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AN ACTIVITY MODEL AS A TOOL FOR ANALYZING COMMUNICATION IN ENGINEERING DESIGN

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1. Introduction

In the field of engineering design, concurrent engineering concepts have been introduced for a long time in most of the great industrial companies. These industrial organisations have then implemented the participation of a great variety of experts coming from different departments of the company including sometimes sub-contractors. This cross-functional organisation allows the expression of the design constraints and the confrontation of the various rationales undertaken by the different domains. This is a group of experts from different domains, gathered in project teams, that is in charge of the achievement of the design. Today these project teams are not necessarily located in the place nor they always belong to the same company. This research focuses on remote co-operative work and particularly the study of group work sequences during design meetings. This paper proposes to report on the analysis of the design activity observed in the aforementioned context. We make the assumption that remote synchronous design can be described by the two groups of activities, one related to communication and the other related to product modelling. We will particularly study the communication activities in this paper. The aim of communication activities is to help the designers to build a common understanding (or reference) of the present situation, the design problem and the design solution. We will present a case study related to remote project reviews within the Volvo Group. We will introduce the concept of activity and propose a classification in relation to the literature. This theoretical framework will then allow the analysis of the case study. This case study will reveal the evolution of a specific object including graphics and textual annotations, showing how this object became a tool for supporting cognitive synchronization among the participants and a less ambiguous record of the results of the evaluation activities carried out during the meeting (i.e. the design decisions).

2. The concept of activity as a relevant level for the analysis of collaborative practices

2.1 Our point of view on the design process

Companies have to answer a relatively simple problem on its statement but complex on its achievement: designing a profitable product with the required functionalities, as fast as possible, with a cost and a quality the customer can accept. Consequently the organizations tend to evolve toward integration through simultaneous engineering taking into account the whole product lifecycle [Lonchampt, 04] and the extended enterprise [Browne, 95]. The various aspects treated successively in the sequential organizations must now be taken into account simultaneously. The various stakeholders need to collaborate earlier and more intensively. Therefore collaboration between designers is even more necessary today as the complexity of the product and the organisation increase introducing an increasing number of participants from various domains of expertise, sometimes dispersed around the world. In this paper we will consider the collective (or collaborative) side of the design process that requires the co-operation of several participants, as well as the coordination of their efforts [Lonchampt, 04]. Our approach will be global, i.e. we will consider the actors of the design process, the organization and procedures, the tools used, etc., in fact as much as context elements as we can embrace. The observed situations correspond to a classical concurrent engineering organisation and we will consider a particular distant design situation where the designers interact through a digital media. We observed sequences of synchronous and asynchronous work. More precisely, the elements we propose here result from a study on synchronous work situations that occurred during design review meetings. During these meetings design solutions were proposed by the designers and discussed by the other participants which were representing other domains of expertise (e.g. assembly, after sales services, etc.). Designers tend to share a common goal and contribute to the solution through their specific competences [Darses and al, 00]. Considering this level of observation, we found more suitable to use a theoretical framework based on activity models rather than phase models.

2.2 From phase Models to activity models

Although many definitions can be [Deneux, 02] found the design process can be regarded as a set of interwoven activities more or less organised in a sequential and/or parallel mode, using human and material resources in order to satisfy objectives (that are seldom clearly defined). This process consists of a transformation of an initial unsatisfying situation into a situation in where this dissatisfaction is reduced by the definition of an artefact. This transformation involves a flow of information through a succession of activities and makes it possible to describe the process. Le Moigne [Le Moigne, 90] describes the modifications of flow as follows: “the modification along the time (T) of the position of the product in a “Space-Form” reference frame (E-F) and being able to be identified with a sum of processes flow of product in the space (transport), time (storage) and in the form (transformation)". These modifications are mainly the result of a human activity which relates to the science of the artificial. The resolution principles used are based on cognitive activities of deduction types, induction and abduction. In products design, the problem is ill defined by nature, opened and complex. Various work highlight that the process can be described at a phase level along the design cycle [Pahl and Beitz, 96], depending on its type (innovating or adaptive), on its degree of structure, or the tools which are involved [Ullman, 92]. According to the complex dimension and the ill defined nature of the design process one can represent it as a co-evolution of the problem and solution (also call co-evolutionary models) [Lonchampt, 06]. Even if the design process is difficult to model from a cognitive point of view, several process models have been proposed among which [Coils, 00]. We can classify them into three categories: the prescriptive models which describe the design process as a complex procedure the actors should follow the descriptive models which account for the activities actually performed on an individual or inter individual level and "computational" models which aim to automate and computerise the design process. Lonchampt [Lonchampt, 04] describes the models of design according to three approaches: an approach based on the concept of phase, an approach based on the concept of activities and an approach based on the concept of fields. The approach based on the activities will be considered in the following.

