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Improving design coordination in computer supported environments in SMEs: implementation of a tool for capturing and analysing collaboration between actors

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Abstract

To remain competitive in a context of multi-partner projects companies are increasingly concerned with the coordination of design projects. Information systems such as PLM or CSCW are implemented to support the coordination of product information flows. Project managers are nevertheless finding it increasingly difficult to manage projects effectively. The impact of collaboration aspects on the design process is especially difficult for them to evaluate. Indeed, failing to integrate collaboration aspects into coordination can account for a great deal of design mistakes and finding a solution could lead to improved design coordination.

The main objective of this research is then to help project managers improve coordination in design processes through a detailed analysis of collaboration between actors. A model of coordination and an associated model of collaboration have been devised together with a tool ("CoCa") to be used by researchers, consultants or project managers in the analysis of collaboration. This analysis can lead to the understanding of collaboration aspects and identification of the problems caused.

Consequently, guidelines can be defined to prevent the re-emergence of the identified design problems in new projects. These guidelines are recommendations to introduce collaborative aspects, flexibility in the design process and elements for decision making when defining future design situations. Finally, a study of a specific application implementing PLM tools demonstrates that they are not able to manage firstly design projects and human resources whilst taking into account collaborative aspects or, secondly, the necessary synchronisation between human design activities and document workflow tasks. It is thus evident that these two factors are needed in PLM tools in order to apply the proposed model of coordination.

An industrial partnership with an SME led to the study of its information system, an experiment with the CoCa tool, practical design process improvements, and implementation of a PLM prototype.

Acknowledgements

Author profile

The author obtained his degree of engineer in Global Product Design from the Higher School of Advanced Industrial Technologies (ESTIA, France) in 2003. The same year he graduated with a Master of Science from the Engineering School at Cranfield University.

Since 2003, Mr Guillaume POL has been a PhD student at the School of Applied Sciences at Cranfield University (UK) and has done his research in the Laboratory of Industrial Processes and Services Engineering (LIPSI) at the Higher School of Advanced Industrial Technologies (ESTIA, France). His research interest is focused on collaboration during design activities in order to rationalise design processes in SMEs and to incorporate the adequate level of flexibility into these processes to improve the coordination of design projects. His work is based on a socio-technical approach of industrial design situations in SMEs. He is currently developing methods and tools to help the analysis interactions and collaboration between actors.

In this context, the author has given lectures, tutorials and workshops for the French students in the Engineering school ESTIA. He has worked in close collaboration with Ederena Concept an innovative SME where he has tested his methods and tools.

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Glossary

Actors: The word "actor" is used to denote any person involved in the complex network of collaborative relationships during design projects within and across the company's boundaries.

CAD: Computer Aided Design.

CND: Customer's Need Definition (Ederena terminology).

CoCa: Collaboration Capture.

CSCW: Computer Supported Cooperative Work.

ERP: Enterprise Resource Planning.

ESPRIT: ESPRIT, the information technologies (IT) programme, is an integrated programme of industrial R&D projects and technology take-up measures [ESPRIT 2000]. They support the EU's policies for improving competitiveness, growth and employment.

GRAI: "Groupe de Recherche en Automatisation Intégrée" i.e. Research Group for Integrated Automatisation.

GUI: Graphical User Interface.

ICED: International Conference of Engineering Design.

IMDEV: As CIMMOD, it is conference of Esprit Working Groups.

IDMME: Integrated Design in Manufacturing and Mechanical Engineering.

IDEFØ: IDEFØ is a method designed to model the decisions, actions, and activities of an organisation or system. IDEFØ was derived from a well-established graphical language, the Structured Analysis and Design Technique (SADT).

IPPOP: Integration of Product – Process – Organisation for engineering Performance improvement. IPPOP is an RNTL labelled project by the French Ministry of Economy, Finances and Industry.

IT: Information Technology.

PAT: Project Administration and Tasks (Ederena terminology).

PDA: Personal Digital Assistant.

PDM: Product Data Management. These IT systems help to manage design documents of the company.

PDS Assessment: PDS assessment is an approach often used in the PTC Company to improve the consulting process. This approach is based on audits.

PLM: Product Lifecycle Management. These IT systems are an evolution of the PDM systems where the management of documents is supported by life-cycles and workflows (processes).

PTC: Parametric Technology Corp with PLM (WindchillTM) and CAD (Pro/Engineer) systems.

RNTL: French National Network on Software Technologies

SME: Small and Medium Enterprises.

UML: Unified Modelling Language. This is becoming an industry standard for visualising, specifying, constructing, and documenting the artefacts of a software-intensive system. UML facilitates communication and reduces confusion among project stakeholders.

1 Introduction

This Chapter outlines the background of the research and explains the focus of the thesis, detailing the relevance of the research to the current body of literature. The research aim and objectives are outlined, along with the research approach taken and the overall research deliverables. Finally the structure of the thesis is presented.

1.1   Background

During the last fifteen years, there has been a growing research interest in the study of the design activity. This evolution is justified by the strategic place of design in the product life-cycle. It is now well established that design is the step where the reduction of cost and lead-time can be the most effective. The decisions made in design have an impact on all the following life cycle steps. Consequently, in the face of a more and more aggressive worldwide competition, industrial and research laboratories have worked together on the concept of "concurrent engineering" to improve product development. Tomorrow it will be necessary for the company to become a collaborative one, and to know how to mobilise the collective intelligence and knowledge of its internal and external parts (employees, suppliers, customers...). Thus, it is important to develop collaboration between the actors in order to improve design as the result of work made jointly, and to enable knowledge to be shared within the team.

Nowadays a significant proportion of software tries to take into account collaborative aspects of designing industrial products. In particular, information systems like PLM or PDM systems manage information, documents, responsibilities, people, and try to deliver the right information to the right person at the right time during the process of product development.

In this context, more and more companies are focused on continuous product innovation and process improvement in order to reduce the time to market and development costs. Ensuring the coordination of the whole development of a new product is a challenge for managers at the different levels of such projects, especially in SMEs (Small and Medium-sized Enterprises) [Fenves, et al. 2003].

Various words are used in this thesis such as cooperation, coordination, collaboration, processes, and workflows. These words have different interpretations but have interpenetrated realities in design. Cooperation is the process of working together to the same end; whereas Coordination is the process that aims to plan and schedule different

tasks, and to distribute resources. The complex combination between Cooperation and Coordination is used to define Collaboration. A Process in design is a group of design activities. Lastly, a workflow is a predefined process implemented into an information system. A detailed definition of these words is arrived at in Chapter 3. These words are the key words of the thesis and are used extensively throughout.

The objective of this research is to find ways to improve Design Coordination in SMEs by analysing and fostering collaboration between actors. This work is mainly focused on the organisational aspects of SMEs involved in networks composed of large companies, subcontractors and other industrial partners. In this context, the design process of a manufactured product is complex and depends on parameters which are based on multiple aspects combining organisation, project management and relationships between suppliers, customers, and subcontractors which are also difficult to define precisely.

In the SME and in this study, the project manager's task includes the organisation and the scheduling of design projects around an appropriate structure. [Coates, et al. 2000] suggest that task management and scheduling together with resource management are the most important issues when it comes to operational coordination. However, this requires that the design process can be rationalised and organised using a prescriptive approach. In an SME respecting deadlines is the main performance target. The project manager must ensure that the outputs from designers converge and do not interfere with any of the others. The performance of the collaboration between co-design partners and also with suppliers offers the possibility of gaining fast access to specialist knowledge and capabilities, of spreading and sharing costs and risks, and of better exploiting the expertise of the partners. According to integrated design methodology [Tichkiewitch 1996] models, tools and methods must be developed to control the exchange and sharing of data during the design process in order to reduce risks of redundant or contradictory data and to facilitate effective collaboration. Engineering design can be viewed as a system where decisions coordinate and control technological activities which transform product and process knowledge by exchanging adequate information. The most recent works demonstrate that it is necessary to integrate product, process and organisational points of view in order to control the performance of engineering design [Merlo and Girard 2004].

In terms of tools, PDM (Product Data Management) and PLM (Product Lifecycle Management) systems are intended to support product data structuring and management throughout the product development process. They are often based on Internet-based technologies and offer groupware-like functionalities for collaboration between actors.

As part of this thesis project an industrial case study was carried out with an SME which, in the 1990's, had developed an innovative manufacturing process for structures using honeycomb sub-assemblies. This new technology confers lightness and significant vibration absorption on products whilst maintaining a similar rigidity to steel. The company reached new markets and has grown strongly in recent years, from three people to forty. So,

it was involved in a period of organisational change in order to rationalise its information flows, which is the primary concern of the company.

