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Management of Engineering Design Process in Collaborative Situation

Vincent Robin, Bertrand Rose, Philippe Girard, and Muriel Lombard

Abstract: Product development cycles are greatly shortened and subjected to a growing competitive pressure. In parallel, product and process complexities are increasing. This situation requires new organizational concepts in order to satisfy evolutionary market demand. The various design actors, provided with diverse expertise and culture, are therefore invited to collaborate more closely, in order to perform an effective product design. It is then, that the collaborative design process re-groups actors which have to achieve a common objective: develop a product via interactions, information and knowledge sharing, along with a certain level of co-ordination of the various activities. This paper will show how organization and co-ordination of projects are possible, thanks to the use of design environments, which are adapted to each design context. We will focus particularly on the study of various collaborative forms and collaborative knowledge to manage design environments.

Keywords: Collaborative design, collaborative knowledge, conflict management

21.1 Introduction

The product design phase has been a main research field for many years, due to its influence on enterprise performance. The design process is considered as a set of activities, to satisfy the design objectives and product definition. However, it is not sufficient to focus on product definition only, because the design objectives are constrained by the enterprise organization [1] and by the design steps. Furthermore, they are influenced by technologies or human and physical resources [2]. Design is mainly a human activity and is very complex to understand the activities carried out by designers [3]. Many design models have been proposed [4]. The study of these design models points out that, according to the design type,

the design objects are different. When the resolution steps are known (routine design process) the project is structured according to different activities, which transform the product knowledge. In the other cases, design could be considered as a creative or innovative process, and activities do not structure the project. Design must be identified as a process that supports the emergence of solutions [5]. In this case, the design project is organized to favour the collaboration between the process actors and the project manager strives to create design situations that facilitating the emergence of solutions. He/she decides on the adapted organization, favouring collaborative work and supporting the sharing of information and knowledge. This paper focuses on the study of collaborative knowledge, required by the design actors of the design environment, and is implemented to respond to a need for collaboration. We will show how exchanged knowledge during the design process allows a project manager to control the evolution of this design environment. Lastly, we will analyse the influence of this capitalized knowledge, to increase the performance of the resources allocation process during design projects.

The first part of the paper analyses collaboration in design and underlines the importance of the exchanged knowledge during the design process, to increase efficiency of collaborative work. The second part defines the different knowledge exchanged during the co-design process. The third part presents the control of the design environment. This control is based on collaborative knowledge analysis, according to the design environment evolution during the design project progress. The last part of this paper, presents an example illustrating the proposed concepts.

All concepts proposed in this paper are developed through the IPPOP project - "Integration of Product Process Organization for Performance improvement in Design"- <http://www.opencascade.org/IPPOP>. This project is supported by the French Government, as part of the RNTL program ("Réseau National des Technologies Logicielles").

21.2 Collective Work Analysis

Collaborative design process is not prescriptive, even though a nominal process could be defined. During collaborative work, the designers' tasks are performed in parallel and their results should be convergent to satisfy design objectives. These objectives could be refined as the design project progresses. Therefore, it is important to understand the collaborative design process to be controlled. Rose *et al.*, [6] propose to study the various works performed by co-designers and their occurrence during collaboration. Three main collaborative works are identified: decision-making in collaboration, information in collaboration and management of conflicts during collaboration (Figure 21.1).

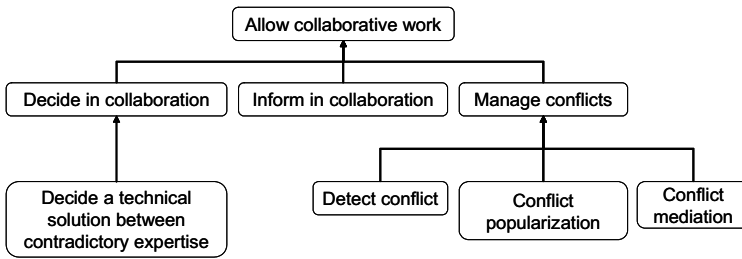


Figure 21.1 Typology of collaborative work

Efficiency of each collaborative work depends on the actor’s capabilities to collaborate. Therefore, it is necessary to be able to analyse progress of these situations, according to collaborative context and design objectives evolution. Girard *et al.* [7] have shown how it is possible to encourage collaboration, thanks to an adapted collaboration form (Figure 21.2).