2.3 Cognitive level approach and activity models

The study carried out by Detienne and al. [Detienne and al., 04] underlines several categories of design activities. Whereas the concept of phase allow a clear description of the sequence of design stage leading to define a design procedure and a framework for planning the design process, the concept of design activity accounts for what is actually done during design. With the aim of describing and modelling the activity structure of the design process works describe the activities undertaken by the actors during design. Those works present various possible classifications of design activities. They model the design process like a course of a whole set of activities and thus allow the description of the dynamics of a given design process. These activities represent a kind of elementary components of the design process that are rearranged in any single design situation. We have partly used Detienne’s activity categories [Detienne and al., 2004] in order to characterise our own observations, and account for what really happened during design meetings. The activities are classified into generic categories suited for describing design meetings and more generally interactions between designers (e.g. meeting management, argumentation, assessment of a constraint, etc.). Using this model we obtain a description based on a temporal decomposition of the course of the design activities organized in units of action: “an actor + and one or more activities + the artefacts and tools”. We will now propose our own activity categories which better suits our observation methodology.

2.4 Proposal for a typology of activities for analysing synchronous collaborative design

In industrial projects, the design process is structured in phases and tasks and the convergence is assured by gates and milestones. During design meetings the participants have to manage an agreement on the design solution presented at the given stage. For example, if designer C_1 and C_2 (figure 1) must find an agreement upon a given point they will engage a set of activities (e.g. evaluation, constraint negotiation, etc.). In the model presented figure 1 C_1, C_2 and C_3 are actors of the design process. C_1 and C_2 are designers with technical competences (e.g. designers, manufacturing, assembly, marketing, etc.). C_3 has a management role in addition to his technical skills (it is usually referred to as architect in the French companies). They all have to interact during the meeting, the group not being limited to the three but encompasses a wide variety of participants (more than ten sometimes). Thus there are necessarily a great number of activities between the various C_i involving sometimes discussions between more than three participants. We only present in the model figure 1 the elementary interaction schema, the reality is a composition of this elementary schema.

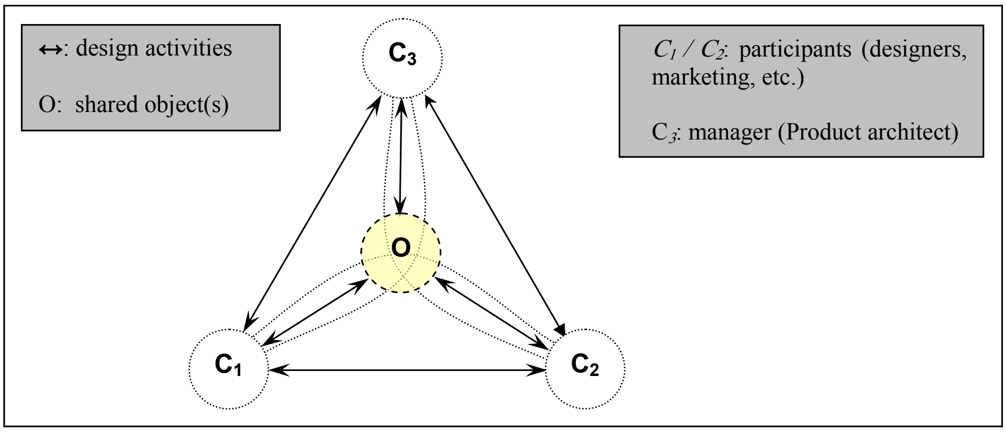

Figure 1. Model of situation of collaborative design synchronous

In addition the designers generally share objects O which are representations of the product under development (for example 3D CAD models as shown figure 2, a simulation report, etc.). The aim of the model is to account for the interactions through shared objects and characterise them in order to propose new ways for interacting with objects, and may be propose other forms of objects. This model thus makes it possible to identify various activities which are represented by the arrows in our model: One can then characterise for example cognitive synchronization between C_1 and C_2 via O and solution proposal activity between C_1 or C_2 and O.

