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MODELLING THE PROCESS OF CREATING A MUTUAL UNDERSTANDING IN DISTRIBUTED DESIGN TEAMS

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1. Introduction

Cooperation is an important issue in design teamwork. With the introduction of the concurrent and simultaneous engineering approaches, the companies tend to put together experts from several domains of expertise in order to anticipate design tradeoffs, reduce the time-to-market and finally to design products that better meet the customer requirements. Today the design activity is mainly organised in projects where the participants work jointly in order to integrate various aspects of the product; e.g. quality, cost, product performance, maintenance, etc. Consequently the study of the collaborative aspects of design is becoming a key toward success. In the field of engineering design, over the last fifteen years we have seen an increasing number of studies on teamwork. Mayor works have also been carried out in the field of linguistics describing the general principals of contextualised communication [Sperber & Wilson 1995]. However the specificities of remote synchronous design sessions require additional studies especially due to the particular role played by physical artefacts in design communication, example includes the characterisation of cooperation and coordination aspects, knowledge creation and learning processes, cognitive synchronization, etc. Some researchers have studied the socio-technical aspects of design, others the decision-making process, others again the issue of design efficiency, etc. However, few studies have been carried out regarding the relationship between the cognitive level of cooperation and the design activity in order to specify more accurate tools. Experimental studies, with appropriate protocols are good methodological tools in order to approach these questions. However there is a clear lack of theoretical framework and models in order to analyse the output of such distant mediated protocols today.
Considering remote synchronous design sessions, this paper is an attempt to contribute to a theoretical framework through the modelling of the process of creating a mutual understanding mediated by design artefacts, in line with our previous research on design cooperation [Boujut & Blanco 2003]. We present here some reflections based on a review of the available literature in engineering design, on the experience accumulated in empirical field studies over the past ten years and on a distributed design protocol we have recently carried out. The objective of the paper is to propose a model of an elementary design interaction between two participants of the design process. We take here the Situated FBS Framework [Gero & Kannengiesser 2002] as a basic individual cognitive model and we propose to extend it through the concept of design intermediary objects [Vinck & Jeantet 1995] and cognitive synchronisation [Darses 1997].

In the next sections we will introduce the concepts that are the foundations of our model, particularly the FBS framework, the design intermediary objects, the cognitve synchronisation concepts. We then introduce our model and finally we propose a discussion on the implementation actually in progress.

2. Theoretical background and core concepts

2.1 Design methods

The literature on engineering design models appears to be divided into two main categories: process models and descriptive models. A process model generally presents the design process as a sequence of phases or stages that have to be achieved in order to obtain a product. These phases can be developed in a sequential or in an iterative way until the solution proposed fulfils the functions required by the specifications. This category of models is often the result of a combination between the author's own experience and a reflection on what should the design process be. The most illustrative and historical example of this kind of models is presented in [Pahl & Beitz 1996]. A descriptive model is an outcome of the systematic study of a wide range of design processes. This kind of models is the representation of the design process that had been carried out by the designers in order to complete their job. An example of this model can be found in [Minneman 1991]. Inside this category of models we find the activity model. Activity models aim to represent of the activities of the designer during the design process. Usually this kind of model is heavily linked to individual process often describe as problem solving. An example of this model can be found in [Rasmussen *et al* 1994].

2.2 The Situated FBS Framework

Among the activity models a particular one drew our attention by his suitability to our understanding of engineering design. This model is the Situated Function-Behaviour-Structure Framework proposed by [Gero & Kannengiesser 2002], (Figure 1).

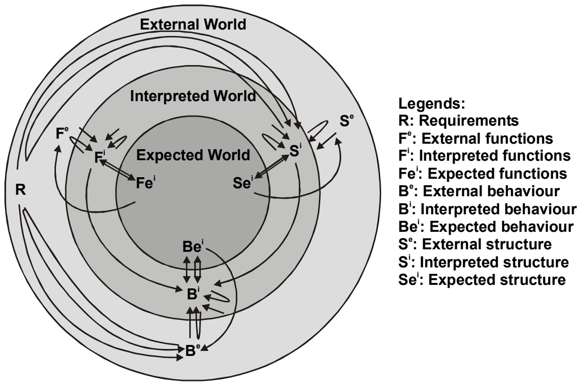

Figure 1. The Situated FBS Framework after [Gero 1990]

This framework is the result of the evolution of the Function-Behaviour-Structure Framework proposed by [Gero 1990] as a means to represent the design activities. The FBS framework is articulated around three main concepts i.e. function, behaviour and structure which are linked together by different processes that represent the transformation between a functional state of the product into a structural description of the same product.