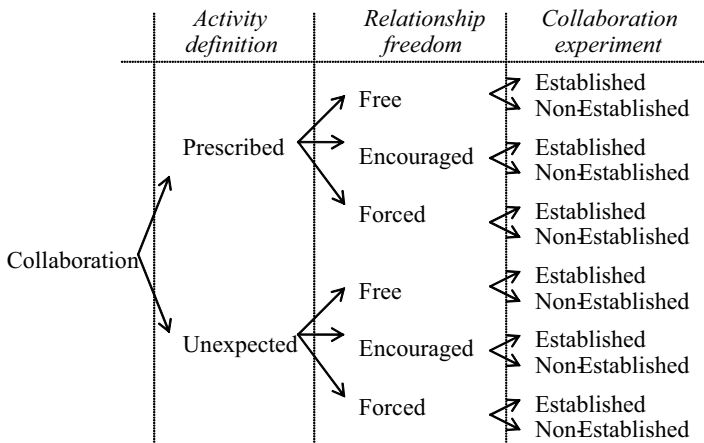


Figure 21.2 Taxonomy of the collaboration

This taxonomy permits the evaluation of the collaborative work according to the activity definition, the relationship freedom and the collaboration experiment of the actors. Consequently the project manager identifies which characteristics they could act on to increase collaboration in order to satisfy design objectives. For each type defined in this taxonomy, some action levels are identified to inform the project manager on their capabilities to change the design context.

Nevertheless, Girard’s taxonomy is generic and does not clearly take into account the shared knowledge during collaborative design processes, whereas it is very important to succeed in collaborative design activities. Indeed, Traum and Dillenbourg [8] emphasised that collaborative situations depend on whether

participants are at similar levels of knowledge and ability, and whether or not they share common goals. They discussed the level of symmetry of:

- action, participants able to and allow to perform the same tasks,
- knowledge may be at a similar level, but not necessarily within the same field,
- status within the community of collaboration.

Therefore, shared knowledge has to be considered to correctly manage the collaborative design process. We propose to extend the notion of the collaboration experiment, proposed by Girard. First of all, it is necessary to study what “knowledge” is, in a collaboration situation, in order to define precisely the collaborative knowledge. The following section presents a description of the exchanged knowledge during a collaborative design process.

21.3 Exchanged Knowledge During Collaborative Design Process

We can define collaborative knowledge as being the support of a partial and superficial exchange of knowledge among various actors and software tools involved in a project. This exchange authorizes the collaboration among these various participants, coming from different professional horizons, each with a different past, by sharing models or common references in order to perceive a global vision of the problem. Collaborative knowledge has to be considered with the product, process and organization visions. This knowledge is distributed in the context of which the actors are evolving and could appear under a heterogeneous, imprecise and incomplete shape. All actors are supposed to store this knowledge of "popularization" in the application field of the project, allowing a common coherence between various expertises involved during the design process. Therefore, some prerequisite components are requested to characterise this knowledge. Characterization occurs by a common project culture and a common language for each expertise represented in the project [9], which is based on basic knowledge inherent in each discipline involved in the project.

To create this language, it is necessary to have capitalised the pertinent information during previous projects to prescribe collaboration, as well as during the current project, in order to be reactive when a need for collaboration appears. If this has been efficient, the design activities have to be traced to capitalize the design process. Knowledge and collaborative experiment of each actor also have to be taken into account. Consequently, the actor is a predominant factor for the performance of the design process. Knowledge of each actor could be defined as being the meeting of both in-depth knowledge and collaborative knowledge. They re-group all their expertise into one or several given domains. In each situation, collaborative knowledge could be structured in:

- Popularization knowledge acquired by the actor, coming from the other members of the group.
- Popularization knowledge distributed to other actors of the design project. It supports problem resolution.

- Knowledge-being, used by each actor when they have to initiate communication with the other actors. It can be seen as interface ports to reach the other actors of the surrounding context.
- Synergy knowledge, implemented to carry out and maintain the intra-group knowledge exchanges. It's a support of communication.

