INTERNATIONAL DESIGN CONFERENCE - DESIGN 2010
Dubrovnik - Croatia, May 17 - 20, 2010.

USING SITUATED FBS TO MODEL DESIGN INTERACTIONS IN A DISTANT SYNCHRONOUS COLLABORATIVE SITUATION

C. Masclet and J.F. Boujut

Keywords: collaborative design, synchronous collaboration, mediated collaboration, situated FBS, serious game

1. Introduction

Design has always been a collective activity where human and social dimensions played a critical role. Today new information technologies allow distant interactions in an increasingly smooth way and designers interact more and more often through collaborative tools in their everyday work. This is mainly due to organisational factors and will certainly increase in the coming years due to the environmental consciousness of the population.

The literature currently distinguishes two kinds of collaboration, i.e. synchronous and asynchronous. Both collaboration modalities are complementary and cannot exist separately. For supporting asynchronous collaboration new information systems integrate collaboration functionalities and all the modern PLM systems provide full web services allowing distant access and management of design workflows and data. Some recent works propose advanced annotation functionalities that provide support for recording some elements of the design rational [Lene et al. 2009] and the web 2.0 technologies have a critical impact on the software architecture and functionalities of our CAD systems. This is an important research issue today. In the mean time synchronous collaboration in distant design teams have seen dramatic development. Despite new software tools and synchronous environments available today, many research issues remain. In particular there are issues related to the design practice itself and design cooperation that are still not very well documented.

Therefore, a deep attention should be paid to design interactions in synchronous distant situations. Our research project is to provide a design environment that allows emulating various collaborative situations in order to provide a research tool for studying distant design dynamics.

In this paper we present an approach based on a on the Delta Design[1] serious game [Bucciarelli 1991], that proposes a versatile design scenario. We focus on the modelling aspects of the design situation and particularly we pay attention to the interactions modelling. The situated FBS model is used as a basis for building our descriptive model and we show how we can propose a model of some key interactions and help to understand the mechanisms of the process of creating a shared understanding (linked to the concept of constructive memory as defined by [Gero 2004] or [Riegler 2005]). In order to study more deeply this process of shared understanding and other issues related to synchronous collaboration we have built a collaborative platform, implementing the delta design situation in a distant configuration. The characteristics of our software are consistent with the FBS modelling we propose in this paper so that we can anticipate that the dynamics of the interactions between the internal and external worlds will allow the emulation of various design configurations that can be

[1] *Delta design is a serious game developed at M.I.T for engineering curriculum.*

found in a distant collaborative situation (e.g. designers behaviour regarding shared spaces use, restriction of information access, lack of awareness, etc.).

2. The design situation

Thanks to a longstanding and successful use of the Delta Design game, in our engineers' curriculum at both university and engineering school [Prudhomme 2003], we decided to study more deeply the design situation generated with this game. This game perfectly highlights some classical issues in collaboration such as conflicts management, knowledge sharing, or the importance of argumentation and inter-personal aspects of design, the need for organization, the importance of intermediary objects, etc.

As a short description, the game is basically a scientific role-playing game which consists in a team of 4 designers who must collaborate in order to design a house in a fictitious 2D world (materialized by a board game). Four roles are involved in the game (architect, structural engineer, thermal engineer and project manager primers), each one having a set of domain specific rules clearly stated. Hence, each expert is privately given a set of definitions and rules for its own domain. The team must reach a set of requirements that is shared by the group. The game material is very basic (plastic board game and red and blue triangles), and requires very simple manipulations. It is therefore fast and easy to organise. Some roles (for instance Thermal engineers or Structural engineers) must operate intensive calculus to evaluate the design. Players should be learning their own roles during the game, but also they must learn from other members' role in order to be able to cooperate. Each player's rules are antagonistic enough to ensure that no good solution can be found which satisfies everyone without building compromises.

In the next section, we will analyse the game interactions through the FBS framework.