The elementary activities suggested can be simple activities between actors or of activities between actors involving the object O. The relational level of the activities (e.g. social interactions) occurs necessarily directly between the different actors, whereas the other more technical activities rely on the objects for their achievement. We have identified 6 categories:

- Cognitive synchronization (definition of the common principles of design, share solutions, task objectives, shares requirements, shares design strategies. In fact all activity that lead to create a common reference for action): between C_1 or C_2 through O.
- Proposals (requirement level or solution level): from C_1 or C_2 toward O.
- Evaluation (of the solutions, the requirements): from C_1 or C_2 toward O.

- Project management (manage design meetings, tasks Planning, and Resource allocation): C_3 towards O.
- Coordination management (data-processing resources, information documents and sources, sound, speech, technical problems, interfaces visibility, interaction supports): from C_3 towards C_1 or C_2 via O.
- Relational: between C_i.

We will see in the following, how this model can be instantiated in the study of the Volvo case.

3. Case study within the Volvo Group

During this study, we have observed several collaborative project reviews that occurred during the design process of a truck. This study took place within the framework of meetings called "Acceptation Maquettage Serie" (AMS) which are part of the general design procedure of the 3P (product process purchasing) Business Unit of the Volvo Group. In order to carry out these observations, we have been involved as an IT support within the Group during nearly 2 years. We thus could take part to meetings and collaborative work episodes. These AMS meetings were project reviews that involved experts from various departments. This case study took place in the wire and pipes routing design team. The purpose of routing pipes (mainly fluids) and electric cables is to guarantee the product compliance that reduces actions undertaken by the operator on the assembly line, and also to ensure customer satisfaction (i.e. no after sales service). AMS Meetings require various experts from the design, industrial process (group level and plant level), assembly, after sales, group quality and plant quality. Their objective is to validate a solution from an industrialization and maintenance point of view. These meetings are preceded by “Working Groups” meetings known as "Groupes Metiers" (GM) whose objective is to define the technical solutions before presenting them during the AMS. Therefore the objective of the AMS is not to define technical solutions, rather the goal is to check parts incompatibilities (mainly geometric) and conformity with the various quality constraints, the procedures and the requirements of the group. The objective of the AMS is thus to evaluate the solution from a multidisciplinary point of view, whereas the objective one of the GM is to produce the solution from a single expert’s point of view. We will now describe this case study starting from three key elements of the AMS meetings: actors, workspace and product.

- **Actors:** The meeting is animated and coordinated by the “Architect” responsible of the considered product zone. A designer (one for each solution presented), comes to present his solution to other group members. The audience is composed of: other designers (different parts from the vehicle, if necessary), Group and Plant process engineering experts, Manufacturing operators, After-sales experts, Group and Plant Quality experts.

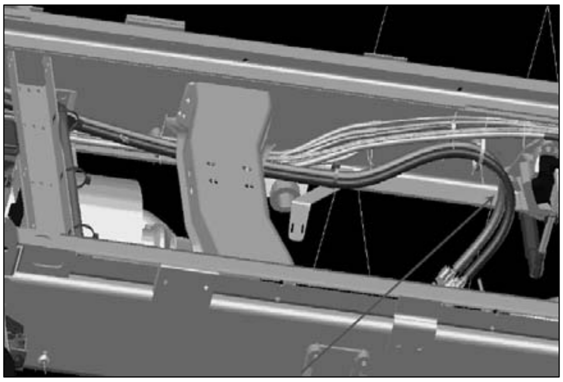

Figure 2. 3D CAD Model of routing

- **Workspace and shared objects:** These meetings take place between actors based on different sites distant from several hundred kilometres. The workspace is shared and accessible to all the participating actors. The product view is shared through NetMeeting or Sametime. The audio channel is shared via a conference call. Each AMS meeting is very tightly scheduled by a very precise agenda. For each raised point, a designer presents his solution to all the participants through NetMeeting. A few days before each meeting, the architect sends an e-mail including the agenda of the upcoming meeting. This document indicates the various points to be validated as well as the participants required for the presentations. A minute containing the main conclusions is published after the meeting. It is the form of this report which we will studied in the following.

- **Product:** the product is the routing zone represented by a 3D CAD model: flexides hoses and rigid pipes of a truck (see figure 2) integrated in the chassis environment.

