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A TAXONOMIC CLASSIFICATION OF COLLABORATIVE DESIGN

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Abstract

Much collaborative design research to date has focused on developing tools to facilitate the design process while neglecting to fully examine why and where assistance is needed. A clearer understanding of collaborative design issues and how they affect the flow of information in the design process is necessary. This paper proposes a taxonomy of factors influencing collaborative design (team composition, communication, distribution, design approach, information, and the nature of the problem). This work, based primarily upon literature review, is in preparation for building a collaborative design model that describes the flow of information in the design process and clearly identifies components that introduce resistance to the process. By identifying these areas of resistance, better-directed tools for collaborative design can be developed.

Keywords: Collaborative Design, Design Taxonomy, Information Flow Model, Resistance

1. Introduction

Companies in a wide range of industries are finding that success in the modern marketplace requires effective competition in global markets with reduced cost and lead-time. The concept of collaborative design has emerged both as an effect of globalization and as a prospective tool for enabling this new business approach. The opportunities and limitations presented by collaborative design, however, are not well understood, and the actual gains of applying collaborative design are not clear. A survey of recent collaborative design research shows a focus on developing tools to facilitate communication of ideas and information within collaborative design teams [1]. Because the information exchange requirements of the teams have not been fully explored, though, these tools may be inadequate or poorly directed. Further research into collaborative design should provide a clearer understanding of the communication issues faced by collaborative design teams and allow for development of better-directed tools.

In order to facilitate the effective application of collaborative design, information flow in collaborative design must be analyzed and the factors that introduce resistance to process must be identified. The first step required to develop this understanding is to create a taxonomy that classifies issues affecting collaborative design. A model of the collaborative design process may then be constructed to clarify at which interfaces and in what manner these issues impact the design process. The design process can be described by the flow of information and the opposition to that flow encountered throughout the process. This paper begins with a brief background of collaboration in design. This is followed by a hierarchical classification of the

characteristics of collaborative design through six major factors: team composition, communication, distribution, design approach, information, and nature of problem. Conclusions and summary are provided.

2. Background

Engineering design has been defined as the process of formulating a plan for the satisfaction of a human need through a cycle of steps that include problem definition, conceptualization, embodiment, and detailing [2, 3, 4]. This process is traditionally achieved in a design environment consisting of collocated teams with project managers and selected technical discipline specialists [5]. It may be noted, though, that even in collaborative design, individual work represents typically 70% of the effort as compared with teamwork [6].

Collaborative design works to achieve the same objective, but does so in an alternative environment. In this environment, participants contribute to an interactive design team structure with a goal of achieving a common task by sharing expertise, ideas, resources, or responsibilities [7, 8]. The team may be multi-disciplinary, and the members, information, and resources may be distributed across geographic or organizational boundaries. Additionally, design tasks may be performed in parallel (concurrently) or in series. The collaborative design process is carried out by agents, which include team members and reasoning systems. Three primary approaches exist for modeling design, with the focus of the model varying in each approach [1]. These three modeling methods are built on a methodology framework (technical decision driven), workflow framework (information driven), and socio-technical framework (actor driven).

A survey of collaborative design tools developed to facilitate collaborative design shows that the tools are based on insufficient models or simply on presumed needs [1]. Current tool evaluation and validation is typically conducted in the field after the tools have been developed [9]. A more efficient and effective process would involve basing tools design on a model that clearly defines areas of resistance in the collaborative design process.

3. A collaborative design taxonomy

This taxonomy organizes issues into a framework to offer direction in identifying areas that may need investigation. Research into multiple subjects, including engineering design, collaboration, and teamwork, has shown that collaborative design can be described by several attributes. These attributes, which compose the top level of the taxonomy, are: team composition, communication, distribution, design approach, information, and nature of the problem. A description of the effects of the primary collaborative design attributes follows. The sub-levels of the taxonomy for each factor are displayed with each explanation.

3.1 Team Composition

Extensive research has been conducted in the fields of psychology and sociology to analyze the impact of team composition on effective and timely team performance [10, 11, 12, 13]. Team composition can be divided into characteristics of the group, characteristics of individuals, team member relations, and leadership styles as shown in Table 1.