3. Situated FBS as a framework for modelling design interactions

In the 90s cognitive studies began to become popular among the engineering design community. The increasing complexity of the products, the organisations and the technology shed a new light on the design activity and the design process. It appears that human behaviour studies could provide a valuable input in the research of a better understanding of design and efficient tools to better design. However, one of the key issues is to link these observations and models with the work carried out on design tools and product modelling, i.e. the well known contradiction between descriptive and prescriptive models. Linking the structure of the products, the functional level and describe the design activity is the aim of the FBS model [Gero 1992]. This model has been discussed and complemented by Vermaas, Dorst and Galle [Vermaas and Dorst 2006] [Galle 2009] in two much documented papers. In this paper we will mainly consider the FBS model on its descriptive side and use it as a tool for analysing a distant mediated design situation embedded into a design game.

The initial purpose of the model was to propose ontology of designing by considering three categories: function, behaviour and structure and eight elementary design steps allowing the transformation of functions into structures and eventually the description of the artefact. We recall here the original definitions:

- Function: The design intention or purpose
- Behaviour: how the structure of an artefact achieves its functions
- Structure: the components which make up an artefact and their relationships

This model is unfortunately not applicable in our case as we want to consider the cooperative aspect of design and therefore we need to model the interactions between the involved stakeholders. In order to overcome this problem we will use the situated FBS model proposed in [Gero and Kannengiesser 2006]. This model aims at introducing the distinction between the so-called "external" and "internal" worlds and therefore it introduces indirectly the notion of actor (even if this actor is reduced to some basic cognitive functions). With this model we can start to introduce several actors and reflect on the relations that bond them. The situated FBS provides a simple but useful cognitive model which can be used to describe collaborative situations, Kan and Gero [2009] used this model in order to analyse the corpus of a collaborative design session.

Basically the situated FBS introduces the interactions between three worlds (see figure 1).

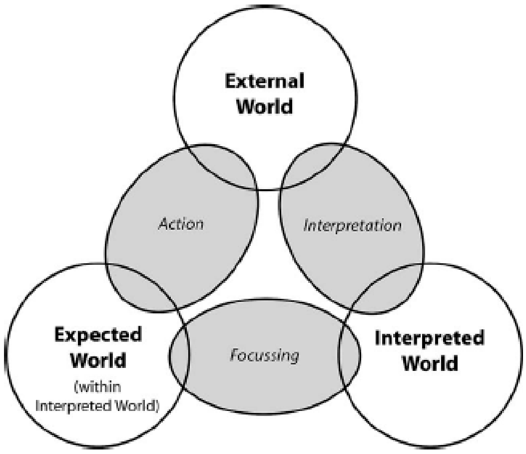

Figure 1. The three worlds of the situated FBS and the respective interactions

- Basically, the expected and interpreted worlds are "internal" (or cognitive) worlds thus we consider that they are attached to each individual and therefore the only way to go from the one internal world to another is to go though the external world. This is why we pay a particular attention to this external world and especially by analysing the artefacts that populate it.

The eight elementary design steps have been analysed in the situated framework and form a complex network of moves between the various worlds (Figure 2).

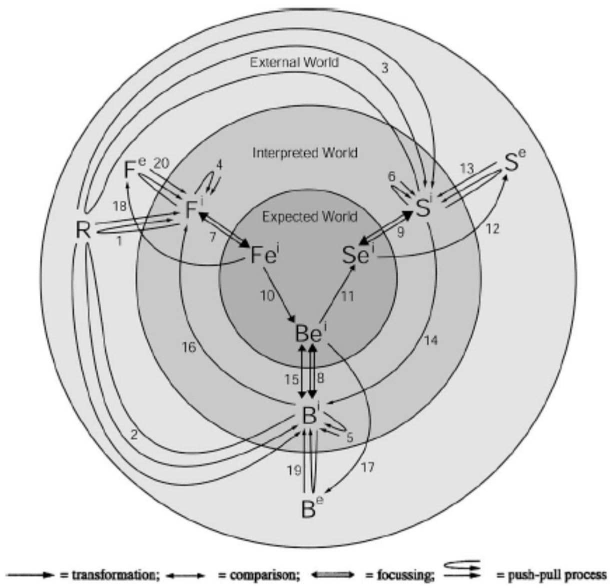

Figure 2. The full situated FBS model with the elementary design steps described

In this model the authors had to split the entities into entities in each world (e.g. Behaviour is split into Behaviour expected (B_e^i), behaviour interpreted (B^i) and external behaviour (B^e) and so forth for the three).