4. Analyzing the evolution of the minutes of meeting support tool

We can now analyze the situation described in the previous section starting from the analysis framework proposed in section 2. Using the diagram proposed figure 1, we propose a model of the AMS situation at the activity level by identifying the various activities (see section 2.4) undertaken by the participants. In our case, C_3 is the Architect *A*. Others participants are the required participants (Industrial *M* or designer of other close subsets *C*, for example). The object *O* in the middle of the interactions is primarily the 3D CAD model (figure 2). The activities contribute to describe the action on the artefact and to characterize the exchanges and the mutual influences between the actors, the group and the design context. Figure 3 illustrates the exchanges observed during an AMS meeting.

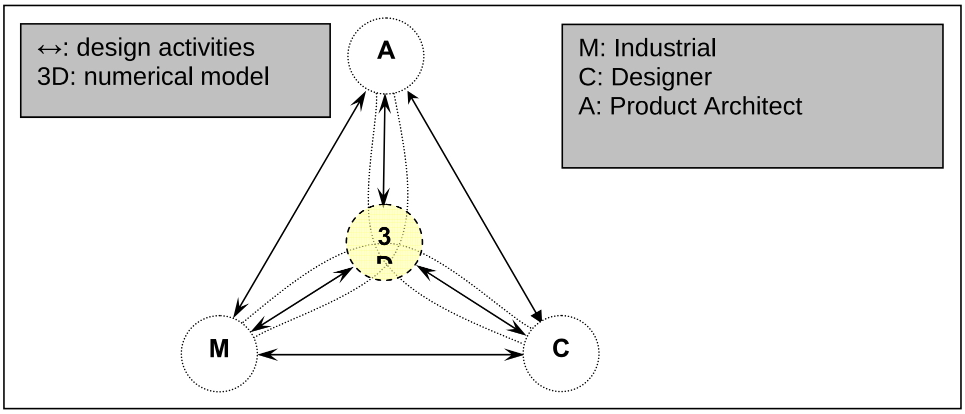

Figure 3. Instantiation of the generic model with the case of the AMS: Design review model

If *A* needs to coordinate the current project review, he will talk directly to *M* and/or *C*. This activity of coordination management is not supported by the *3D* representation but occurs directly between the actors. This kind of direct interactions often refers to the relational register [Detienne and al., 2004]. It seems a factor of cohesion for the whole group. On the other hand, when *C* presents his work, he will propose his solution to *M* who will ask for clarification if necessary making then reference to the *3D* model. This is a cognitive synchronization process that occurs by the means of the *3D* object and that is different from an evaluation process.

These lines highlight the interactions at the heart of the suggested model. By analyzing this model, we can notice that all the possible elementary activities are not present within the framework of the AMS. The framework of this process is given by the activity of project management which rate and ensures the unfolding of the meetings. For each AMS meeting, validating a solution requires making an evaluation of this solution and this evaluation is only possible after a cognitive synchronization between *C* and *M* mainly via the *3D* representation which is then used as support during the discussions. Complementary to evaluation, it can be called upon solution proposal, requirement analysis, coordination management, etc. The minutes of the meeting represents the summary of the decisions taken during AMS and defines the actions to be carried out before the next AMS. The minutes are written by architect, on line during the AMS. All the discussions and debates that occurred during the meeting are not explained in the document. The report indicates only decisions or actions to be undertaken. There is an obvious lack of information that often led to mistakes in the past. The actors were brought to make evolve this report in order to reduce misunderstandings and mistakes. We present in figure 4 a representation of the role of the report (CR) in the communication of the AMS results. The minutes act then like a mediation carrying the results of the project review.