Depending on the situation, it is necessary to use this kind of knowledge to perform efficient design collaboration. For instance, during a design activity, one actor uses their in-depth knowledge to solve a given problem. They also use some pre-requisite information to accomplish the task. The actor dealing with the design task could solve the problem alone or with someone. In this case, the initial actor must communicate the problem data to the second actor by using synergy knowledge that enables the communication and popularization knowledge to explain it. The resolution of the problem goes through a succession of popularization and mediation actions. Each actor respectively uses their popularization knowledge to communicate with the other and their in-depth knowledge to find a solution to the problem [6]. Moreover, each actor uses different synergy knowledge and pre-requisite information according to the situation. At the end of the collaborative resolution process, a knowledge set is generated, related to the retained solution and the historic resolution. This generated knowledge not only contains product information (structural definition, calculation results, machining process, *etc.*) but also information about the process and the organization adopted to solve the problem. Figure 21.3 shows different knowledge types involved during collaborative design. Among the various kinds of knowledge identified above, it is essential to capitalise the production of the generated knowledge regarding a given design project, by structuring the exchanges of popularization knowledge.

The following section proposes integrating the collaborative knowledge in the management of the collaborative design process.

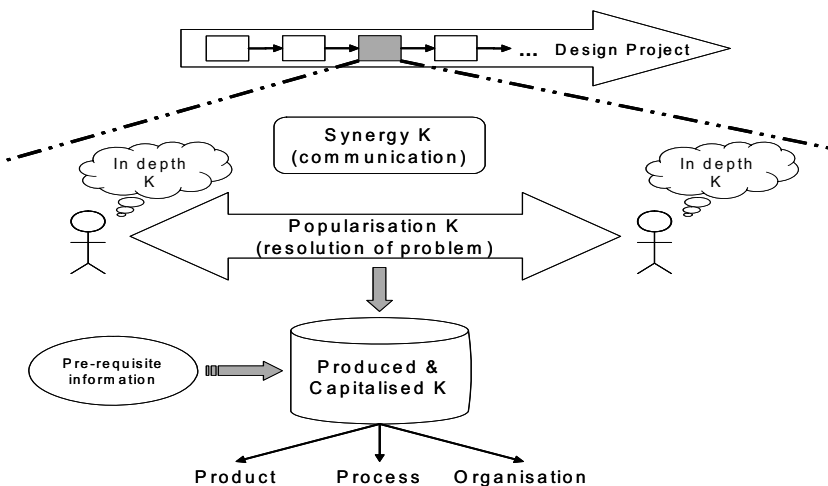


Figure 21.3 Exchanged knowledge during collaborative design process

21.4 Control of Collaborative Design Process

The design process has to respond more and more to restrictive cost, delay and quality objectives; designers are increasingly dislocated through the extended enterprise; technologies are more and more integrated. In this context, design control should be more reactive and take into account external constraints. Therefore, the collaborative design processes control requires an understanding of the context, in which those processes take place [10] in order to modify them to facilitate the actors' work. The GRAI model [11] offers a framework to control the creation, the deployment, the follow-up and the evolution of the adapted design context to improve collaboration. The GRAI reference model [12] describes the engineering design system as composed of 3 subsystems: the decision system, the technological system and the information system. The project manager's decisions to organize the technological system are structured according to time criteria (Horizon-Period), defining the strategic, tactical and operational levels (lines), and to functional criteria defining products or project-oriented decisions (columns) (Figure 21.4). In this structuring, intersections between lines and columns represent a decision centre and the biggest arrows (vertical or horizontal) represent decision frames. A decision centre describes the way a project manager will take to make decisions.

At a specific decision-making level, decision centres control the technological system broken down into design centres. Each design centre receives a design frame from the decision centres to specify its design context. A design centre is a local organization and is responsible for a set of design objectives. The structuring in a design centre and the definition of the design frame are decided by the project manager (or a group of people) who is responsible for the decision-making level. A design centre is the place for collaborative work.

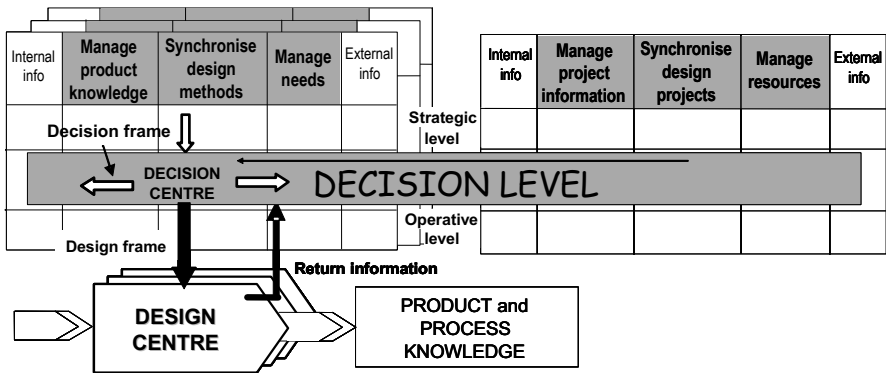


Figure 21.4 The GRAI model to control design centres

The design context may change as the design project progresses. Therefore, a design environment is defined as the context in which the project manager decides to place design actors in order to achieve the assigned objectives.

