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EDUCATIONAL PRACTICES FOR COLLABORATIVE DISTRIBUTED DESIGN OF AN INNOVATIVE ECO-DESIGNED PRODUCT

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ABSTRACT
This article presents an academic experiment in the design of an innovative eco-product, by two Master's degree student teams from two universities. We used observational study as a research methodology. The originality of the work is that it promotes a framework for analyzing and teaching collaborative design projects in a context of cloud computing. To conclude, we present an analysis of the use of these new design and communication tools in such a mechanical context.

Keywords: Collaborative engineering, cloud computing, design.

1 INTRODUCTION

This paper reports on an observational study of the design process in an academic context, with the objective of optimizing collaborative design projects. One of the most important changes in design approaches in the first decade of the 21th century is the phenomenon of Business Process Outsourcing, also known as BPO, in various professions [1]. In order to give mechanical engineering students a first view of the extent of globalization, many engineering schools have integrated into their training programs design projects involving students as participants [2-4]. We describe the challenges that these developments in product design raise for education in engineering. We then present an experiment carried out between the Arts et Metiers ParisTech School of Engineering and the University of Strasbourg, in which the goal was to design a three-wheeled bicycle in a collaborative distributed way [5].

Based on the above, we extracted the following motivations for this study:

Motivation 1: Our students will in the future be involved in collaborative distributed design, in the context of globalization and BPO [1]. We therefore need to train them in these new technologies (ICT) as early as possible, to meet the needs of industry.

Motivation 2: Today, the development of eco-friendly and sustainable products is a major asset in product design. Engineers therefore have to take environmental aspects into consideration [6].

Motivation 3: The development of collaborative "all public" tools (like Skype or Dropbox) have significantly changed modes of distributed design. The main originality of our study is that we promote a full “in the cloud” storage solution, in order to analyze the impact on collaboration of the use of these new kinds of internet-based tools.

Recent developments in technology allow for the implementation of innovative working practices, such as cloud computing.

2 CLOUD COLLABORATION AS A NEW WAY OF WORKING

Product design techniques are evolving towards the implementation of concurrent engineering methods where different views on the product are taken into account throughout its life cycle. In order to improve interaction among various stakeholders of the design process, new organizations, tools and methods have been emerging in recent years.

Communication, coordination, cooperation and collaboration are discussed extensively in the literature. We can say that each of these four terms contributes to the characterization of team work in its own way:

- communication is an essential tool for interaction within the group;

- coordination is a means to organize team work;
- although cooperation and collaboration both apply to the process of team work, cooperation focuses on participation in common work, while collaboration focuses on the importance of working together [7].

A number of experimental studies regarding concurrent engineering in education have been conducted in recent years. These include the work of the GRACC consortium (four French research teams working in the field of mechanical engineering design and conducting collaborative multi-site experiments).

The analysis of various experiments has allowed for the identification of properties which are suitable for collaborative design in a distributed environment. These experiments have also led to the characterization of different tools for product design [8]. However, no studies specifically target the use of cloud computing for design projects in education, even though its potential has been recognized [9]. Cloud computing offers the possibility of concentrating more on teaching and research activities rather than on complex IT configurations [10]. It is said that cloud computing solutions allow all categories of users access to stored files, e-mail, database and other applications from anywhere [11], which leads to a more efficient use of information. Nevertheless, most of the studies in the literature are more or less targeted towards e-learning [9].

The originality of our work is therefore to promote a fieldwork study of a collaborative distant design experiment within a student project. In the following section we examine this design project.

3 EXPERIMENTATION

3.1 Educational approach and experiment objectives

We propose an educational approach based on two kinds of tools:

- the "engineering toolbox" with different CAD tools to create and share data,
- the "communication toolbox" with communication tools such as Skype for videoconferences and Dropbox or internet to exchange data.

In the proposed design project, two distant teams collaborate and must face problems which are related partly to general aspects of distributed work – such as effective communication, building and maintenance of a shared understanding, and conflict management – and partly to the very nature of the design process [12].