The critical point of our approach stands in the particular attention we pay to the artefacts produced during the design sessions. The first question we will address is then: which kind of representation plays the role of each external entity (e.g. R, S^e, B^e)? Second, what kind of design step is it necessary to add to the model in order to account for knowledge creation (constructive memory) if necessary or, if not, what are the corresponding existing steps?

4. Modelling game interactions

During a typical game, multiple and unpredicted sequences of design steps occur. Sequences are organised during design in many ways depending of the team's strategy, but we can identify some repeated patterns such as proposal, evaluation, argumentation, exploration, interaction or project management... These categories are coherent with previous works of researchers working that have analysed complex corpus of collaborated design situations [Detienne et al. 2004], [Lund et al. 2009]. Among the community we find a certain agreement on the main categories. First we distinguish two levels of categories one related to the nature of the activity or the interaction (e.g. argumentation, proposition, evaluation, etc.) and the other related to the object of the interaction (e.g. requirements, current solution, expert rules, etc.) [Detienne et al. 2004]. One of the most controversial items is the "cognitive synchronisation" one. It is hard to define clearly what relates to this category that includes more or less all the interactions that conduct to a better understanding in the group, to build a common ground of shared knowledge that allows mutual understanding. This work is also an attempt to help better defining this category.

The external world is encompassing all the material the designers are in contact with: all the primers given at the beginning of the game and the game material. Often, extra material appears onto or besides the board (pencils, sheets of papers, pocket calculators...): some objects clearly aim to make explicit some notions that have to be shared between designers, while others are purely personal stuff involved to ease the private work. When teams are co-located, designers hardly succeed in managing a small private area (a private workspace) on the game board to carry out their own activities. Closeness of other partners prevents to get a sufficient level of privacy and thus complicates the "self-learning" process. On the other hand, having a look to the others' workspace gives precious hints to the gamers (the awareness is a key issue in collaborative systems).

4.1 Identifying Function, Behaviour and Structure in the game external world

Before entering any interactions modelling, we need to associate the design situation artefacts to the fundamental elements of the FBS theory.

Function (F) are known and shared by the whole team. They should be part of the design task description, i.e. the primer that is preliminarily delivered to every designer (referred to as the primer figure 4). However, the specification list is too poor for simulating proper requirement elicitation and transformation into functions (R->F). Therefore specifications are not real functions in the sense of FBS. Designers have to build their own interpreted functions from the specifications given in the design task description and from their domain primer. We must keep in mind that, even if everybody has read that a house must be warm, spacious and reliable, only few of them know exactly how to reach these requirements and specifications. Thus, functions will be built independently by agents, and thus are disseminated in the deign team. Consequently, part of the requirements expressed in the design task description remains incomprehensible (and so not usable) for most of the designers: e.g. expressing a maximum cost for the house doesn't make sense if one doesn't know how to calculate the cost! Hence, designers will have to carry out some knowledge sharing to take out their team partners from this deadlock. Then ways they will meet the requirements depend on the behaviour of the whole team.

Behaviour (B) is contained in the domain specific description. Technical and scientific elements are provided in these documents that guides the designers in the interpretation of the behaviour of the structure. It ranges from "what is nice and have smooth facade" for the architect, to a "what is a comfortable average temperature" for the thermal engineer for example. In concrete terms, designers will focus on specific parameters that have sense in their expert domain, but it is worth noticing that they do not share interest for the same parameters. For instance, colour of triangle are fundamental to evaluate the cost of the house (Project Manager) while it has no importance for the structural engineer, as the weight and strength of the structure elements are independent of their colour. Conversely, anchors are only meaningful for the structural engineers, while other experts may not even know what they're talking about, and so forth.