Table 1. Team composition issues in collaborative design

1. Team Composition	A. Group: *Size, Culture*
	B. Individual: *Personality, Expertise*
	C. Team Member Relations: *Positive, Neutral, Negative*
	D. Leadership Styles: *Autocratic, Consultative, Collective, Participative, Leaderless*

Research suggests that the size of the team should match the complexity of the task [10, 11]. Willaert suggests that teams that are too large may become unmanageable and require additional organizational structure, while creativity may be inhibited if teams are too small. The quantitative effect of a range of group culture variables on innovative productivity was studied by Hurley [12]. He found that group cultures that emphasize participative decision-making, characterized by openness and involvement in decision-making, are associated with higher levels of innovation. The organizational hierarchy, as well as the leadership styles within the design team may influence this area of the group culture.

Diverse theories have been developed relating team members' personalities and the performance of design teams. The five-factor personality model (FFM), which includes conscientiousness, extraversion, stability, agreeableness, and openness to experience, brings some order to the field of personality research [13]. Reilly, et al. [14] proposed relationships between a team's average level of each personality factor and the overall team performance to suggest preferred team composition for particular design types.

The amount of knowledge or experience perceived to be required before making a contribution to the team may affect productivity of younger engineers [15]. Varying levels of experience on a team, however, may facilitate success in innovation by combining the wisdom of age with the energy and idealism of youth [10, 15]. Additionally, the type of design problem may dictate which areas of expertise should be included in the team composition. Including several disciplines in a team seems to both enrich and complicate many areas of the design process [3].

Although engineering design is mainly a technical activity, it truly functions as a social activity. Lloyd proposes that design is a process of building on individual, social, and organizational experiences [16]. If a collaborative design team is distributed, its ability to collectively utilize these experiences may be hindered. Research has found that group cohesiveness is positively related to team success, and team member relations have a major positive relationship with team performance and team satisfaction [17, 18].

In addition to team cohesiveness, leadership styles may also influence collaborative design. The Vroom-Yetton model, which includes autocratic, consultative, collective, participative, and leaderless styles, may be used to classify leadership styles [19]. Austin, et al.'s empirical studies of interdisciplinary teams found that a team needs to be led through the design activity [20]. Further, the team needs to agree on who should lead and what leadership style should be used in order for the group to work effectively. Other research has found positive relationships between leadership style and team performance, work climate, and team learning [18, 21].

3.2 Communication

By definition, collaborative design teams share expertise, ideas, resources, or responsibilities, which necessitates a strong communication system. The issues outlined in Table 2 impact this sharing process.

Table 2. Communication issues in collaborative design

2. Communication	A. Mode: *Verbal, Written, Graphic, Gestures*
	B. Quantity: *Frequency, Duration*
	C. Syntax: *Common Language, Translators*
	D. Proficiency of Team: *Techniques, Technology*
	E. Dependability of Resources: *Reliability, Availability*
	F. Intent: *Inform, Commit, Guide, Request, Express, Decide, Propose, Respond, Record*

The form of communication that is chosen at various collaborative design interfaces may facilitate or hinder the process. It follows that some communication forms (verbal, written, graphic, or gestures) may be better suited for use in particular tasks or phases of the design process. Team members' selection of particular communication forms may be influenced or even governed by the perceived importance of the information to be communicated, dispersion of the team over time and space, the task in the design process, the effort required to use each method, team composition, and other factors [22, 23]. Collaboration technologies are necessary to overcome the inherent resistance to the flow of information encountered by distributed design teams [24].

The proficiency of the team in using various communication tools might influence form selection, frequency, and success [23]. Effective communication may be inhibited if team members use various languages in their communication. This includes spoken and written languages, as well as information and query languages. The needs of agents receiving information may determine the required syntax or view of the information [25]. If communication systems are not reliable, low user satisfaction will likely negate enhanced functional capabilities the systems are intended to provide [26].

A list of ten communicative actions (inform, commit, guide, request, express, decide, propose, respond, and record) has been developed to represent the intent of communication [27]. Some modes of communication and information forms may have more than one purpose.

3.3 Distribution

In collaborative design, the teams members and information may be collocated, but are more likely to be distributed across some variety of boundaries, (geographic, organizational, temporal) as shown in Table 3.