As part of our project, the main IRs [13] generated were CAD parts (mainly with STEP format) and Microsoft Office documents. Post-collaboration knowledge [14] was archived as best-practice documents in the database, to capitalize on the solutions found to the main technological challenges that emerged during the project. Then we analyzed the relevance of the used tools and their impact on designer activity, and more broadly on the design process. This was done using indicators defined by Martin [15], adapted to the design situation under consideration: context, number of participants, space, duration and design phases.

We will now present the project which served as a basis for this experimentation.

3.2 Project presentation

In this section we present first the context of our study and then the product whose design served as teaching material in our project.

The product to design was an innovative three-wheeled bicycle. The study described in this paper mainly focus on collaboration issues. For this product, the main design phases were: analysis of the requirements and the existing research on innovative concepts; evaluation and generation of ideas sheets; preliminary design and detailed solution. The originality of this design project is that it concerns product-driven innovation, unlike most studies which focus on collaboration around previously proven products, with routine or parametric design [16-17], or on redesign project [18].

To conduct the project, the teams were organized as follows:

- 4 students in Paris supported the development of the front of the three-wheeled bicycle,
- 4 students in Strasbourg took care of the eco-design and the rear of the three-wheeled bicycle.

Each student team was supervised by two teachers. An industrial project manager tele-guided the project according to previously defined functional specifications. The project lasted 80 hours (scheduled time) and was sequenced in 4-hour sessions, from September 2011 to January 2012. It was launched with a meeting on Skype with the manufacturer. Each team then worked in collaboration with the project stakeholders to develop a product according to specifications. A physical encounter between the two teams was held in Strasbourg in the middle of the project so that the teams could exchange notes on the progress of the project. The manufacturer was present, via Skype. The work subsequently continued and a final joint presentation was scheduled in the middle of January 2012. Figure 1 shows the interaction and the methodology defined between the project stakeholders.

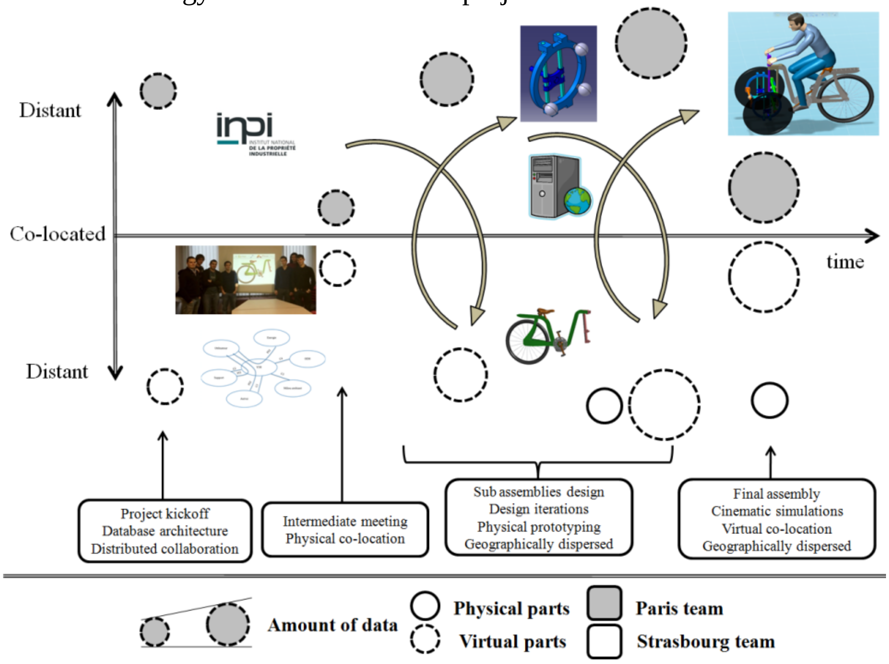

Figure 1: Mapping interaction between project stakeholders

The professors monitored the project, using an Excel spreadsheet on which the students recorded all their mutual interaction. The themes identified in this table are the date, duration and type of situation for collaboration, as well as stakeholders and the framework for such collaboration (during the project or on their free time). A summary of decisions was also written in a few lines. To store more cumbersome data (CAD parts etc.), a Dropbox account was created and project stakeholders were invited to share this folder.