In the situated framework the authors propose a cognitive model of the design process centred on the designer's activity. The mental representations are articulated into three worlds that interact through three processes, which describe the dynamic and situated aspects of design, (Figure 2). The three worlds are as follows: the external world is an environment composed by "representations" manipulated by the designers; the interpreted world is a world that is created by the designers in their "minds" including concepts, percept and sensorial experiences. So it is here that the designers build their respective representations of the external world.

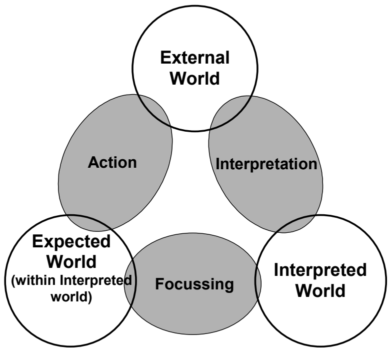

Figure 2. Situatedness as the interaction of three worlds after [Gero & Kannengiesser 2002]

Finally the expected world is the "projected" world that will frame the designers' action upon the real world. This model introduces a distinction between internal (or mental) and external environments and in the same time represents the relationship between them. The three processes that link the three worlds are: the interpretation process that transforms variables from external world into interpretations located in the interpreted world; the focussing process that describes the focussing on specific elements of the interpreted world and the transformation into targets in the expected world; and the action process that brings changes on the external world in accordance with the targets defined in the expected world. This model will be used in the following as a basis of our reflection on collective design processes.

2.3 Design intermediary objects

From empirical field studies [Vinck & Jeantet 1995] have proposed the concept of "design intermediary objects" (DIO). Throughout the design process the designers spend much of their time in creating, manipulating, discussing, interpreting, evaluating, transforming, etc. objects (understand here artefacts) like texts, graphics, tables, sketches, digital mock-ups, CAD models, etc. these objects are supports and traces of the design activity and can be considered as the physical side of the external world of the FSB model. The concept of DIO is therefore a way to analyse the design activity.

The DIO's have three main characteristics: mediation, translation or transformation and representation. The first characteristic relates to the nature of the object and particularly its ability to foster cooperation or not. We then talk of "open" or "closed" objects. The second characteristic relates to the evolution of the representations throughout the different phases of the design process. The translation process is much more a transformation process by addition and combination of multiple points of views than a linear sequence of modifications. Finally, the third characteristic stresses the fact that the DOI's are representations of the product, they are not the object itself in the way the representations do not embed the entire characteristics of the product. For example a digital mock-up may be visually very realistic but functionally very poor.

This concept appears complementary to the FSB framework and brings a new dimension related to the external world and the link between external and internal worlds. DOI's have mainly been used up to now for analysing cooperation between designers and especially the creation of specific shared artefacts and associated knowledge [Boujut & Blanco 2002] and user-defined annotations [Boujut 2002].

2.4 Cognitive synchronisation

Designers have to synchronise themselves in order to reach a shared understanding during teamwork [Darses 1997]. This synchronisation is guided by two complementary goals: to synchronise themselves at the cognitive level and in the flow of action. The purpose of cognitive synchronization is to model the human cognitive process of setting up a context of common knowledge, or constructing a common operational reference. Cognitive synchronization describes the two main designers activities: first, to make sure that each participant involved in the verbal exchange has knowledge or facts related to the situation status, (e.g. problem data, solution states, accepted hypothesis, etc.) and second, to verify that everybody has a common knowledge concerning the domain, (e.g.: technical rules, objects in the domain and their features, resolution procedures, etc.). The synchronisation in the flow of action is the operational synchronisation and relates to two functions: first, it describes the attempt to ensure a correct task distribution between the design partners and second to ensure the achievement of the sequence and synchronisation of the tasks. Cognitive synchronisation is a prerequisite to the coordination and cooperation activities.