Design Environment

Robin *et al.* [13] have defined a design environment as the actors' context of work, developed in order to optimise performances relative to customers' or enterprises' expectations. This permits the project manager to promote collaboration between actors, during the progress of the project. Creation and deployment of a design environment obliges the analysis of the design situation it has to optimise. A design situation is defined as: the state of the technological system at a specific point of time [14]. A design environment will be defined as a combination of many parameters, which will evolve during the project's progress, according to the design system situation. The management of design environments consists of a continuous phase of adjustment and evolution of the environment according to the design situation.

The dynamic of design environment's management is based on four main phases [15]:

1. Identification of the need for collaboration,
2. Description of the as-is design situation,
3. Analysis and the comparison of this as-is situation with the objectives of the design system in order to make decision using action levers,
4. Implementation of the new adapted design environment to change efficiently the design context.

Nevertheless, it is the quality of the knowledge exchanged between the design actors that will influence the evolution of the design environment. Indeed, results of the collaborative design activity directly depend on the relationships between the design actors.

Analysis of Exchanged Knowledge to Control Design Environment

Integration of exchanged knowledge in the design environment model could be made into the description of the design situation and during the control of the evolution of the design environment.

The description of the as-is design situation is used to develop a design environment. This description takes into account the actors' experience concerning similar projects, their knowledge and their socialization. We suggest that popularization knowledge, coming from the other members of the group and is distributed to the other actors of the project, has also to be integrated into a general human resources description. It permits defining collaborative knowledge, which is described in Section 21.3. It will subsequently be possible, after many projects' capitalization, to suggest pertinent information in the design environment to favour creation of a common culture and of a common language for each expertise represented in the project. This information will enable a creation of collaboration between actors. We therefore propose to complete the description of the as-is design situation with characteristics concerning knowledge:

- Actors, particularly their roles and their uses in the design process. Their experience(s) concerning similar projects, their knowledge and their socialization have to also be taken into account. The objective is to properly adapt their work environment according to their needs.

- Product, according to its nature, its complexity, its status in the process and its interfaces.
- Process and in particular the design approach, the design type (routine, innovative or creative) and the collaboration type.
- Material and financial resources (business premises, computers, budget,...).
- Constraints of the enterprise and particularly, constraints of its environment.
- Popularization knowledge, knowledge-being and finally, synergy knowledge, which permit to help the decision-maker choose an adapted collaboration form and help actors communicate and collaborate.

Previous work on the conflict resolution domain enables us to define a dynamic protocol for conflict management in product design [6]. This dynamic protocol was improved by proposing a data model to depict the various states of the product [16]. Nevertheless, this protocol and data model could be generalized to every type of situations in collaborative design. The dynamic protocol presented in Figure 21.5, which takes place in the design environment, is divided into three (3) sequences:

- First, an initialization sequence, corresponding to the implementation of the design environment.
- Second, the main phase, based on a stage of popularization/mediation activities. It corresponds to the decision-making phase of problem solving. It consists of explaining the current problem by using elements and arguments from popularization knowledge for the popularization stage; proposing and arguing about alternative solutions to fit the problem at hand for the mediation stage.
- Third, the closing phase consists of informing the various interested actors involved in the solving process, if a solution is commonly accepted after n iterations. Otherwise, in case of failure, this means that the design environment is not well adapted. Consequently, the problem is brought to the design centre in order to inform the decision maker of the necessity of a new design environment.

In order to run efficiently the popularization/mediation protocol, a subscription list of potential interested actors must be set up during the definition phase of the design environment. This list is obtained by matching the availability matrix of each actor with a competence matrix and a responsibility matrix. The competence matrix selects the actors of the projects by their effective skills and competencies in a specific domain. The responsibility matrix selects the responsible person for a part of the product to design and specify the users. Those users can access this entity and the authorizations that have been granted to them (create, modify, delete or just read). The matrices are based on the information collected during the capitalization phase of previous projects. In this case, the follow-up and the capitalization of the process described in Figure 21.5 are very valuable. They allow the project manager to progressively complete each matrix by applying pertinent performance indicators on actors' work, in order to precisely define the

information contained in the description of the collaboration experiment of each actor (Figure 21.2).