The synthesis in Table 1 below shows the tools used during this project.

Team	Voice/video	CAO	Technical data
Paris team	Skype, telephone	DS Catia	Dropbox, e-mail
Strasbourg team	Skype, telephone	Autodesk Inventor + DS SolidWorks	Dropbox, e-mail
Manufacturer: remote	Skype	DS SolidWorks	Dropbox, e-mail

Table 1: Tools used by different project teams

In the next section we analyze the results and deduce a standardization of the design method.

4 PROJECT ANALYSIS AND STANDARDIZATION

In this part, two kinds of results will be presented. We first consider all the results of the project regarding the prototype designed, and then the results that can be interesting from the point of view of the standardization of such an experiment.

4.1 Product results

During the Skype kick-off meeting, it was decided that the team from Paris would develop the fork of the bike and review the state of the art concerning the components and patents. This fork, which kinematics is original, had to be able to tilt and rotate at the same time (see Figure 2). The team would also have to find creative new solutions to include in the bike. A review of the state of the art of different solutions for brakes, suspension, lighting and a tilting system was first drawn up. In parallel, the team also explored existing systems with three wheels (mainly scooters) through a study of patents. Creativity sessions were then organized on the themes of front fork architecture and on the accessories and equipment that could fit the bike. Following these sessions, 18 ideas sheets were generated, divided

into three categories: accessories, storage and security. Five of these ideas sheets were selected by the manufacturer and an opinion poll was conducted by students on a sample of 40 individuals representing potential users of the three-wheeled bicycle, to test these innovative solutions and the concept of the product itself.
The Strasbourg team, on the other hand, had to develop the frame of the bike and to lead the global eco-design analysis. The frame of the bike was developed according to the requirements of the industrial partner: a solution with good stability when the bike was stopped, a very broad consumer base, and an eco-designed concept. Regarding the industrial specifications, the solution was designed to receive an electric engine as an option. Based on these requirements, several sketches were made and exchanged among the various stakeholders of the project.

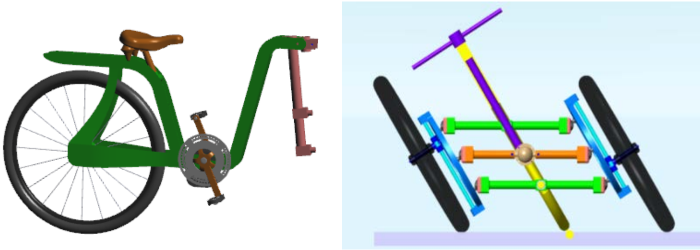

Figure 2: 3D PDF of the rear part of the three-wheeled bicycle (left) and CAD model (right)

This design, inspired by Dutch bikes (see Figure 2), allowed for good rigidity of the frame. It was also a solution that facilitated industrialization of the bike at a reasonable cost. In parallel, an eco-design study was conducted, based on an eco-design analysis regarding traditional material used in bicycles: aluminum and steel. A precise impact analysis was run on the Simapro 7.3 LCA tool. Six indicators from the impact indicators study were selected, namely ozone layer depletion, land occupation, aquatic eutrophication, global warming, non-renewable energy and mineral extraction (see Figure 3). The solution integrating an aluminum frame and steel wheels was retained. With this solution, the six impact indicators could be retained and would also be compatible with the expected standard of quality regarding the final product.