Structure (S), in the external world, is represented by a layout of coloured triangles equivalent to a floor plan. Design parameters are very simple: a house can be entirely described by the location, colour, orientation, number and length of contact of its triangle. Another parameter is the anchor point that has only meaning for the structural engineer. Thus, designers share the same artefact (floor plan) of the ongoing product design. It should be underlined that the floor plan has an ambiguous status: at first it is a model of the product. It begins as a prototype, mostly to test and understand the behaviour models provided with the primer. Along the game, it reaches the status of product model. Different interactions will take place around this artefact, according to the status it has at a certain moment of the game.

4.2 Identifying some interaction between external and internal world

Knowledge sharing is an important aspect of collaborative design, especially when dealing with distant mediated situations. As we saw before, this aspect is difficult to observe in real life settings as it is mostly diluted into longstanding time scales. Because the process is running in the long term and the so-called "experience" allows the stakeholder to behave with a lot of implicit gained along the numerous past projects, observing proper knowledge elicitation and sharing is a big challenge in real industrial situations. Our situation allows the sharp reproduction of this phenomenon. This led to consider two types of interactions: knowledge acquisition and sharing through expert rules elicitation and learning through solution evaluation.

4.2.1 Knowledge sharing through expert rules elicitation and sharing

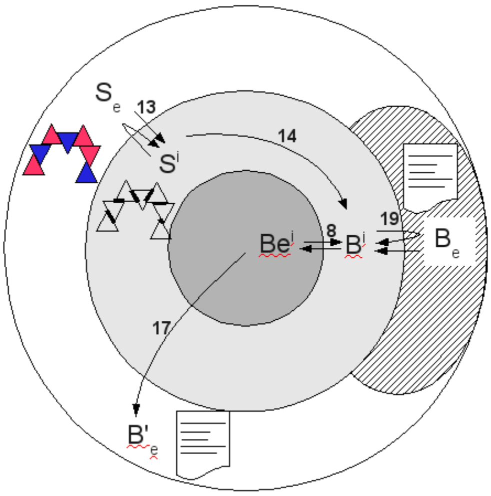

Figure 3. Knowledge acquisition through rules elicitation

Knowledge sharing is an important aspect of the game. In order to collaborate efficiently, designers must elaborate specific rules that they can to share with the other designers. This is a good indicator of the performance of the collaboration. Indeed, rough domain rules are too complex to be shared among the team. Due to the limited cognitive ability of the designers and to the time pressure on the project, the designers try to simplify and formulate their understanding of the rules so they can quickly evaluate the solutions and share (or sometimes impose) their view with the team.

The model of this interaction is presented in figure 3 (hatched zone represents the private space). Three fundamental processes are involved in these interactions. First, the designer needs to understand the rules given in the domain primer and construct his own background: that is achieved through type 2 reformulations (processes 8, 14 and 19). Second, the designer is conducting an analysis process (processes 13 and 14) using the examples given in the respective domains primers, but also on the shared workspace (or private workspace if the designer has already built one). Finally, the designer produces new rules (B'_e) from the expected behaviour under different forms (oral or written, constraint or rule of thumb...). It must be considered as a documentation process (17) exclusively concerning behaviour.

This new knowledge has been dynamically constructed and is in line with the theory of the constructive memory as it will be recalled and reshaped when facing the structure on the board game (S_e) provided by the other designers. This knowledge is can be shared among the group and we have observe a good correlation between this factor and the performance of the design team.

4.2.2 Learning through solution evaluation

Design process has proven to be highly iterative. Often poorly accurate, evaluation interactions are numerous in the beginning of the game, they progressively becomes sparse (and more accurate) as the structure is growing and becoming more complex. The first proposal is often the output of the architect and this first draft is very much linked to the ability of the team to share the first domain knowledge elements gained through the process described in 4.2.1. Starting from this first "draft", each expert tries to evaluate the solution while proposing some modifications regarding its own constraints.

Designers are learning actively during the game from the evaluation of others proposal, but also from their own proposals. Evaluation constitutes a mean for regulating the designers' activity.