In Ederena three types of product are designed then manufactured according to six criteria. These criteria and types allow the design process to be adapted. 80% of designed products are redesigned from an existing product, 15% are a similar product and 5% are new and innovative products for the company. The main phases of all design processes are feasibility, preliminary and detailed design, prototype and production. Initially, the projects were managed by a "chargé d'affaire" who was in charge of the whole project with informal collaboration with external actors.

1.2   Context and research aim

In the present international context, the design of manufactured products relies on people from different disciplines as well as on the levels of knowledge and expertise from disparate organisations (services, departments, companies). Many studies on collaboration have been carried out from the viewpoint of various disciplines such as sociology, management or cognitive sciences, but this topic is a new concern in the engineering design field. In the last few decades, the main concern of design research has been on manufacturing, costs, quality, and lead-time. Nowadays, design problems have evolved, and these new problems have become as important as previous concerns. Thus, a way for a company to differentiate itself from another one relies on whether or not it is able to take into account such design problems. These "new" design problems include, for example, knowledge management, innovation, creativity or collaboration.

In this context project management must on one hand ensure the coordination of resources and activities, and on the other hand foster cooperation between actors, in agreement with defined objectives. So, nowadays more and more research is focused on coordination, [Duffy, et al. 1997] and on cooperation [Perrin, et al. 1995] in design.

In this research, collaboration is described as a complex combination of coordination and cooperation processes. This prescriptive process defines the designers' activities and their interrelations. An actor is viewed as a resource in the project processes but also as an autonomous actor who can learn, decide, and finally create those processes. With an adequate coordination of actors and activities, collaborative work can be fostered. In this context favourable situations for the generation of solutions emerge faster than in a non-collaborative working [Garro, et al. 2001].

Cooperation is considered as an effective and concrete articulation among designers involved in a collective action (working in practice towards a consensus goal). In a given situation it is the cooperation between designers which will be effective in a collective action. During the action of cooperation the designers may redefine the coordination rules and create new interactions [Legardeur, et al. 2004a]. This cooperation is a logical

alternative because the coordination rules cannot prescribe all the situations that can occur during product development.

So, the main objective of this research is to focus on the analysis of the collaboration between actors in order to improve various design coordination aspects.

In SMEs actors are often multidisciplinary and must be able to use various different skills: from economic to technical [Thouvenin 2002]. SMEs often have no fixed borders between departments; one actor can possess various design roles and can be incorporated in several departments. Most of the time one actor looking for information or technical help knows who is able to help him and goes to speak to them without the need of a formal schedule or hierarchical validation. In a small structure such as in an SME, actors have understood that if someone helps a colleague, this colleague may help him in the future. On the other hand, this form of collaboration requires permanent availability from employees and makes their work pattern disjointed. This collaboration in SMEs is very important in a large project where one person is not sufficient to manage it. Moreover, innovative SMEs whose key to survival is the continuous innovation of their products are concerned about collaboration [Filson and Lewis 2000b]. Collaboration fosters the emergence of new ideas, improves mutual learning, and keeps flexibility in the operative design processes, and does not stifle the emergence of innovation.

So, this research is focused on collaboration in design activities and, more precisely, in the industrial context of SMEs.
The research reported in this thesis aims to help project managers in SMEs to improve coordination in the design process through to a detailed analysis of the collaboration occurring between actors. This analysis of collaboration concerns the study of various topics like: organisational structure, coordination/cooperation between actors, design processes, information flows, tools and software. A brief description of these topics is given in order to have a clearer description of the research context.

- The organisational structure of the company is very important for actors who wish to know what their functions in the company and in projects are and to understand the consequences of their work for the progress of projects. In a small structure, such as the one encountered in SMEs, the workforce is often changing and is dependent on the demand from clients. So, the company must manage, within a short lead-time, the integration of new people who must adapt themselves to the company.
- In this context of innovative SMEs, several contradictory collaboration characteristics are generally noticed: flexibility versus low level of prescription of design process, intensive and informal collaboration versus lack of skill management... Consequently this collaboration needs to be analysed in order to help the management of the company to enhance the right type of collaboration with

more efficiency in design projects. Collaboration is considered as an effective and concrete articulation among designers involved in a collective action (working in practice towards a consensus goal).

- Coordination is the process that aims to plan and schedule different tasks, and to distribute resources during projects. A prescriptive design process defines the designers' activities and the interrelations between actors. Nevertheless, the coordination of design processes defined by senior managers or project managers is often based on simple rules like weekly meetings, lead-time control and provision of documents. Nevertheless coordination is a global approach that cannot be restricted to these aspects; this will be studied in Chapter 3.

- Coordination also allows management of the information flows in order to ensure the management of projects where for each activity of the design process, the input and output data are defined.

- Tools and software are a support for the coordination and the cooperation by creating a shared framework used daily by actors during design activities.

The success of management and coordination of design processes lies in the identification of points of flexibility and in the quality of the collaboration between actors. Indeed, the introduction of flexibility in processes is not intended to define design processes less formally but to allow actors and project managers to adapt design activities to the specific context of the design situation. In the SME environment it is essential to identify what must be really controlled and so predefined through design processes, and what must be encouraged and not detailed. The management of the product development processes requires greater flexibility in the activities [Weber, et al. 2002]. Moreover, flexibility is very important to foster exchanges between actors and the emergence of new ideas. Concepts of flexibility, collaboration and coordination are significant preoccupations for innovative SMEs. So, these concepts make up the basis of the research work of this thesis.

The introduction of flexibility is based on the study of the design processes and the interactions between actors. So, this study will be able to help the management of the collaboration processes integrated with an accurate measurement of the collaboration in order to assess the "quality" or the performance of the collaboration used [De_Vreede and Briggs 2005]. Then, it is essential to know what measurement concepts are important when assessing collaboration.

The final objective of this research is to improve coordination in design in SMEs through a detailed analysis of collaboration. For this reason, this thesis attempts:

- To identify methods and tools to follow projects and record collaborative events occurring during the design process in order to identify generic "good practices" or to help to identify the origin of design problems.

- To define a model describing these collaborative events in order to understand the chain of events occurring during projects and the collaboration between actors and in order to be able to automate recording this through a software tool.
- To propose recommendations to transform this information recorded on collaboration into knowledge for project managers. The information recorded leads to the analysis of the collaboration aspects occurring in design projects. This analysis is the basis for the definition of "guidelines" for the future management of projects.

For that purpose, a tool has been designed and implemented to be used by researchers, consultants or project managers in order to track all the collaborative events and the project context. The tool progressively accumulates qualitative and quantitative data that can be analysed to gain a detailed description and understanding of complex collaborative processes. This tool is based on theoretical models characterising collaboration, collaborative events and other data which must be recorded to allow an analysis of the collaboration. A posteriori, all this data may be used by project managers to study the collaboration between actors in order to adapt the design process to the form of collaboration used in the company and identify "good practice" and improve managers' decision making.

Currently, various types of tool support the management of coordination or cooperation work in design. As for example, CSCW systems (Computer Supported Cooperative Work) or PLM (Product Life-cycle Management) systems lead companies to coordinate their document flows (office files, CAD models, technical files…) by processes of validation [Johansen 1991], [Pol, et al. 2005b]. Such tools support coordination between actors in projects by sharing a reference environment composed of the same language, objectives, methods and tools. These tools are used, to share product data, and automate associated processes via workflow technology. All these tools contribute to the coordination of elementary activities. However, the collaborative aspects of projects are not sufficiently taken into account by these tools. They act, for example, on "what, when, who, for what", but they do not define how actors work: are they in synchronous or asynchronous mode, present or distant, with what degree of formality? In fact CSCW and PLM tools do not address the operational functionalities for project managers which would allow them to coordinate and control collaborative design processes.

All these tools support asynchronous and distant collaboration thanks to various technological functions. However these technical functions merely support and do not manage or foster collaboration in design.

Before trying to manage and foster collaboration it is essential to analyse it. For that, it is interesting for project managers to know the real and detailed sequence of events occurring during projects with an accurate understanding of what happened between actors, in terms of collaboration i.e. inter-relationship.