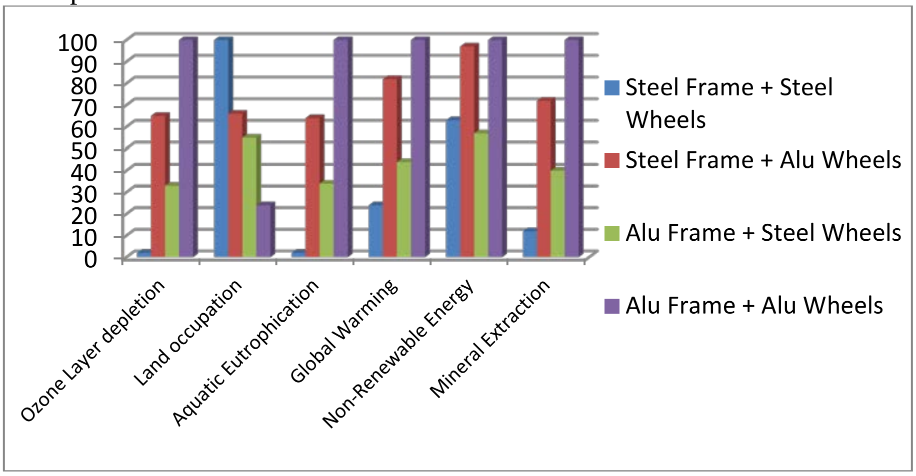

Figure 3: Environmental indicators comparison extracted from Simapro indicators

Optimized design implementation of the frame parts in the aluminum plate allowed for some savings on raw materials. Incidentally, the welding of the aluminum parts was quite easy to implement and would not impact the overall cost of the three-wheeled bicycle.
We will now analyze the results of collaboration between the teams.

4.2 Collaboration results

After presenting the results of product design, we analyzed the cooperation between the two geographically distant teams. Two variables were used: the distribution of synchronous/asynchronous work, and the distribution between cooperation and coordination activities of the two teams over time.

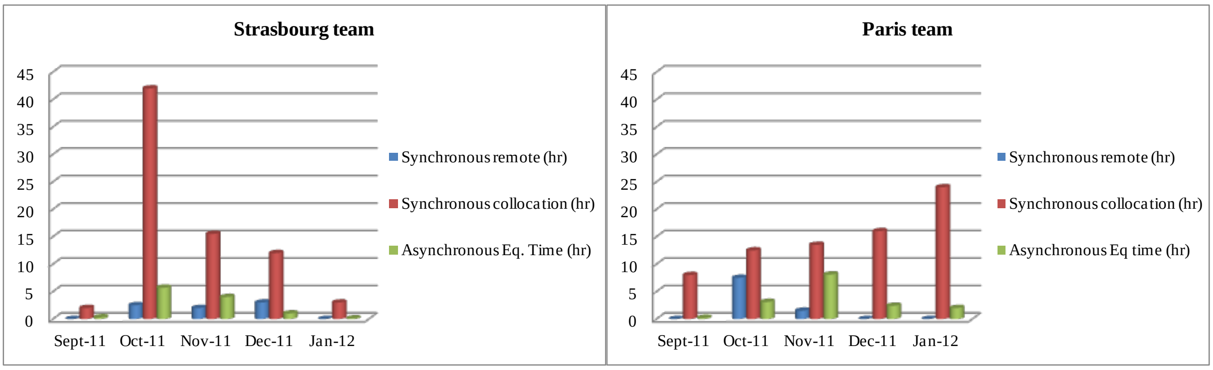

Figure 4: Time distribution of both teams (synchronous, asynchronous)

Figure 4 shows the distribution of work synchronously or asynchronously at the two sites. At both sites the majority of time was spent in "synchronous co-location". This was due to the niche reserved for the project within the timetable. The Strasbourg team had spent much time in "synchronous co-location" early in the project, and the Paris team at the end of project. During the project (November-December) these two teams met with the same frequency (10 to 15 hours per month). The asynchronous mode (e-mail exchange) had been used more than the synchronous remote mode (via Skype meetings); thus, few sessions were held in the same slots. Finally, we notice time distributions that are opposite for the synchronous collaboration (increasing for Paris team, and decreasing for Strasbourg). This was mainly due to the different distribution of work sequences between the two teams.