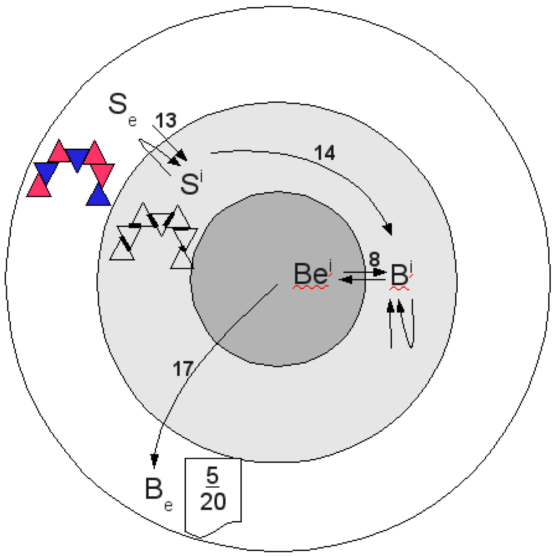

Figure 4. Knowledge elicitation through solution evaluation

Starting from the shared board (S_e), the designer interprets the model of the structure, according to what makes sense for him, i.e. the useful parameters for his expert activity. The behaviour is then evaluated during the analysis process (13 and 14). The designer compares the interpreted behaviour (B^i) with the expected behaviour (Be^i) (what should be a good behaviour (8) for him). The interpreted behaviour is evolving (push-pull process) thanks to the constructive memory principle (6). Hence, expert ground of the designer is also growing proportionally to the number of conducted evaluation. Finally, the designer acts (17) toward others to give his expert assessment of the actual structure (for example, pointing out the hot deltas, identifying the weak joints in the structure, etc.).

It is important to notice here that the expert's knowledge is made of a mix of his own domain knowledge and of the others' domain knowledge providing the possibility to take into account a wider range of constraint when proposing modifications. The more cross domain knowledge is built the smoother the collaboration and the better the result.

This generic model should be improved, but it already gives an interesting account on an important mechanism in collaborative design that should be addressed in collaborative software developments. In the earlier phases of the design, evaluation interactions are the entry points for reformulation. In latter phases of the design, designers can follow on their evaluation with modification proposals. So appears Se^i in the model that may be materialized via a new structure (S_e), not represented in figure 6.

5. The e-MediatE collaborative platform

5.1 Collaborative business software

Engineers are offered software solutions to ease their collaboration and enhance their productivity. A rough classification can be made by distinguishing expert tools (CAD, planning, simulation tools …), management tools (PDM, ERP), and communications tools (Collaborative plateforms such as QuickPlace, SharePoint, etc.).

The first family of software is clearly dedicated to the scientific and technical activities (CAD, simulation tools …). They support the added value of the expertise in the design process but are seldom shared between a large panel of collaborators, as these tools belong to expert communities and remain incomprehensible for outside communities (CAD tools for marketing for example). These tools cannot be considered as efficient media to communicate between domains.

Management tools aim to help engineers to define or follow the management strategies and to organize the activity (workflow, project management, shared calendar, etc...). For instance, digital documents management has become a real concern in engineering teams and software solutions like PDM and PLM are nowadays essential, even for SMEs, provided that they can afford the significant cost of implementation. An important limitation of such tools is their inability to support informal exchanges between members particularly synchronous collaboration.

Last group of software is formed around the communication needs. Developed and promoted by the CSCW community, groupware are challenging the support of both synchronous and asynchronous tasks [Johansen 1988]. Every traditional means that used to support communication e.g. regular mail, internal notes, telephone calls... tend to be replaced by e-mails, instant messaging and computer mediated audio-conference, embedded in more complex software solutions. Gains in time, money, environmental impact obviously support the dissemination of these solutions.

These three categories of software are obviously complementary and, despite the fact that the frontiers are not strict between the categories, they provide however very different kind of support to the design teams.

Our plate-form has a different purpose and it is important to distinguish it from the previously described software. Our objective is to emulate a distant design situation through an information tool that is designed for tracing and studying the designers' interactions. This tool is therefore a research and educational tool. It is not a design tool.