Indeed, a detailed analysis of such collaboration might help project managers to identify the "good practices", and thus a favourable "collaborative prescription" to prescribe the

persons, where, when and how for each design situation. This correlation between problems in design and collaboration could only be made if it were based on a finely detailed analysis. Project managers can then make decisions with assurance during the design process based on "good practices" previously identified. Thus decisions in design will be influenced by collaboration aspects and not only by technical factors. Moreover, this analysis of collaboration allows a better understanding of the design problems occurring during the project since design problems can not only be due to technical deficiencies but also to problems in collaboration. The identification and the understanding of such mistakes would allow project managers to avoid making the same mistake again and also allow them to make forecasts about the management of future design activities. The forecasts would also concern the coordination of the design process. Indeed, project managers can adapt the design processes to the company and to the actors involved in a project.

In this analysis the impact of various factors on collaboration like: organisational structure of the company, design processes, project management, information flows, coordination, cooperation, knowledge management, IT system is studied. Before now, forecasting the appropriate situation in which to collaborate has depended on the know-how, experience, expertise and skills of project managers to analyse and evaluate the collaboration between actors during design activities. In this research, a model of collaboration has been implemented to help project managers to analyse the collaboration. Two sorts of criteria are defined: quantitative criteria and qualitative criteria. These criteria define the form of the collaboration occurring during the event. For example quantitative criteria show if the collaboration is synchronous or asynchronous, present or distant, forced or free, formalised or un-formalised… And the qualitative criteria allow the evaluation of e.g. efficiency factor, effectiveness measure, satisfaction measure, consensus, and usability measure [Hengst, et al. 2006]. All these criteria are associated with the context of the project, in order to have not only a detailed view of the collaboration but also a global view of the environment of the collaboration.

Project managers can improve the coordination of the design process through a detailed analysis of collaboration. This analysis is assisted by the record of the collaborative events occurring during the design process, the definition of a model of these collaborative events and by recommendations to transform information recorded on collaboration into knowledge for project managers.

Thus the deliverables of this thesis are both theoretical and practical.
In the theoretical area, this research presents firstly, a method of formalising and structuring coordination in SMEs. Secondly, conceptual models of collaboration aspects are implemented in order to represent collaboration and to support its analysis in the company. This model of collaboration incorporates the main factors which influence collaborative events and the links between them.

In the practical domain, a tool named "CoCa" is developed to help the analysis of collaboration in design. An industrial case study in an SME allows the testing of this tool in the industrial context and thus validates the theoretical model of collaboration. The research programme is orientated toward to collaboration aspects and based on previous work done on coordination in SMEs to lead to the analysis of the collaboration to improve various project coordination aspects.

1.3   Thesis plan

This thesis is composed of seven further Chapters which are described below:

Chapter 2: Research methodology

This Chapter describes the research methodology used in the study. The first part is a description of the research method based on a theoretical approach coupled with a participant observation in an industrial case study. The second part exposes the main steps achieved in the thesis to reach the objectives. And in last part of Chapter 2, the industrial case study environment is described. It was carried out in an engineering SME located in the South West of France named Ederena.

Chapter 3: Literature review

The literature review Chapter examines the main subjects set out in this thesis. In a design project, these topics are essential to manage it successfully. This literature review introduces the necessary detailed state of art on the main topics tackled in this thesis for a better understanding. The main key words are: design, collaboration, SMEs, innovation, organisation structure of the company, knowledge management, and IT tool which supports the collaboration and the coordination.

Chapter 4: Models of coordination and collaboration

The aim of the Chapter 4 is to demonstrate that models can be used to assist project managers in their work of coordination of design projects in SMEs. The definition of these models is supported by an industrial case study in an SME and illustrated by various examples in order to make a link between theory and reality in SMEs. Firstly, a coordination model is defined, specifically aimed at helping project managers in their work in SMEs. This model formalises all the concepts and information needed by the project managers through class diagrams that explain what information has to be stored and managed. The use of the model in a company and its limitations are detailed and these

mainly concern the low inputs of collaboration aspects in the model of coordination. Therefore, secondly, a model describing collaboration is introduced specifically for the analysis of collaboration in design activities in order to fill the lack of collaboration aspects in the coordination model. This model of collaboration characterises the collaborative mechanisms in design activities. Indeed, it represents the design activities with collaboration inputs and it leads towards the collaboration analysis.

Chapter 5: Tool "CoCa": development and use in Ederena

This Chapter is focused on the CoCa tool. It will explain how theoretical models can lead to a tool and why class diagrams are provided before the implementation. The aim of CoCa is to help the analysis of the collaboration occurring in SMEs design projects. CoCa records the collaborative events in detail that occur in design projects by collecting such data as: projects, events, and collaborative criteria (time, location, tools, methods, level of formalisation …). These records provide the right data to the analyst, in order to analyse the collaboration. This analysis allows the identification of deficiencies in collaboration and in design events in order to improve design coordination.

Chapter 6: Results for collaboration analysis and coordination improvements

This Chapter describes the results achieved in this research work and makes the link with the research and industrial objectives. These results begin with the definition of the environment to coordinate projects, indeed the definition of an organisational structure and the processes to support the coordination of projects. On one hand, the possible tools like PDM and PLM are studied and tested to manage the environment defined previously. On the other hand, the analyses of the collaborative practices are explained. These two last results form the basis for the definition of possible improvements for design coordination.

Chapter 7: Discussion

This Chapter sets out to draw comments on the results during this thesis in terms of synthesis, discussion and possible improvements. This approach is essential to stand back from these results and to propose new perspectives and evolutions. This discussion deals with the CoCa tool, the analysis of the collaboration, the coordination in design projects and the tools to support the coordination and the collaboration in design like PLM tools.

Chapter 8: Conclusions, contributions and implications for further work

This Chapter presents the main conclusions of the study. It shows how the research objectives were met and presents areas for future research.

In this thesis plan, we have a closed-loop approach. At the beginning it was shown that the present PDM tools are not capable enough to manage projects and the coordination models used are not mature. Moreover, the collaboration aspects are not completely integrated in the management of projects. Thus, improved coordination and collaboration models are proposed which lead to the implementation of a tool "CoCa" in order to support the analysis of the collaboration. This analysis of the collaboration allows the definition of guidelines and strives for an improved project management. And finally, the loop is closed back on the PLM tools where the approach to managing projects with these tools is explained and an example is described along with the necessary functionalities.

2 Research methodology

This Chapter presents the methodology used in the research. The first part is a description of the research method based on a theoretical approach coupled with observation as a participant in an industrial case study. The second part presents the main steps achieved to reach the objectives of research. And the last part introduces the industrial company where the study was carried out: Ederena. Moreover, a description of the Ederena's problems and objectives linked with the research objectives is given.

2.1   Method of work

The design process is considered in this thesis as a collective and social process of new product creation. Before presenting the industrial case study, it is important to present the research methodology since the results presented here are strongly linked to the methodological premises of this thesis. This study, based on intervention research [Boujut and Tiger 2002] and participant observation [Hales 1987], has been carried out in an innovative SME: Ederena. The company wants to improve the coordination of projects, and the research objective is to improve the coordination of projects by the analysis of the collaboration between actors.

Ethnographic studies are grounded on anthropology and are widely used in industrial sociology. This method of observation has contributed significantly to the description and understanding of how various groups or societies work and in particular it is intended to apply it in this research to the "designers' society". Ethnography mainly relies upon direct observation and total immersion of the researcher in a given environment. The researcher gains a deep insight into the situation since he lives among the natives. The recorded information includes data (i.e. subjective data, informal exchanges, the implicit aspects of decisions, design choices…) that are drawn from direct observations and non-structured interviews. All this "raw material" is collected in diaries, and analysed during systematic meetings with the research team and formalised in internal reports. The researcher's interpretation is the richness of the method when properly analysed by means of a reflective analysis [Schön 1983].

In the steps of [Buccarelli 1988] who was one of the first researchers to carry out this type of study, this research is based on an ethnographic style, spending long periods of time in companies, involved in design projects as full time participants. In this particular case, the thesis work started in a company: Ederena Concept where the author was involved as an

engineer in a development project. "Empirical studies not only describe characteristics and their co-occurrence with successful (or unsuccessful) project outcome, but attempt to explain the observed links in order to allow the development of effective recommendations for designers" [Baumgärtner and Blessing 2001].

In fact, this work shares the action research position with the social sciences; the main difference between this work and the social sciences lies in the outcome of the research. Although the story of a specific innovative process is related, the relevant literature is relied on to provide a general characterisation of the important factors underpinning innovation. The general method of this research begins with an ethnographical case study in Ederena Concept, and also uses in parallel a classic method (problem definition, literature survey, characterisation of solutions, solutions modelling, tools implementation, test in use and improvements). The aim of this type of method is to work in a company to link the research work to industrial requirements. This method is represented in Figure 1.