3. The hybrid individual-collective cognitive model

3.1 A framework for analysing distributed design situations

The concept of Situatedness is very interesting for modelling the context of design and the relationship between the cognitive processes and the environment of the designer. The situated FBS framework provides an interesting insight into the mental process of individuals involved in a design process, including the context. This is why we propose to extend this model towards collective activities. Besides, the design intermediary object concept proved to be very useful in understanding the role of artefacts in design communication. Our goal is to propose a model for understanding the complex relations between cognitive processes and the collective production of artefacts, especially in distributed design situations. The model presented in this paper is the result of a combination of a critical analysis of the literature of the actual engineering design models, the experience accumulated on empirical field studies and a distributed design situation. As a result of this reflection, we propose a model that represents the processes of an elementary design interaction between two designers at a cognitive level. It allows the analysis of design cooperation including the relation between mental processes and the artefacts produced and used for the purpose of communicating during design (figure 3).

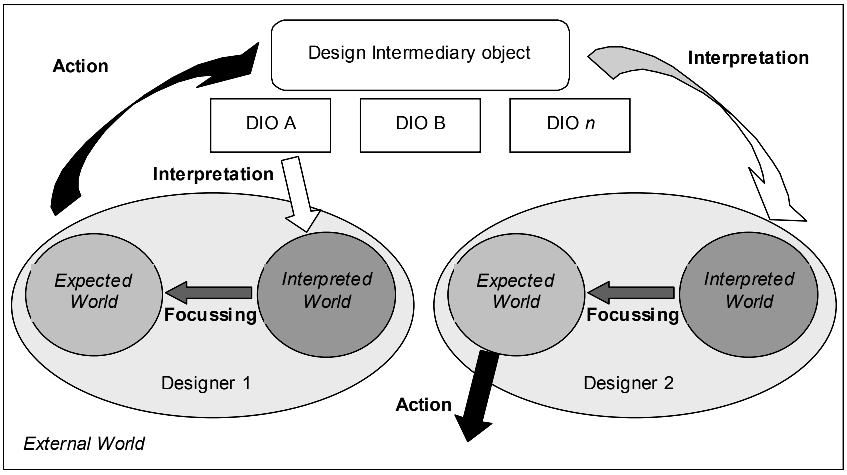

Figure 3. The hybrid individual-collective cognitive model

Gero and Kannengiesser [2002] model situatedness as the interaction of three worlds through three different processes (figure 2). This model describes the cognitive process of a single designer. We propose here to extend this model and modify it in order to represent a collective design activity (figure 3). We give here the description of the model in its most basic situation, the case of two designers. If we consider that the external world is the environment of the designers it therefore includes all the artefacts and tools available. We will consider two designers that are involved in a process of creation/interpretation of various representations of the product. These representations are materialised into DOI's [Boujut & Blanco 2003]. The right-hand side arrow describes the interpretation process of a representation embedded into DOI leading to a mental representation part of the interpreted world of the designer. The two arrows inside the bubbles describe the focussing process which is the mental operation of focussing on a specific goal (proposition of modification, evaluation, etc.). This goal is actuated through the action process (bottom and top-left arrow) and the mental representation is then transformed (actuate) into another DOI. This action process is in fact the process of creating or modifying a DOI (i.e. sketch, a plan, a CAD model, etc.). This last action is then the input of a next loop where the other designer interprets the proposition of the previous designer and so forth… Through consecutive loops the process leads the designers to build a shared understanding and foster cognitive synchronisation.

3.2 Analysis of distributed design situations and cognitive synchronisation

In this section we will exemplify the model presented above. For this purpose we will use a design protocol carried out for understanding cooperation and coordination mechanisms in distributed design situations. This protocol is based on a research conducted by four French laboratories of the Research Group on Collaborative Design Activities[1].