The following of the dynamic protocol of popularization and mediation process, subsequently permits:

- to follow the evolution of the design environment,
- to complete the different matrices established, to define actors' availability, competencies and responsibilities,
- to refine information about the collaboration experiment of each actor and about the collaboration in the teams,
- to build-up and empower more efficient work teams in an adapted design environment together with an adapted collaboration form.

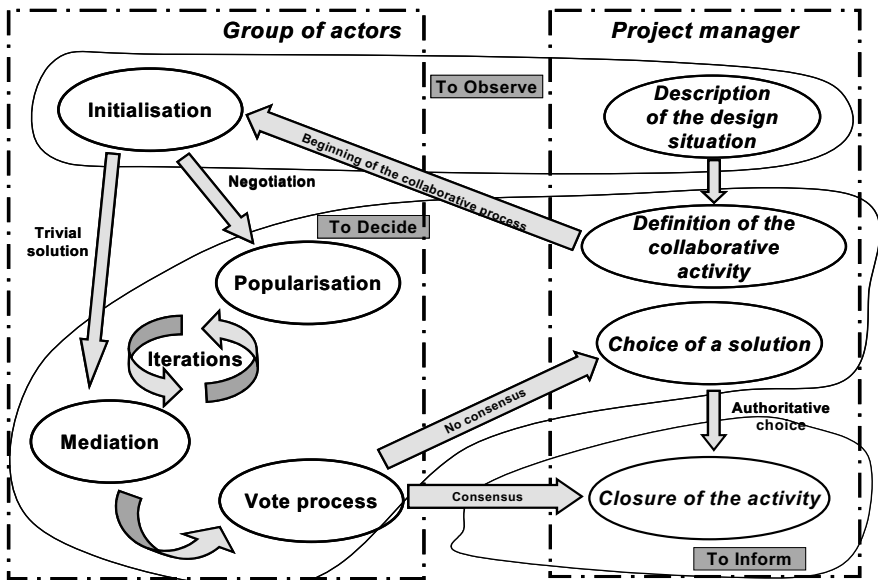


Figure 21.5 Dynamic protocol of popularization/mediation process

21.5 Example

The example that illustrates the proposed concepts is developed in the IPPOP project. It concerns the design of the fixing between the rack-and-pinion and the support of a translation system of a bowl on a mixer. This design phase is representative of the needs for collaboration that could appear during a design project. Three design actors are involved to co-design the fixation: a design expert, a manufacturing expert and a material expert. In our example, IPPOP identifies that the third expert modifies data, which concerns the material of the fixing system. As this data is critical to the manufacturing methods engineer, a conflict could appear between two experts and IPPOP notifies the project manager. He/she creates and

deploys a design environment that groups the three experts together, in order to develop a dynamic of collaboration between them to solve the conflict. Before the creation of the new design environment, the design process was sequential and the design activities' sequence was not precisely defined. Now, thanks to IPPOP, a project manager can follow the evolution of the design process, in the design environment frame, and they are able to capitalize this process. IPPOP collects and distributes information concerning product, process and organization. Consequently, the project manager could complete a different matrix concerning actors and refine their knowledge of the actors. Thanks to the dynamic protocol of popularization and mediation process, they can complete knowledge on the collaborative experiment of each one and satisfy needs for information. The last iteration summarises the various stages of the solving process, while embedding the collaborative knowledge used to solve the problem and agree on the proposed alternative solution. This information permits the project manager to be reactive to the group's needs and to capitalise this experiment to reuse it in a similar future project. At this moment, since the manager will have to optimise the design process, the contents of the design framework and the team composition by considering capitalised information about the actors, they will be able to propose a more efficient design environment. This example suggests interests of IPPOP to put into evidence the need for collaboration and to supply a detailed description of the design situation. IPPOP permits the user to be more reactive and more adaptive in the creation phase of the design process, in order to satisfy the need(s) for collaboration between actors. This also increases the reactivity of the project manager towards a potential conflict, and/or when a conflict appears during the design process.

21.6 Conclusion

Engineering design processes are very complex, and now-a-days, it is not enough to only consider the design activities' results to improve their performances. It is necessary to manage and to capitalise on relationships as well as to exchange knowledge between actors and more generally, the design process as a whole, with a particular attention to the organization that was set up to satisfy the objectives. Therefore, the organization has to integrate aspects centred on the actors, in order to be reactive and efficient, considering the design process evolution.

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