In terms of formalism, three formalisms are used in this thesis:

-   IDEFØ: For a global description of a process or activities, IDEFØ is useful to represent concepts by arrows, boxes at various level of description.

-   UML (Unified Modelling Language): the UML formalism [Booch, et al. 1999] is an oriented object formalism used in order to define the specifications of software and to prepare its implementation. In this study, UML is used for the implementation of the CoCa tool by modelling class diagrams, use case diagrams, activity diagrams, state/transition diagrams, and entity/relation diagrams. Moreover, the class diagram formalism is also used at a conceptual level to represent scientific concepts of collaboration and coordination which must be managed by project managers.

-   Ederena formalism: a specific formalism is used in this thesis when the concept comes from a work carried out in Ederena. This internal formalism is commonly used and understood by the actors in the company and it is the form taken by the "materials" collected during the observation step.

The use of a case study all through the research work and the use of the UML formalism have already been applied in other projects such as the IPPOP project and in other research contexts [Eynard, et al. 2004].

2.2   The research approach
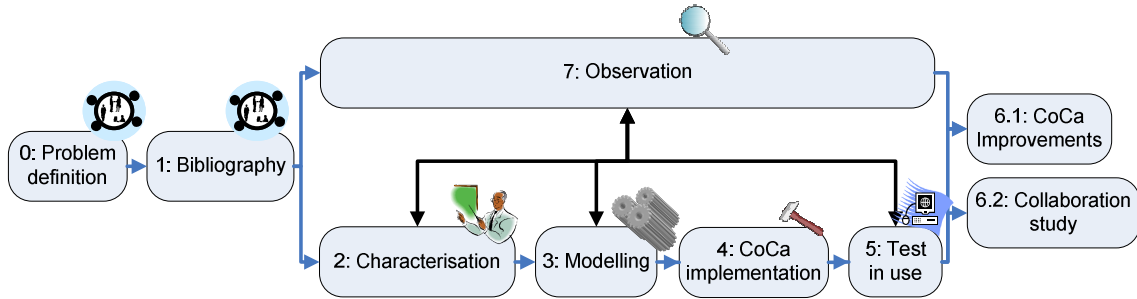
Figure 1:   General approach of the research

Figure 1 shows the general approach of this thesis; it is a mix of a classical research work and a case study observation. As can be seen, during the five last steps (2, 3, 4, 5 and 6) another parallel step "observation" represents the industrial case study. This step "observation" connects the research work to industrial concerns. This method is a specific method used for this thesis. Moreover, "CoCa" is the name given to the tool implemented in this research work. CoCa is based on theoretical models and is used to help the analysis of collaboration by analysts in design projects.

2.2.1 Step 0: Problem definition

This step is focused on the research field of "coordination and collaboration in design". More precisely, the study is oriented towards "how design coordination can be improved by analysing collaboration between actors". At the beginning a global subject was defined; dealing with collaboration in design. This subject has been refined with restrictions, problem, context definition, and deliverables according to current problems in design. Thus, the context of the work is now defined as "the collaboration in design in innovative SMEs". After a short study in this field, it was noticed that companies are mainly concerned about cost, quality, and lead-time. To control these concerns the coordination of design processes is necessary, but in this design coordination, collaborative aspects such as relations between actors, document transfers, organisation of the structure, design processes, and project management are important. Consequently, the problem of the research work is defined as:

How the analysis of the collaboration by project managers can be supported in order to improve the design coordination during projects in innovative SMEs?

This problem is the starting point of the study and implies many other questions, such as, for example, the following:

- What brings collaboration to design?
- Is it possible to define what a "good" collaboration is? And how it can be assessed?
- What are the factors which influence the collaborative situations?
- Can categories of guidelines be identified for project managers to improve the coordination of design projects thanks to an adequate form of collaboration?

All these questions are developed in the Chapters that follow. Before answering them; it is important to make a complete literature survey on the subject, in order to build a detailed state of art of what the existing problems are and where they are.

2.2.2 Step 1: Bibliography

A literature survey is indispensable to position the work in the field of research and to know what has already been done. At the beginning of the research this work is an onerous but profitable task to see what is already done on the subject and it continues throughout the project, with less effort, to be aware of the latest work done in the topic. So, it can be seen that work on reviewing the published literature has been made during the whole research progress.

The literature survey is focused on collaboration in order to define what the forms of collaboration are, what the necessary factors are to be used to analyse collaboration. Then, the literature survey deals with the context of research with questions like what design is, what the individual characteristics of SMEs are, with an extra study for innovative SMEs. And finally a part of the literature survey sets out to define the factors influencing collaboration in design such as the organisational structure of the company, the coordination of design processes, the information disclosed during informal design activities such as coffee breaks…

Moreover, a part of this literature survey deals with the measurement of collaboration between actors for the purpose of evaluation. The goal is to help project managers to analyse collaboration in order to improve the coordination of the design processes, and with that in view, project managers have to measure the "quality" of the collaboration used during design. For a long time this assessment was done by project managers based on their experience and know-how, but in the literature models of collaboration can be found which help to define "forms" of collaboration, criteria to characterise it and indicators to measure its quality.

2.2.3 Step 7: Observation

This step "observation" corresponds to the industrial case study in an innovative SME named Ederena. This case study ensures the link between the theoretical work and the industrial reality. Moreover, this study corresponds exactly to the research context; indeed, it is an SME of 40 employees where innovation is the main concern.
This step 7 takes place in conjunction with steps 2, 3, 4 and 5 in order to remain in contact with the industrial field and compare the results of the research to the industrial context.
This industrial observation in an innovative SME is an adequate place to correct, test and validate research results such as the theoretical model of collaboration, the tool to help the analysis of the collaboration and gather ideas to enrich theoretical reflection.

2.2.4 Step 2: Characterisation

This step of characterisation is based on the step "problem definition" and expresses preliminary ideas and direction of solutions. Before finding an answer to the problem of how project managers can improve coordination of the design process through consideration of collaboration, it is necessary to know exactly what collaboration is. So, this step attempts to define what the collaboration between actors in design is. Collaboration is defined in the thesis when actors combine efforts to reach a consensual goal and is a complex combination of coordination and cooperation processes.
In this step, the global factors influencing collaboration are defined such as, for example, the organisational structure of the company, the information flows, the design processes, the form of project management, the cooperation between actors and the design tools and methods. All this work of "characterisation" is the support for the next step "modelling" which aims to define a model of collaboration.

2.2.5 Step 3: Modelling

The step "bibliography" aims to describe the existing models of coordination and collaboration in design. These existing theoretical models are based on engineering design research ideas such as the GRAI method, from research projects like IPPOP (Integration of Product – Process – Organisation for engineering Performance improvement) [LAPS 2005], or concepts taken from sociological fields such as the model of collaboration proposed by [Hoc 2001]. The outcome of this study is to understand previous work done on coordination/collaboration in design, which inspired this research work and find limitations in these previous methods related to the specific context of this PhD subject.

Thus, a model of collaboration in design in SMEs is proposed. The modelling of the model can be divided into three main steps:

- First, a conceptual model is defined to represent the main concepts involved in this research work and the link between them.
- Second, criteria of collaboration are defined to characterise and help the analysis of the collaboration.
- Third, the two last steps are used to merge the conceptual model with the criteria to obtain a final model representing collaboration in design.

All these models are presented and explained in Chapter 4 "Models of coordination and collaboration". These models are the basis for the implementation of a tool named "CoCa" (which stands for Collaboration Capture) whose goal is to help the analysis of the collaboration in design.

2.2.6 Step 4: CoCa implementation

A model of collaboration is not sufficient to help project managers to analyse the collaboration in a concrete sense, i.e. during projects in their companies. For this reason, a tool (CoCa) is implemented on the basis of the previous model of collaboration. However, the theoretical model is defined to understand the main concepts and their relationships rather than for the purpose of developing a tool. Therefore, a new class diagram (in Appendix A) must be obtained to take into account all the concepts of the theoretical model and to represent the IT classes for the implementation i.e. all the necessary classes for the management of the data related to the database, for the Human Machine Interface (HMI) and for the operational management of data. So it is also necessary to make corresponding use case diagrams, activity diagrams, and class diagrams. The chosen approach also leads to the formalisation of traditional entity-relation diagrams to describe the structure of the database and finally GUI forms to characterise the HMI. Nearly all these diagrams are represented with the UML formalism and are explained in detail in Chapter 5.