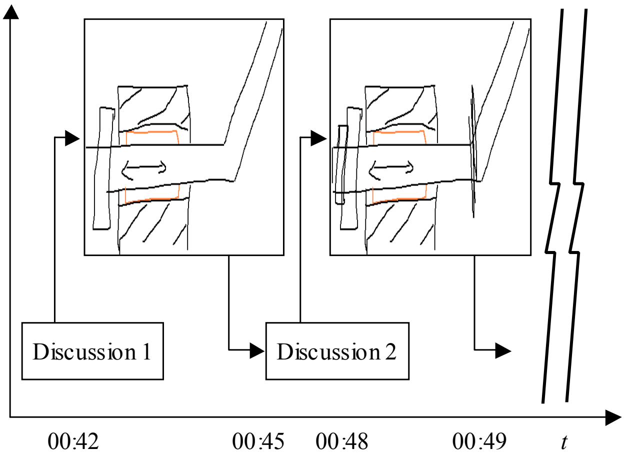

Figure 4. The sequential effect in a distributed design situation

The situation analysed involved the participation of designers located in different cities and the use of Internet communication tools. It was composed of four two-hours synchronous design meetings spread along a one-month period where asynchronous work was achieved. The assignment was to make the embodiment design of a technical device. The preliminary analysis [Ruiz-Dominguez *et al* 2003] of the distributed design protocol showed some evidence that cognitive synchronisation was a key concept in design cooperation. Figure 4 shows clear distinct phases in the process of creating sketches: a sequence of a sketching time and an argumentation time. We called this particular sequence the sequential effect and we found that it was slowing down the cognitive synchronisation process.

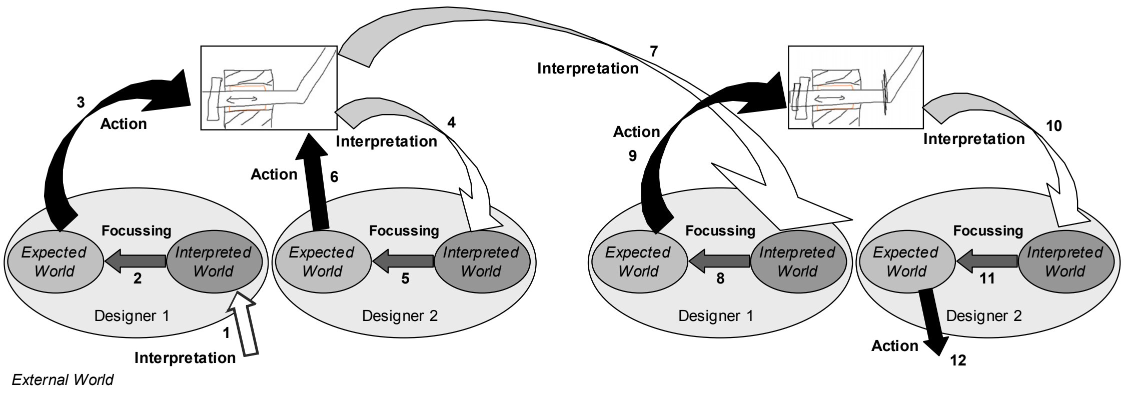

Figure 5. Sketch-argumentation phases of the cognitive sequential effect

In order to analyse this sequential effect we will use the proposed framework. When the participants in the design process are discussing solutions, one of them makes a sketch (action process of designer 1) in order to present his idea, then the participants sequentially begin a discussion (interpretation and focussing processes of designer 2 for example), in order to evaluate this proposition. Only one

[1] See http://www.3s.hmg.inpg.fr/ci/project/GRACC/

designer can take the control over the software in order to perform his action process. After this, designer one arguments again (action process). The resulting sketch is interpreted by the designer 2 who produces another argumentation process, in our case to validate the proposal.

4. Conclusions

The Situated FBS model is an activity model of a single designer; however it is a good base for a distributed model that represents the creation of a shared understanding and cognitive synchronisation. We have used here the concept of design intermediary object in order to model the material and visible side of the process. We then proposed a model based on an extension of the Situated FBS framework that takes into account the collective dimension of the cognitive process of the designers' interactions through design intermediary objects.

We think that the social side of the design process needs to be emphasised especially when we study collaborative situations. We suggest that there is a need to re-think the ways in which design teams can be supported during this social process, especially the creation of a mutual understanding in a distributed situations. Thus a framework that could give support to this purpose is a fundamental tool for understanding the coordination and cooperation mechanisms involved when the designers perform their job. This model is currently used for analysing mediated design protocols and modelling industrial situations in our current research.

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