Dispersion of team members may have a significant impact on the team's choice of communication techniques, frequency of communication, and language [20]. Research to compare the graphic communication of distributed teams to those of collocated teams showed that remote designers spent 51% more time making graphic acts than their collocated counterparts [28]. However, the production of sketches, which are considered important because

they impose order while stimulating reinterpretation, decreased significantly when teams were distributed. Some research has found that collocation had neither direct nor indirect effects on project outcomes [29].

Table 3. Distribution issues in collaborative design

3. Distribution	A. Personnel: *Collocated, Geographically Distributed, Distributed Across Organizations, Distributed Across Time Boundaries*
	B. Information: *Collocated, Geographically Distributed, Distributed Across Organizations, Distributed Across Time Boundaries*

The availability of communication resources may also be inhibited, primarily by geographic and organizational boundaries. Cohesion and efficient operation in distributed design teams requires exceptional computational design support versus the needs of non-distributed teams [24, 30]. Information or tasks may also be distributed in the same manner as team members. When information or tasks are distributed across geographic or organizational boundaries, supplementary resources are typically required to facilitate communication. Distribution of people, information, and tasks in collaborative design often introduces challenges to efficient coordination of the design process.

3.4 Design Approach

Several factors of the team's design approach, shown in Table 4, may affect the collaborative design process. These factors include the design tools, how progress is evaluated, the structure of the design approach, and the process type.

Table 4. Design approach issues in collaborative design

4. Design Approach	A. Design Tools Applied in Each Phase: *Recognition of the Need, Problem Definition, Synthesis, Analysis and Optimization, Evaluation, Presentation*
	B. Evaluation of Progress: *Self-Assessment, Assessed by Outside Parties*
	C. Degree of Structure: *Company Policy, Chosen by Team, Not Well-Structured*
	D. Process Approach: *Generative, Variant*
	E. Stage: *Clarification of Task, Conceptual Design, Embodiment Design, Detail Design*

The selection of design tools (e.g., idea generation methods, decision-making techniques, risk analyses) to apply in various phases and tasks of the collaborative design process may impact the efficiency and productivity of the team. Some tools or approaches may be appropriate in team environments or particular types of problems [3]. In her analysis of the design approach at a product development firm, Parks found that the absence of a product design specification hinders task clarification activities and objective evolution of the design [31].

Studies into the effects of regular self-assessment on the performance of design teams found positive relationships between the two items [32]. This was marked by higher self-rated and group-related effectiveness when teams completed a self-assessment halfway through the design process. Group satisfaction increased when teams participated in a self-assessment.

Similarly, the degree of structure in methodology and team organization may impact the team's performance. More structure may be required for distributed teams to be productive because of the physical barriers they face [18]. In studies by Austin, et al., designers believe they have performed better as a team when they agree on and follow a design process [20]. However, no evidence was found to prove that an increase in actual productivity or success of the design team could be related to the team following a systemic design procedure. Other research, though, found that methodical design process assists in the solution development for problems in which engineers have no previous experience [31].

The primary approaches to design have been classified as generative and variant [33]. Using the variant process, the goals of the new design are achieved by adapting existing design specifications of a similar subject. Conversely, the generative process is an original design effort.

The stage of the design process also characterizes work in collaborative design. While a number of authors [2, 3, 4] have proposed definitions for the stages of the design process, the stages defined by Pahl and Beitz [4] are among the most popular and are referenced in this taxonomy. These stages include clarification of the task, conceptual design, embodiment design, and detail design.

3.5 Information

Information flow throughout the design process is a crucial measure of collaborative design effectiveness. Information related issues identified in the taxonomy are shown in Table 5.

Table 5. Information issues in collaborative design

5. Information	A. Form: *Design Artifact, Process Knowledge*
	B. Management: *Ownership, Permission to Change Parameters, Security, Change Propagation*
	C. Perceived Level of Criticality: *High, Medium, Low*
	D. Dependability of Information: *Reliability, Completeness*

Design information can be characterized as design artifact or process knowledge [34]. Design artifact knowledge is the actual design data and structures, such as technical charts/graphs, object attributes, and design reports, in which design data is represented. Process knowledge, or the expertise or resources that enable manipulation of design data, can be separated into reasoning (rule-based, history-based, first-principle) and tasks (search, analysis, modification).