The tool records, organises and displays information on the collaboration occurring throughout project events. This information included in the model and the tool is chosen to help project managers to analyse the collaboration used during their projects. Then, with this analysis, project managers can make forecasts on the form of collaboration to use for the next event or to understand what collaboration mistakes occurred during design activities.

All the diagrams and the approach to implementation of the tool are explained in detail in Chapter 5 "CoCa Tool".

2.2.7 Step 5: Test in use

After the definition of a model of collaboration, and the implementation of a tool, it is necessary to test this tool in an industrial context in order to improve and validate the tool and the models. The tool ought to be tested on many case studies but in this thesis work only one industrial case study is carried out, other case studies could be carried out to improve the results achieved. The industrial case study is carried out in the SME partner Ederena. In this step "Test in use", the models and tool are offered to the project managers with the aim of using the tool during projects. With the tool, all collaborative events occurring throughout projects are recorded with criteria describing the collaboration and the quality of the collaboration. The goal is to demonstrate that this tool helps project managers to analyse collaboration.

First, collaborative projects are selected in the projects portfolio of the company. These projects are often large and always include various multidisciplinary actors. After that, these projects are "followed" and the tool is used to capture information on the collaboration. During this 'test in use' step the definition of criteria is refined, qualitative criteria of the collaboration are added and useless criteria removed. Consequently, based on the analysis of the collaboration, the project manager can try to improve the design coordination of projects. At the end of the step, it is demonstrated that the analysis of the collaboration is effectively possible, improvements on the model and on the tool are put forward and the possible improvements in coordination are exposed.

2.2.8 Step 6: CoCa improvements and Collaboration study

In this step 6 the results of the previous step "test in use" are analysed and improvements are proposed. The improvements are focused on practical level (step 6.1) and theoretical level (step 6.2).

On one hand, the improvements at a practical level concern the tool implementation in terms of GUI forms, charts, or figures to drive the analysis. The practical improvements will also propose new advice about the use of the tool in an industrial environment in order to limit the problems encountered during the "test in use".

On the other hand, the improvements at a theoretical level concern the coordination and collaboration models. After the step 5 "Test in use" it will be possible to have feedback on the models defined in the step 3 "Modelling" in order to introduce new concepts not initially developed. The theoretical improvements will also deal with the methodology to analyse collaboration with CoCa, thus it will be possible to describe the approach for analysing collaboration with CoCa data. Finally, the possible improvements are concerned with the various ways to improve the coordination of projects according to the analysis of the collaboration made by CoCa results.

Nevertheless, all the possible improvements will not be able to be implemented within this work, thus from these improvements it will be possible to propose openings for further work for post-graduate study or for a new PhD project.

2.3   Case study presentation: "Ederena Concept"

As already stated an industrial case study in an SME has been carried out to test and validate the research work.

2.3.1 Ederena's products

Some years ago this company developed a new means of manufacturing structures using aluminium honeycomb sub-assemblies and bonded sandwich structures with glue for assembly (Figure 2). This innovation confers lightness and significant vibration absorption on products whilst maintaining similar rigidity to steel.
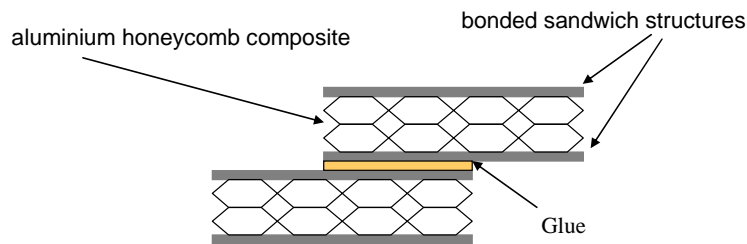
Figure 2:   Concept of Ederena's products

The company has captured several markets with products manufactured using this technology. Thus, Ederena works mainly for large companies which are leaders in their field. It manufactures products such as: milling machine tables, structural panels for urban furniture or partitions for transport vehicles (Figure 3).

milling machine tables

train or plane partitions

structural panels
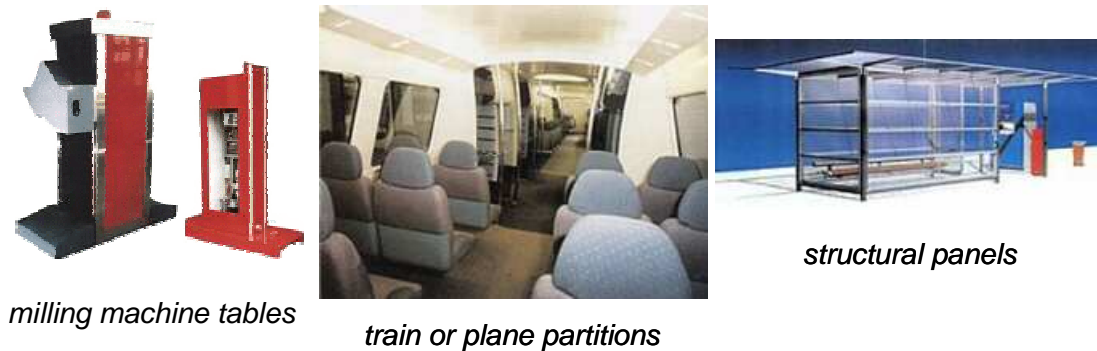
Figure 3:   The main products of Ederena

The company designs three types of product:
-   "Re-design" product for 80%. Most of the products are designed in "re-design" where the main elements are known but need to be checked, validated or studied with new parameters as dimensions, type of glue, new materials…
-   "Similar" product for 15%. A similar product is completely defined (quotation, suppliers, tools definition…) with the elements from the costumer's request and by analogy with a previous well known product.
-   "Innovative" product for 5%. An innovative product requires making a full design process in order to define all the new elements and to validate the elements already known.

2.3.2 Design activity and product development process

In the initial state of the study in Ederena the projects were managed by one person called the "chargé d'affaire". This person was in charge of the entire design of the tool: from the first quotation to define the price of the product until the manufacturing in mass production.

The main phases of the design process are: feasibility, design, prototype and production.
-   Feasibility: the tender invitation from the customer is studied by the "chargé d'affaire" in order to see if the product can be produced in terms of design, manufacturing and quality. At the end of this phase a financial quotation is proposed to the customer.
-   Design: a preliminary and detailed design is carried out by the "chargé d'affaire" in order to propose a prototype.
-   Prototype: the prototype is manufactured, tested, modified and validated.
-   Production: the product enters in the "mass production" state. This phase is carried out by the workshop and controlled by the quality department.

Thus, the "chargé d'affaire" has official contacts with the marketing person at the beginning, and with the workshop at the end of the design process for the launching of the product. Between these two phases he is the only person responsive of the product design. Nevertheless, during the design process, he has a lot of informal collaboration with other designers to help him on difficult aspects. All these informal relationships are very difficult to manage in terms of lead-time, workload, resources, and collaboration.

Moreover, the type of product has an influence on the design process. We have seen earlier in section 2.3.1 that the products are either "re-design", "innovative", or "similar" products. In Ederena, six criteria are used to differentiate the "similar" and "re-design" products. These criteria are:

1. One dimension affected by safe loading is changed
2. Use of new material or new pairing of glue/material (epoxy, carbon, stainless steel…)
3. At least one manufacturing process is changed (new process to glue, or to machine materials)
4. One tool is changed
5. One supplier is changed (to machine carbon for example)
6. The quality control is different

If none of these criteria are met then the product is a similar product and the design process is the same as a previous well known product. A quick validation of the main steps is required but the results of each activity of the design process are easily achieved by comparison with previous products.

If at least one of these criteria is met then the product is a "re-design" product and the design process needs to be followed completely in order to check, test, modify, and validate each step of the design process. Of course, the more criteria are met the more the design process will be longer and difficult to carry out.

Example from the industrial case study:

If the material and glue are the same as a similar product then, in the detailed design the test to the fatigue and to the fire will be the same as the similar product. Thus, this activity will be quickly defined and validated.
Nevertheless, if the process to glue the part changes then the designer must verify that this new process of gluing has no impact on the resistance to fatigue or that the resistance remains acceptable within the specifications.

When no comparison is possible with an existing product because a new technology is used or because the company addresses a new kind of product or market, then the product is innovative. As a consequence the process is more complex with additional tasks of experiments, tests, validation… and more expert knowledge is necessary. The design is then more collective inside of Ederena and may also involve external specialists.