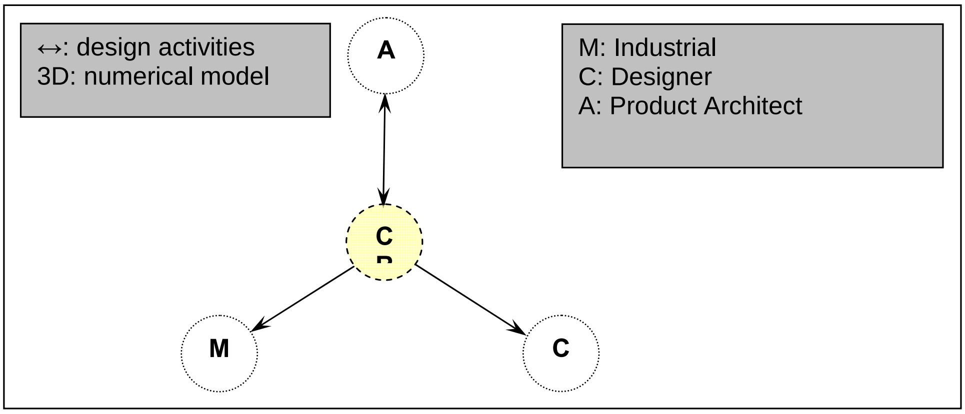

Figure 4. Instantiation of the generic model in the case of the AMS minute

In the definition of an AMS process, we indicated a list of required actors. The difficulty in this kind of industrial situations is that there is generally a difference between the theoretical process and the real situation. Indeed, the time pressure and the work load of the various stakeholders often leads make decisions, validate solution in the absence of key actors. *C* or *M* sometimes are not able to understand the overall the logic of a given decision and it is necessary to enable this document to include some elements of context and may be some element of the rationale of the decision The report thus does not simply remain an expression of the solution state, but a support for the cognitive activity of the designers and a simplified expression for the project management. It becomes an intermediary object of the design.
In our study, we have seen the evolution of this report from the first form (figure 5) which is a simple e-mail containing the minutes to an illustrated and annotated PowerPoint (figure 6).

Pré-AMS pour validation B-release

- Interférence faisceau commande à câble avec appoint d'huile (Cabine basculée). A valider au physique TH11M (CAG) et TQ14M (CAD) => Actor 1/ Actor 2/ Actor 3

- Interférence remplissage appoint d'huile avec la grille MV avant => Actor 4/ Actor 2/ Actor 5

- Valider process appoint d'huile => Actor 1/ Actor 3

Figure 5. Textual minutes

It is very interesting to notice this evolution which is today still in process (new forms of shared documents through Teamplace solutions). The report allows today:
The interest to present this minute to the different actors is:

- to recreate keep trace of the different activities: from C_1 to C_2 through *CR*, from *A* to C_1 and C_2 via *CR*, etc.
- the annotation can support the cognitive synchronization outcome and rationale of a decision as a memory for the designers that have to carry out an actions following this AMS
- the interest for the missing actors to view the context of the problem and understand more easily the work to be done
- these annotations also make it possible to support a cognitive synchronization relation between *A* and the missing designer.

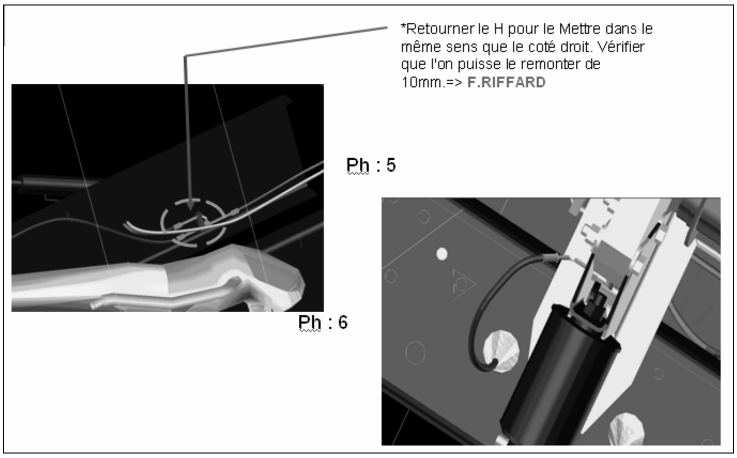

Figure 6. Aannotated minutes

In fact, the satisfaction of the actors following the proposition and implementation of this new minute report was real. One of the limits however is the size of the files produced (sometimes more than 15 Mega). We make the hypothesis that it is an intermediary configuration that will soon be technically solved.

5. Conclusions and prospects

In this paper, we have presented an activity model and described a synchronous collaborative design situation. We showed, with the example of an industrial case within the Volvo Group, how this model could be used for the analysis of the relations between the activities and the used representations. We have presented a case study related to remote project reviews within the Volvo Group. We have introduced the concept of activity and proposed a classification in relation to the literature. This case study has revealed the evolution of the minutes of the meeting including graphics and textual annotations, showing how this object became a tool for supporting cognitive synchronization among the participants and a less ambiguous record of the results of the evaluation activities carried out during the meeting (i.e. the design decisions).This document is now adopted and used in the company. This proposal is only one of the various actions which could be carried out to meet the needs for elementary existences of activities implement. This analysis of the activities associated with a reflexion around the interactions reveals the need to interact with the product representation via something we will call “interactors”. However, and in a second axis of prospect, it is essential not to just specify tools but much more. These means include here artefacts but also teaching and coaching, strategies for fostering a wider participation. This means then including a knowledge management approach.

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