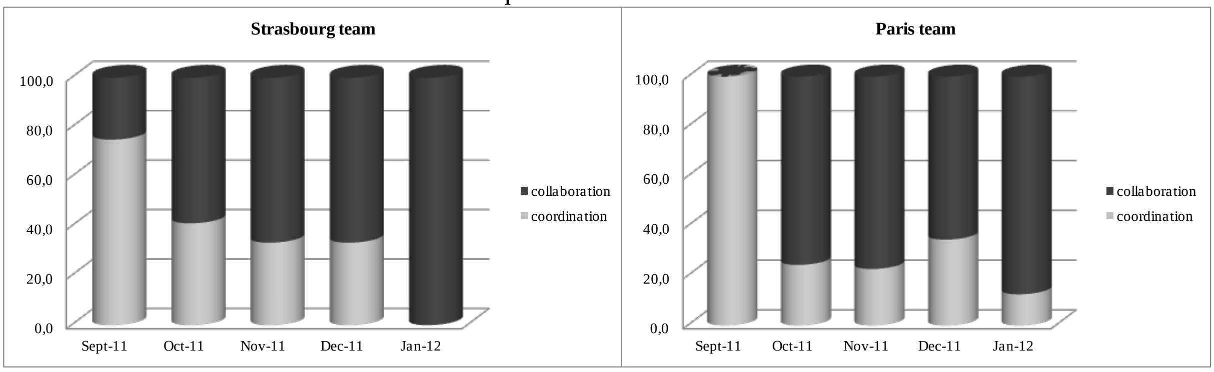

Figure 5: Distribution between the actions of collaboration and coordination (%)

Figure 5 shows the distribution between the activities of collaboration and coordination for both teams. Three phases emerge from the analysis of the two graphs. In the first phase, early in the project (September), the two teams primarily had to coordinate. During the second phase (October-December), coordination decreased while their collaborative activity increased sharply (20% / 80%). Finally, the last month of project (January) was almost entirely devoted to collaboration between the teams. This was totally consistent with the results promoted within the GRACC consortium [19]. The team that coordinated itself with less effort was more competitive in the collaboration phase since the organization was already well defined. The differences in the coordination results between the two teams can also be explained by the level of technicality of the tasks to be done by each team: the Strasbourg team was immediately fully operational, whereas the Paris team needed some time for reflection at the beginning of the project while designing questionnaires.

When discussing the feedback on the experimental aspects of the project, the relative success of the project regarding the educational and industrial requirements emerged. The students from both teams acknowledged the fact that this was a really interesting and challenging project, with real life conditions: interaction with the industrial partner, contacts with suppliers, etc. The innovative face of the project was also highlighted as a trigger for motivation. The way the project was organized, by centralization of the documents over the web, also gave both parties a large degree of autonomy as well as flexibility in organizing their time. Moreover, cloud computing allowed for easier tracking of the interaction, and led to greater efficiency between the meetings. The eco-design also appears as a really interesting facet of the project. Students stated that eco-design constraints were not really in competition with traditional technical and economic aspects, but appeared rather as effectively new constraints that had to be taken into account from the beginning of the project.

Regarding the points that needed to be improved, the general remarks dealt with the need for homogeneity in the tools used during the project. Cloud collaboration was a great experiment, according to the students, but they were a little disturbed by the fact that they had several ways of acquiring information within their cloud computing environment. In this way, best practices were standardized following a loop inherited from the Deming Circle, with a standardization phase at the end of the project: the PoDCaSt sequence [20].

5 CONCLUSION

Cloud computing and new tools and technologies enable the stakeholders of design and engineering departments to work and collaborate in new ways. It is therefore of primary importance to train our students to use these new kinds of tools in real life contexts.

In this article we report an experiment in a distant and collaborative design project between two teams of Masters' students. The innovative support chosen for this experiment was a three-wheeled bicycle developed in collaboration with an industrial partner. After presenting our motivations and the architecture of the experiment, we analyzed the various interactions that took place, mainly using cloud computing tools. We wanted to show the results in terms of collaboration and coordination among the teams, and to look at the pros and cons of working in such an environment for an innovative and eco-design product. We have tried to integrate the positive aspects via a Plan Observe Do Check Act Standardize cycle within the design process. As follow-up, a standardization of the global methodology could be developed via the definition of a model of organization for innovative projects within the framework of collaborative design, including best practices from past projects such as the one presented here.

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