2.3.3 Problems of the company

The activity of Ederena is closely linked with an innovative technology. On the one hand, its expansion is very important, recently: the workforce has grown from twenty to forty people in three years.
On the other hand, the company is orientated toward markets which require important investments and a rapid increase of the workforce. Thus it is essential for the company to manage such evolution and to anticipate its future growth.

In this context, problems of organisation, project management, lead time and relationships with suppliers, customers, and subcontractors come into play.

Thus, the main objectives of Ederena are to reduce its lead time, the adaptation time for the new employees and to improve the relationship between actors. Therefore, the company wants to rationalise its product development processes and introduce flexibility in these processes in order to become reactive faced with the unpredictable nature of the design situations and to manage projects with a project manager and a project team.

Various actions were carried out to achieve these objectives:
-   Ederena must re-organise its structure and formalise the departments, the functions, the actors and the relations between them. This re-organisation is linked to the theoretical model of coordination (in Chapter 4).
-   Based on this re-organisation, Ederena defines rules of coordination on the organisation, the design processes and on the project management. Then, Ederena tests a PDM tool to support this new way of data and project management. Nevertheless, the use of a PDM tool leads to problems of inflexibility. Indeed, these tools formalise and structure the management of data. Nevertheless, this formalism is sometimes defined without enough flexibility to be reactive in the face of design project changes and to foster collaboration between actors.
-   Thus the CoCa tool is tested in use in order to analyse the collaboration and to improve the coordination of projects by introducing flexibility in the design processes.

2.3.4 Approach of the industrial study

In this case study, the approach is based on action-research and reflective analysis. A workgroup was created and different steps were defined: firstly, an analysis step based on interviews and observations; and secondly modelling steps leading to an implementation step based on a PLM system. The objective of the interventions in the case study was to participate in this workgroup by introducing an external point of view and by defining together the new product development environment: organisation, design process, collaboration and information structuring. These interventions lead to the analysis of the collaboration aspects in Design projects in order to improve Design Coordination.

Fully involved in the projects, the author of this study interviewed every actor during the project in order to analyse their way of working. He participated in all meetings. The head of the technical department came from the research field, so he was very concerned with this study and helped to test the results of this study from an industrial point of view. Moreover, the head of the company is also very interested in this study; he understood very well the potential benefits of this sort of study. During the study in Ederena, the head of the company and the head of the technical department made a lot of feedback to give their point of view on both the theoretical and practical aspects.

2.4 Conclusion

In this Chapter 2 the main steps of the research methodology have been explained. The description of the methodology followed during the thesis is important for understanding the links between the proposed objectives and the results achieved.
The methodology used in this thesis begins with the definition of the problem and a literature survey on the context of research. Based on these two first steps, concepts are characterised and modelled; a tool is implemented to support the management of these concepts. Consequently, the characterisation, the modelling and the tool are tested in the industrial context. All through the evolution of the study, the observation of the case study supports the work of research by keeping a contact with the industrial context. Finally the last steps of the methodology are focused on improvements (on the theoretical work carried out as well as on the tool implemented) and on the analysis of the collaboration in design project to improve the coordination.

In this Chapter the presentation of the industrial case study has been made in order to explain the context of research work which is linked with the practical and industrial field. This case study in Ederena will be referred to in the other following Chapters.

The next Chapter 3 describes the literature review associated with this research field. In the sections of the literature review, the main keywords are explained namely: collaboration, coordination, design, SMEs, innovation, design processes, organisation structure and the information flows.

3 Literature review

This thesis work takes place in the specific context of design in innovative SMEs. The objective of this research is to support the analysis of the collaboration in design projects. This analysis leads to improvements of various coordination aspects of project design management e.g. more detailed formalisation of design processes, introduction of flexibility in the design processes, and improvement of project manager skills.
Thus in this Chapter three main aspects are explained:

Firstly, the specific context of the study is presented with the definition of the main notions: design, innovation and SMEs.

The second section explains the notion of collaboration in design. The word "collaboration" has various definitions according to the situation; this section aims to define precisely what the notion "collaboration" means in this thesis.

The third section deals with coordination and describes coordination mechanisms with models and the use of design processes to coordinate projects with a project manager.

And the last section gives an overview on the information systems which support collaboration and coordination in design. This overview will explain the role of the tool (CoCa) in this thesis.

3.1   Design and innovation in SMEs

One of the main characteristics of design is its unpredictability, where any design situation can change at anytime. Thus, design projects must be coordinated to manage them as well as possible and to adapt the prescribed organisation and process according to these changes. However, nowadays, design involves more and more partners in product development, and these partners have to collaborate together in order to complete the design project successfully. Therefore, projects cannot be managed with only scheduling aspects: structuring phases, defining tasks, milestones, and deliverables. Project managers have to take also into account the human aspects in this context of collaborative design.

Thus, before going further it is important to know what "design" is, and what definition of "design" is used in this study. Moreover, the notion of "innovation" is introduced with the relation between flexibility, processes and actors. Finally, the study is for SMEs, thus we will see throughout this Chapter the differences between SMEs and large companies in order to identify the main characteristics of the SMEs.

3.1.1 Design

This study of collaboration is carried out in the design field, but what is design?
Firstly a definition of design from the literature is provided. Next, "design" could be classified into various kinds of design like routine, innovative, and creative design. Many authors try to divide design into processes, activities and tasks to formalise it, a variety of representations emerge from these works like the [Pahl and Beitz 1996] model. Finally to reach the design objectives, methods are defined in design; and a mapping of the various kinds of design methods is presented at the end of the section to focus the context of this thesis work.

3.1.1.1 Definitions

According to [Pahl and Beitz 1996] design is an engineering activity that:
- Affects almost all areas of human life,
- Uses the laws and insights of science,
- Builds upon special experience,
- Provides the prerequisites for the physical realisation of solution ideas.

During the 80s, these authors [Pahl and Beitz 1984] were pioneers in the formalisation of the design process as a succession of steps. This formalisation is not really used nowadays in industry because it is too sequential an approach, but it was the first model which has inspired many other authors to model the design processes.

[Winograd 1996] defines design as a work in creating the individual pieces and relationships that make up the whole. Systematic approaches and methods could be applicable to the design process, but there are no existing effective equivalents to the rationalised generative theories applied in mathematics and in traditional engineering. Design is a conscious activity still influenced by intuition, tacit knowledge, and gut reaction.

Human concerns are the centre of design. Design activities and engineering tasks deal with the management of tradeoffs. Most of the time, the tradeoffs in classical engineering activities can be quantified like material strength, cost, weight, dimension… Whereas in design processes the tradeoffs between actors are more difficult to identify and to assess. Designers are considered at the same time as a resource for the design process, but also as autonomous actors, who can learn, take decisions, and create the design process.

- Design is creative: Many books have dealt with a systematic approach for design, in particular for the emergence of new ideas and finding best solutions [Thompson and López-Mesa 2003].
- Design is communication: When designers construct a product for human use, communication creates a shared framework. This framework is essential to support the collaboration between actors.
- Design is a social activity: Concentrating on the activity of an individual designer, it can mistakenly be assumed that the overall quality of design is primarily a result of the qualities and activities of the creative individual. As Karsenty points out, the designer operates in a larger setting, which is both facilitated and constrained by interactions with other people [Karsenty 2000].

Donald Norman [Norman 2002] describes how design in large organisations is shaped by factors and forces that transcend the considerations of an individual designer. He defines two levels within an organisation which constrain the space of possible designs: the explicit level of working with the different goals and needs of each team in a large organisation, and the tacit effect of an organisation's unique culture. According to [Legardeur, et al. 2004a], the notion of tacit knowledge is knowledge well known by actors without any official description or definition. The notion of "informal" is used to define the relationship between actors when they collaborate without any rigid framework or rules which orient their way of collaboration. These definitions of tacit and informal will be used all through this thesis work.

Moreover, various techniques such as participatory design enlist actors directly in the design process and participate to the social aspects of design [Schuler and Namioka 1993].

Thus, "Design" is not only a formalisation of processes but is also a human activity where designers collaborate in a formal as well as informal way. All these definitions of "Design" argue that the collaboration must be taken into account in design and thus justify the need to develop methods and tools to support and analyse the collaboration in design.