5.2 The e-MediatE platform

For this development, we kept in mind the strong requirement that none of the previous aspects presented in section 4 should be left aside. Hence, the platform must support communication (in the sense of external and internal worlds interactions), as well as experts' activities.

From a technical point of view, e-MediatE (electronic-Mediated Engineering), is based on a client-server framework, coded in Java™ language. It allows multiple client (up to five, according to the four role, plus one observer) to connect, through LAN or internet network layer, to the server. The GUI was designed to remain as close as possible to the original Delta Design board game, but the overall aspect was adapted to suit the conclusions derived from the modelling of the co-located situation.

Firstly we must distinguish two kinds of external worlds that act as public and private workspace (cf. Figure 5). The public external world is considered to be accessible for everyone. By accessible, we mean everything the user can be in contact with (according to Gero's definition). Consequently the private external world may be seen as a restriction of the public external world, only limited to the respective players.

In our case, the external world is mainly (on purpose) limited to the GUI of our collaborative platform. This allows tracing all the interactions between the various stakeholders. The structure of the interface allows the player swapping between private and public spaces, allowing the introduction of a more refine definition of the external world. For us the external world will therefore be divided into a public space accessible by everyone and as much as private spaces as participants. The separation between private and public spaces is entirely defined by the software implementation and the functionalities given to the users; this is a critical issue in all distant design tools.

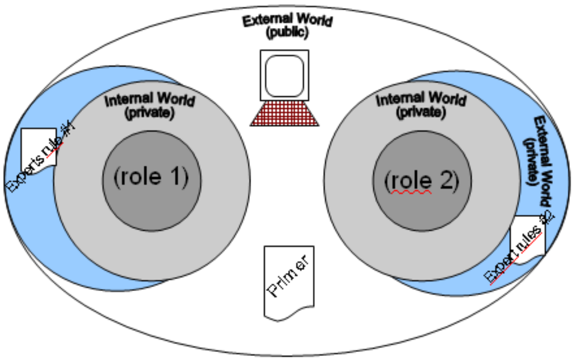

Figure 5. Shows the E-mediatE world with two designers in the situated-FBS formalism

The public space is divided into two subspaces, a fully opened space and a semi-opened space. The semi-opened space allow only visualization and annotation of a proposed configuration (Figure 6 centre), while the fully opened space allow all the participants to modify the proposed solution.
Interaction modalities can be precisely defined by numerous other combinations of restrictions that remain to be studied.

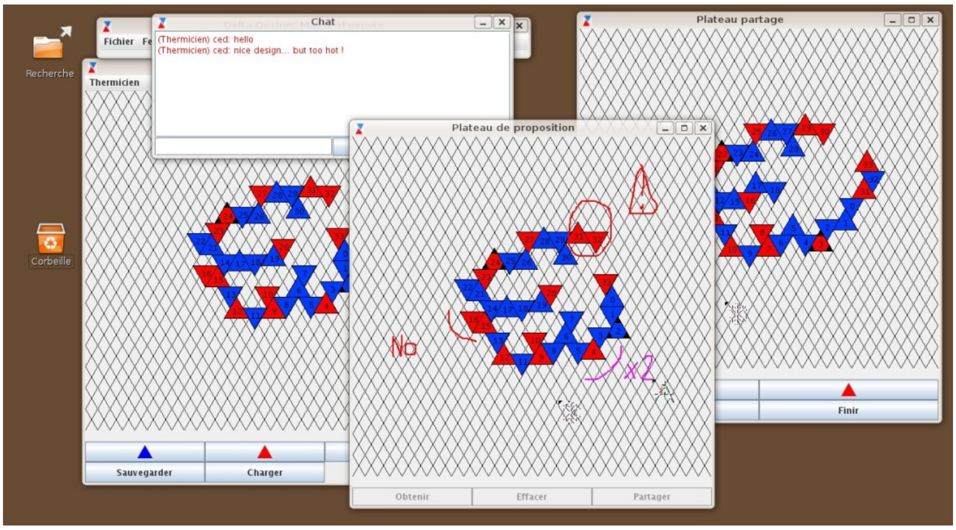

Figure 6. Screenshot of e-MediatE prototype

The platform is composed of several windows simulating the various workspaces. Three of them are dedicated to the definition of the lay out of the house (from left to right):