Effective management of design information is crucial in collaborative design. The most important areas of information management in this context are ownership, permissions, security, and change management. The rights and responsibilities of various agents change throughout the design process [35]. The primary goals of managing information change are to maintain a design history, to enable backtracking, and to ensure that all agents use the most current information.

The perceived level of criticality of information is related with the selected communication method. If the information is considered highly critical, agents will likely select modes of communication in which they have the highest aptitude and confidence in reliability [23]. The

quantity of communication related to a particular information exchange may also be influenced by the perceived importance of the information. The dependability of information may affect collaborative design both in terms of completeness and reliability [24]. Design information is likely to be incomplete in early stages of the design process and this level of completeness may influence the design approach. Some information may be exchanged in the design process even though the information is not yet fixed or validated. Agents in the design process should consider this reliability in decision-making and other design activities. Some options for addressing the reliability issue are probabilistic design and sensitivity analysis [4, 20].

3.6 Nature of Problem

Various aspects of the design problem may impact collaborative design. Primary factors in this area are shown in Table 6.

Table 6. Collaborative design issues based on the nature of the problem

6. Nature of Problem	A. Type of Design: *Novel, Routine*
	B. Coupling of Sub-Tasks: *Highly Coupled, Loosely Coupled*
	C. Level of Abstraction: *Concrete, Abstract, Intermediate*
	D. Scope: *Single Domain, Multi-Discipline*
	E. Complexity: *High, Medium, Low*

The type of design, classified as novel or routine, relates to the knowledge that is required to address a specific problem. If the design team understands what is required, then the design type may be considered routine [3]. However, if the team does not know what knowledge will be required in satisfying the design problem, the problem is classified as novel [4].

The degree of coupling of sub-tasks has a large influence on the communication requirements of the team [24]. When tasks are highly coupled, collaboration technologies with high communication impedance are acceptable. Design problems with loosely coupled tasks, though, require that obstructions to communication be at a minimum. Because the degree of coupling of tasks varies throughout the design process, resources should be available to meet the needs of highly and loosely coupled tasks. Coupling of tasks may also impact the information management requirements of the team, notably in the area of change propagation.

Design teams must typically deal with abstraction of the design problem at some level where design is a continuous process of refining the design problem to a less abstract state [3]. Some design tools and techniques are better suited for certain levels of abstraction than others. Design teams may be better equipped than individual designers to handle this ambiguity because of the range of experiences and expertise present within the group [10].

If the design problem spans a wide range of disciplines, collaborative design teams may be better equipped to handle the problem than a traditional design team [10]. As noted earlier, the ability to utilize resources from various organizations and locations may enable a team to be constructed with a desired composition of expertise. A multi-disciplinary team, however, may encounter communication and organizational challenges.

4. Discussion

Collaborative design is a widely used approach that is growing in popularity despite the lack of understanding of issues affecting the process. While a multitude of tools have been developed to facilitate communication of ideas and information within collaborative design teams, the information exchange requirements of the teams have not been fully explored. Therefore, these tools may be inadequate or poorly directed. Further research into the information flow in collaborative design should provide a clearer understanding of the communication issues faced by collaborative design teams and allow for development of better-directed tools. Constructive research into information flow in collaborative design should include an analysis of factors affecting collaborative design and identification of components that introduce resistance to the process. This paper describes a taxonomy that classifies issues affecting collaborative design. This framework supports the development of a collaborative design model to clarify at which interfaces and in what manner the issues identified here impact the design process [1].

Based upon this taxonomy of collaborative design factors, a description of a collaborative scenario may be constructed. This description is applicable at that given point in time. These descriptions of design situations may be used to develop and compare experimental studies in collaboration. This taxonomy, as a first step, only identifies the descriptive variables of collaborative design. The relationships and dependencies between these taxons are subject to future investigation. Further, the issues identified in the taxonomy may be used to evaluate the completeness of collaborative design models and tools. Finally, the intersection of multiple disciplines through collaborative design dictates that a common language be established and accepted by the community. This taxonomy is an initial step in this direction.

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