencies can be used as anchor points to integrate the individual perspective models and form shared meaning. The conflicts can be managed to support design perspective reconciliation and refine the design process.

Step 5: Manage design perspectives and design process

By manipulating the Perspective State Diagrams (PSDs) and the Design Process Diagram (DPD) interactively, one can examine the design perspective states between/through adjacent pints in time and identify design conflicts in perspectives. As shown in Figure 5, it is also possible to iterate between step 3 and 4 to achieve the desired result (i.e., the desired conflict profile) by rearranging the design process to reconcile the content of the perspectives in PSDs. Given these two possibilities, the design process can be handled to control the conflict behavior in collaborative design. Design efficiency is improved by providing such negotiation support.

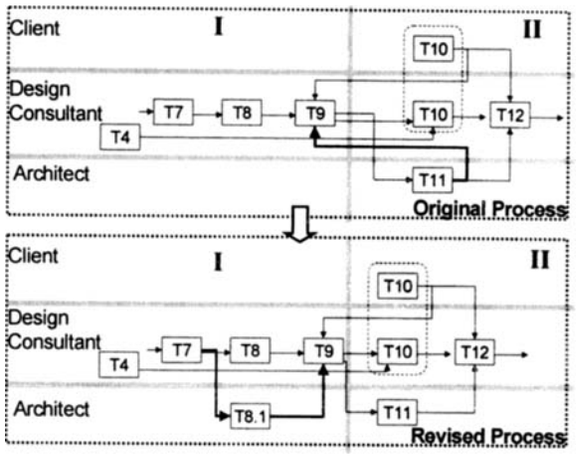

Figure 5: Manage design perspectives and design process

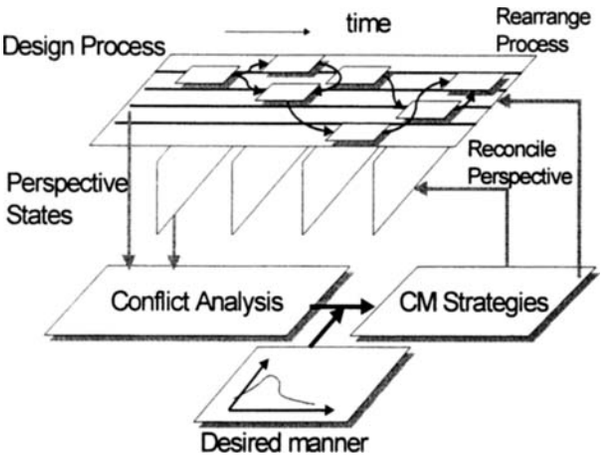

Figure 6: Rearrange design process to resolve conflict

To manipulate the PSDs as a way to converge them faster provides a way of conflict prevention and resolution. Since the patterns of PSDs will largely depend on the interactions among the design tasks, arranging the design process to a desired manner becomes an effective approach to coordinate the perspectives of the stakeholders. Figure 6 shows an example of rearranging design process to resolve/prevent a particular design conflict. The original design process has several task iterations during design stage II due to the high possibility of rework of task T9. When the methodology for analyzing design process and design conflict is applied during stage I, inconsistencies among design perspectives of two stakeholders (i.e. Design consultant and Architect) toward a specific building functions are noticed. A potential conflict is thus detected. It is obvious that by following the original design process, stakeholder architect has little chance to view others technical decisions until task T11. If conflict management strategies are applied to prevent this conflict, a new task T8.1 can be added during stage I to facilitate the negotiation among these two stakeholders. Then the probability of design iteration due to conflict (e.g. from T11 back to T9) is reduced. Since this methodology is applied through design process, the DPD and PSDs in different design stages are manipulated according to the conflict management strategies. By achieving the revised design process and managing design conflict, design resources can be saved while design quality is improved.

4 A PROTOTYPE COLLABORATIVE DESIGN SUPPORT SYSTEM

The Socio-Technical Design Process Management (STDPM) system (Figure 7) is a prototype implementation of the methodology for analyzing collaborative design process and conflict. During design process, stakeholders' perspectives are modeled in the system and their roles are depicted. Communication tools with network and server-client database access functions enlighten the stakeholders to notify his and others' perspectives. Several subsystems (e.g. Conflict management, Process management, and Organization management) are provided to support the interactions and negotiation among stakeholders. The system knowledge repository tracks the evolutions of product and organization data. These changes will be fed back to the perspective models of the stakeholders and influence the design process. While the functional structure and the form of the product are built, the conflict management model analyzes the causes, effects and contexts of conflicts occurred and applies management strategies (i.e. detection, prevention, and intervention).

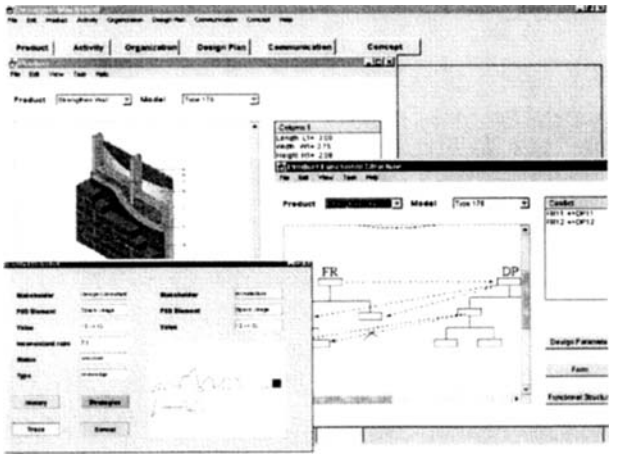

Figure 7: A collaborative design process management system

STDPM has some unique features. First, by providing interfaces to explicitly capture the perspectives of the stakeholders and assist their interactions, the system takes responsibility to detect the conflicts among the provided design information. Second, it helps the group of stakeholders to manage the design process by referring to the conflict management strategies. Third, STDPM can trace the merging of perspectives in the design process and captures the new concepts and ideas. Fourth, the system provides the integrated product model, which fits within the information structures represented by the perspective models. In the long term, the system is not only able to learn the design expertise and the design rationale, but also can improve designers' recognition and the organization structure, norm and culture.

5 CONCLUSIONS AND FUTURE RESEARCH

This paper presents a methodology for analyzing collaborative design process and conflicts with the belief that collaborative design is not only the technical decision making process conducted by a group of expertise, but a socio-technical interaction process among all of the stakeholders. Based on this comprehensive view, the methodology can investigate the relationship between perspective evolution and structure of design process. It also provides mechanisms to detect and manage conflicts and coordination infrastructures to support the refinement of design process. By using conflict management to identify and resolve the deficiencies of design process, a feedback control mechanism is realized to manipulate collaborative design process, while the traditional approaches view it as an open loop system. A framework for information system development for collaborative design support is thus derived from this methodology.

The future research work will further refine the methodology by gaining deeper understanding of the characteristics of design perspective interaction and their influence to design process. Systematic techniques from different domains can be generated to facilitate and handle these interactions. That will significantly improve the collaborative design process model and the design support system.

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