- first workspace, called "private workspace" is accessible (read and write) only to the designer running this client. The designer can propose solutions or modifications and benefits from calculation facilities of it's domain; This is a private space
- second workspace, called the "proposal workspace", can be seen by every player. each designer can make a proposal in this workspace, but it is only an evaluation space as the only possible interaction is to annotate the proposal; this is a public space
- third one, called the "shared workspace", is fully accessible to all the designers. Every basic operations are allowed, all the modifications can be seen in real time by each participant. It is a fully synchronous space with no restriction. This is another public space.

The three workspaces are connected together by a release mechanism that allows the transfer of a proposal from one workspace to another.
Another important window is dedicated to some awareness indicators. It provides (if turned on by the designer) a visual indication of the activity of the other designers on the various workspaces. A last window is allocated to Instant Messaging (IM) which is the only free non graphical possible

interaction. All these workspaces ensure, in various proportions, that all dimensions of collaboration are more or less supported (except the visual and audio). For instance, I.M. is mainly used for communication, but it can also serve as a coordination mean. Audio communications have been voluntary prohibited in order to force every verbal communications to pass via the I.M. system. Given that the platform has the ability to record any event from each partner, the I.M. is the easiest way to keep trace of these interactions.

The computer implementation of such game may change the subtle equilibrium achieved in the original face to face game. For instance, the solution assessment relies heavily on calculus for some roles: although they're easy to complete, they need a long time to output the result, and it generates important discrepancy in the reaction time between designers which raises some organisational and decision making issues among the group. Fully automating such calculus would have discarded this important parameter and led to different coordination strategies.

Nevertheless, computer brings new functionalities that cannot be neglected (e.g. multiple solution instantiations, save and restore, role-specific visualisation...). The study of these functionalities and the way they impact the design process is part of our ongoing research project.

We have tried to provide functionalities that save the specificity of the original delta design situation: particularly the process of creating a shared understanding among the design team This aspect is particularly strong in the initial design situation and remains an original research question as it is pretty difficult to observe this phenomenon in real settings. GUI structure has been thought to enable any constructive-memory process to take place. The movements between internal and external worlds are still available, and further they can take place between different external worlds.

6. Conclusion

The knowledge elicitation and sharing processes are very complex and require deeper investigations to be precisely defined. However we have here an interesting insight in this mechanism thanks to the situated FBS model. We have a good fit with the theory of the constructive memory which mainly states that memory is a process and that human beings constantly reconstruct their remembering by reconfiguring bits of knowledge with the elements of context they are facing. Therefore, one expert may behave differently if he experienced the knowledge of another domain through the mechanisms described in section 3. The interactions capabilities (occurring in the external world) are very much linked to the software interfaces and functionalities. Indeed, our choice can be discussed and the interaction restrictions may appear as an important drawback of the platform as today most collaborative tools provide visual and audio channels. This issue should be studied in future work. It is however important to stress that our research process started with a modelling of the key cooperative interactions and led to reinforce our understanding of design communication. Our approach is compliant with the Gero's situated FBS framework, which allows the analysis of various configurations of the design setting (i.e. rules or interface variations) in relation to the framework. In this paper we have only addressed two points about knowledge acquisition and elicitation mechanisms. Many other aspects can be (and should be) studied, example includes:

- decision making process,
- synchronous process management and dynamic planning,
- collective versus personal design strategies (use of the private and public spaces),
- constraints and requirements management,
- etc.

A general issue for industry remains the performance of such distant design teams. This kind of platform appears as an interesting testbed for learning about distant cooperation.

Acknowledgement

Authors want to thanks the Rhone-Alpes regional council for funding this research via the GOSPI research cluster (http://www.cluster-gospi.fr/).

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Cedric Masclet
University of Grenoble - Laboratoire G-SCOP
46 avenue Félix Viallet - 38 031 Grenoble Cedex 1
Telephone: + 33 4 76 82 70 10
Email: Cedric.Masclet@g-scop.eu