3.1.1.2 History of design management

Before the 20th century, the main objective of the design management was to manage product flow in accordance with the desired result [Tarondeau 1993]. In the early 20th century, companies wanted to manufacture in mass, the demand exceeded supply, and the objective was to produce as cheaply as possible. With the work of Frederick Taylor (1911), then Ford (1913), the way of working became scientific, based on the decomposition of the manufacturing process into sub-systems, the analysis of the elementary operations and the work stations in order to reduce costs and increase productivity. In this industrial context, design had a minor place. Moreover, it was easier to work on the physical flow than on the

information flow. Thus, in this period, the main efforts to assist actors in their work were almost completely focused on the manufacturing device.

From 1960, the balance between supply and demand became stable, and forced companies to incorporate market fluctuations in their strategy: companies had to manufacture what they could sell (regulate production) on a divided market and to increase the quality of the product with delivered services [Perrin 1999]. The product life-cycles were reduced but the principles of Taylorism were still used. Following that, programmes of process re-engineering and investment in information systems emerge in the industrial environment in order to improve the performance of the system of production [Kleinhans 1999].

The system implemented in the Toyota company between 1945 and 1975 by Taiichi Ohno [Ohno 1989] changed the previous production principles which were then exported to western companies. Based on these simple Ohno principles (identifying what must be managed, the initial need, reversal thinking to find the causes and use human capacities), various techniques were implemented to manage production as well as possible. The "Kaizen" principle [Imai 1989] develops a continual improvement process in order to improve the production system in accordance with the changing company environment.

From 1980 the industrial strategy becomes the most important driver for the company and models and methods generated in various adjacent fields like: marketing strategy, the analysis of processes and organisational structure. In manufacturing, the priorities concern costs, quality, flexibility and lead-time [Hayes and Wheelwright 1984]. This context evolved progressively towards studies carried out in social and human sciences which modifies the relations in the actors' way of working and in design management [Eccles and Nohria 1992].

Moreover, various models of design systems emerge; for example the work of [Doumeingts 1984] with the GRAI method, proposes a model of production system modelling and management. [Hughes, et al. 1990] propose a generic model of activities in manufacturing management according to the competitive priorities. The method GIM (GRAI Integrated Method) builds a system to drive design [Doumeingts and Ducq 2001] thanks to the GRAI method. [Williams 1994] puts forward another methodology named PERA (Purdue Enterprise Reference Architecture) based on the description of life-cycles in the design system, of activities carried out by actors and involvement of human factors in the design process. For each state of the life-cycle, various views emerge: the information system, organisational structure, equipment, and the human resources.

The research project IPPOP [Girard, et al. 2002] sets out to provide software to support design management with the integration of the three aspects "product", "process" and "organisation". An objective of the IPPOP project is to define the design process in order to understand and manage it. This project proposes new perspectives in design management by the integration of these three aspects in the phases of analysis, evaluation, and modelling.

Recently, new preoccupations have been generated in design management namely the involvement of the human factors in design and the role of the information system in design

management [Crowder, et al. 2003]. Thus all these definitions of what is design management lead to the necessity to take into account the collaboration aspects into the coordination of projects. Moreover, the integration of information systems must also be adapted to the forms of collaboration used by actors during projects.

3.1.1.3   Various kinds of design

A design classification is generally used by many authors and is systematically used in various design fields bringing out three main classes: "Routine Design", "Innovative Design" or "Creative Design" (Figure 4).
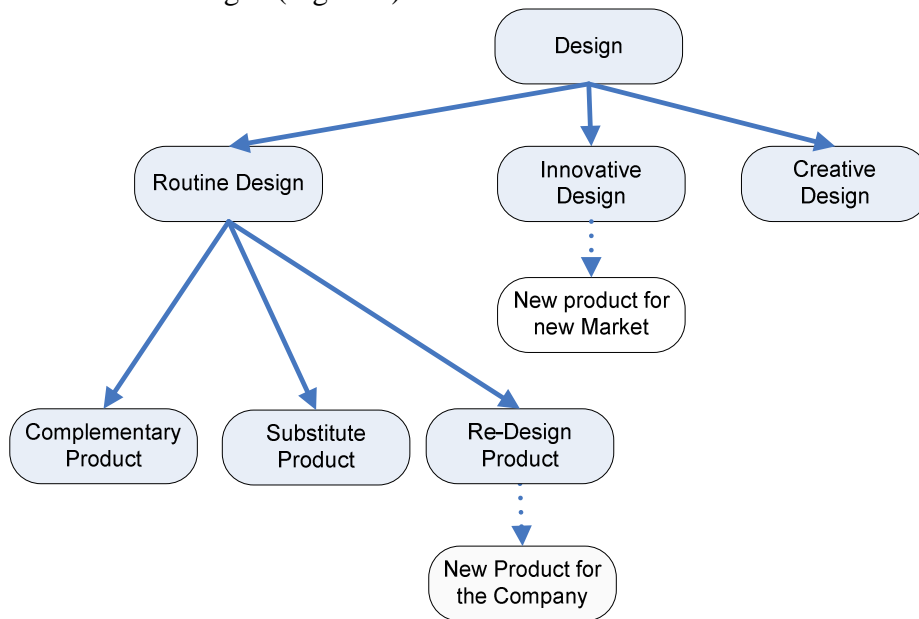
Figure 4:   Type of design and nature of products

- Routine design:

In this form of design, all the knowledge used is entirely available and identified. Moreover, the design strategies are mainly known in advance by the designer. In this case, the designer's role lies in the justification of his choices, to select one solution and not another one, and in other cases to improve or modify previous solutions which verify a set of predefined constraints. Routine design allows only modifications on the parameters of the product. So, in routine design the "re-design" represents approximately 80% of mechanical design activities [Vargas 1995], [Sellini 1999]. In Ederena, the products are mainly "re-design" products and a few "innovative" products when the product is new for the company and for the market. As we have seen in the section 2.3.2, for the company a product can be either a re-design product, an innovative, or a similar one. For each type of product the design process is more or less complex. For a similar product the design

process is already known in advance. For the "re-design" products each activity and phase of the design process needs to be studied in order to evaluate the impacts of the modifications. For an innovative product the design process need to be studied in detail in order to define all the new elements.

In this design context, the potential solution space is known in advance (the characteristics and attributes of the solution), but the search for a specific solution can become complex faced with the large solution space [Van_Overveld and Ivashkov 2003]. These solution spaces can be represented by models. The most widely known is a model put forward by [Gero 2001] which represents routine design space in relation to the creative and innovative design space (Figure 5). Many modelling systems exist for defining design processes: IDEFØ [NIST 1993], IDEF3 [Mayer, et al. 1995], Petri Nets [Belhe and Kusiak 1997].
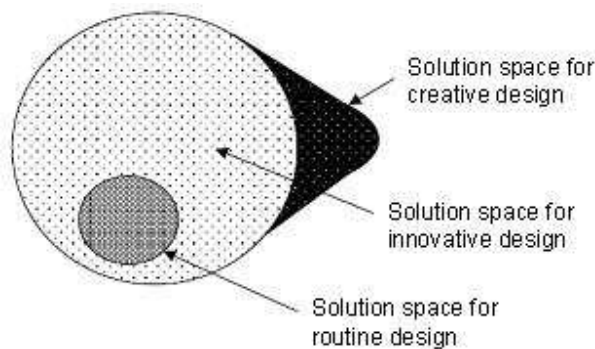
Figure 5:   Solution space for routine, innovative and creative design

- Innovative design :

The knowledge of innovation on a product is often related to a need expressed by clients and yet to be satisfied. During an innovative project, the designer has more autonomy in his work and a larger space of solution as shown in previous Figure 5. However, to explore this solution space; designers become involved in an important and risky activity of research and development. The result of an innovative design stems from an inventive idea manufactured to a real marketed product.

- Creative design :

Creative design [Cross and Dorst 2001] deals with an unknown product where all the knowledge relative to the product and to the processes has to be specified. In this form of design, designers have to compile the specifications to define new functions and new parameters of the product. In creative design projects, new ideas and new technology emerge. Thus, the creation of a new product calls upon intuition and imagination.

Nevertheless, the space of possible solutions is an extension of the innovative solution space with fewer constraints [Gero 2001].

Within this design classification, various forms of design management exist. A specific vocabulary is used to express the form of management according to the field. This paragraph sets out to introduce the three main forms of design management used currently in more advanced industries.

- Co-design: also known as distributed design. In this form of design management, the social and human sciences are used to improve the exchange between actors and across partners in order to pool the work done. The co-design covers not only the products' design but also the design of their related services, the design of the companies' internal processes and finally the design of the network of partners. Practically, to be efficient, co-design must be supported by knowledge management procedures [Zolghadri, et al. 2006].
- Integrated design: this multidisciplinary approach intends to integrate the different tools used by actors all through the product design and requires the management of actors' skills and know-how in the company. Thus actors' knowledge is tracked and recorded in order to re-use this knowledge in future projects.
- Concurrent engineering: The three main concepts are Cost, Quality, and Lead-time with a multicultural organisational structure; indeed a structure based on the sharing and the exchange of information between departments (engineering, manufacturing, and workshop). In this form of design management, the priority is to superpose and to launch activities as soon as possible with generally provisional data [Rouibah 2003]. The organisational structure is different from the classic scheme of sequential activities; the structure is based on the convergence and simultaneity of actions. As to the human aspect, the project is managed with a leader known as "project leader" who tries to maintain cohesion and to animate the group with the management of the actor's skills. On the technological aspect, IT systems support the communication and the management of data throughout the company.

Models of design have often been studied in recent years. Many authors have categorised the different existing models of design, like [Dixon 1987], [Evbuomwan, et al. 1996] or [Perrin 2001].
Dixon and Evbuomwan classify these works into three main categories:

- The formal models which prescribe design with a global view and more or less complex procedures.
- The cognitive models, which deal with actors' activities with a detailed view on the individual and describe the design activity.
- And the "computerised" models, where actors use software (running on computers and based on theoretical models) to carry out design activities.

This classification opposes two visions: first, the vision based on processes as a whole, centred on the transformations of the data and the information flows with input and output data. And the second vision based on the human factors, where the capability of analysis and creation are studied. The "computerised" models provide support for these two visions. Each model (processes model or model based on human factors) can be supported by the implementation of software which is based on a corresponding "computerised" model. A "computerised" model is a transitory model from the theoretical model to the implementation of software supporting the theoretical model. Moreover, in design management, the "computerised" model is limited and is most of the time chosen to solve a specific problem.

[Perrin 2001] proposes a more detailed classification from various view points on design, into five categories, as follows:
- A succession of hierarchical steps [Pahl and Beitz 1996];
- Iteration of an elementary design cycle [Blessing 1994], [Roozenburg and Eeckels 1995];
- The emerging phenomenon of self-organisation [Brissaud and Garro 1998];
- Cognitive processes [Ball, et al. 1994], [Hacker 1997];
- Socio-technical communication and interactive mode [Buccarelli 1988], [Hatchuel 1994].

The three first bullet points above refer to a global design method to prescribe work, whereas the latter two are centred on human factors to describe the work. This entire model is based on a widely known model proposed by Pahl and Beitz. This model describes design as a "succession of hierarchical steps" with a global vision the design activities from specifications until the final product manufactured. According to [Pahl and Beitz 1984], the model is divided into four steps:
1. Requirement analysis: Collect data on the requirements for the specifications and clarification of the needs.
2. Conceptual design: Establish the structures of functions; proposition of suitable solution principles from a pool of alternative solutions generated during a functional analysis phase.
3. Embodiment design: Starting from concepts, the designer determines the layout and forms and designs a technical product or system in accordance with the technical and economic specifications
4. Detail design: Arrangement, dimensions, form, and surface properties for all the parts with the materials specification, the technical and economic feasibility re-checked. In this step, all technical documents are drawn up to allow the manufacture of the product.

The sequential representation of the design process is not suitable for use in design management to describe the real work carried out by actors. Various researchers have demonstrated that, at a micro level (inside each step); actors follow an "elementary and iterative cycle" to solve a problem. [March 1984] identifies an iterative cycle composed of three steps: the "abduction" (analysis and proposition of solutions), the "deduction" (the evaluation of the solution) and the "induction" (retrospectively, the identification of improvements).

In the same way [Blessing 1994] identifies the following phases: proposition of solutions, evaluation of these solutions, the selection of one solution, validation and modification of this solution, and finally formalisation of the specifications for this solution. [Roozenburg and Eeckels 1995] propose the cycle of: analysis, synthesis, simulation, evaluation and decision. This cycle is iterative where each possible solution generates technical specifications used to influence the elaboration of new solutions until the complete definition of the product. However, these models are very global; an extra level of detail could be added by the study of the actors' roles: when various actors collaborate to design, each one uses his own thinking corresponding to his job, experience, or position in the company. The solution accepted after these phases of analysis, propositions and evaluation will be a compromise between these different view points, it is a negotiation between actors in their actors' network. The compromise is built progressively by using common or temporary objects named by [Jeantet and Tichkiewitch 1995] "intermediary objects".

[Perrin, et al. 1995] explain that during these periods of collaboration, actors use a learning process based on organisational, cognitive and hierarchical resources to obtain this compromise. So, it is essential for actors to record their experiences in order to develop their skills. This approach involves long term objectives in design management, longer than the lifetime of one project.

A design project generates various design processes, these processes could be concurrent, interlinked, or overlapped; and each process could refer to a particular model. Thus, the different models presented previously are not opposed but complementary. Some of them are useful for routine situations, whereas others could be more efficient for managing innovative situations. In these works, the main notion of collaboration enriches the classical and mechanical vision of design; as do the recent works on design management presented during the [ICED 2005], [IDMME 2004] and [Design 2004] conferences. In this thesis work, the analysis of the collaboration to improve design coordination is focused on innovative design because in routine design the collaboration between actors is limited. Moreover, in innovative design the flexibility in design processes is very important to allow actors enough freedom to remain creative and to allow the company to remain reactive in the face of design changes.

3.1.2 Innovation in design

3.1.2.1   General definitions of innovation

According to [Carrier and Garand 1996], innovation is a collective and cognitive process based on the interaction between actors; it is different from creativity which is more a personal thinking.

Originally, innovation was introduced in the economic field, as a notion to describe the emergence of something new. This definition seems to be vague and not really specific compared to the previous one. [Tushman and O'Reilly 1997] are focused on the introduction of change in organisations from a strategic perspective. These authors generally associate innovation to something new as a new process, new product, new organisational structure, and new marketing concept; that is beyond finding technological solutions. According to other authors [Cooper 2000], [Johannessen, et al. 2001], innovation could be classified according to the type of "newness". Indeed, innovations can be described as being a continuum ranging from a sum of incremental innovations (with low modification and impact on market) to radical innovations (with high risks and environmental turbulence). In this research work, the definition of "innovation" is close to the definition of Tushman and O'Reilly (1997). Thus, an innovation can be considered here not only as a new product or an innovative technological solution but also as an innovative process, an innovative organisational structure, or an innovative marketing concept. Moreover an innovation is not an invention; an innovation is an idea that encounters success in the market. According to [Legardeur 2001] the innovation process is a logical succession of adaptations and transformations. These transformations and adaptations allow the idea to be launched on the market in order to become an innovation.

3.1.2.2   History of innovation

Historically, economists and in particular Joseph Alois Schumpeter have worked on the concept of innovation which is defined as "the path from invention and sanctioned by a first successful commercial transaction" [Schumpeter 1934].

Ten years ago, the shock of globalisation ruined acquired competitive advantages and segmented markets started to split up. Under the penalty of exclusion, companies had to innovate by taking risks. In order to control the evolution of innovation and risks, innovation became adaptive. In order to control the process of technological innovation, companies have to transform their procedures, to acquire new skills and to overcome cultural differences. Companies have rationalised the organisation of their design activities. Since 1990 various organisational structures for managing projects were developed, namely: transversal organisation by projects [Tarondeau and Wright 1995] and co-development (concurrent engineering); integrated engineering [Tichkiewitch 1996],

simultaneous engineering [Bocquet 1998]. The models, points of view and strategies of companies have changed. Companies can innovate only if the actors collaborate and trust each other. "The innovation process itself is also bound to change; innovation becomes participative, it needs the creativity and skills of everybody" [Legardeur 2001].

Currently, R&D departments strive to become RID departments with an "I" (for "Innovation") which is as well organised as the "R" or the "D".

3.1.2.3   Types of innovations

For an innovative product it is difficult to assess the level of "newness". [Clark and Wheelwright 1993], or [Freeman 1982] present two main types of innovation for a new product:

-   Incremental innovation as "kaizen" or continuous improvement could develop in a linear and stable context. In this form of innovation the technology and configuration of the product are essentially the same, and only minor modifications are carried out on a few products' attributes like shapes, colours, size, materials... Incremental innovation occurs most of the time in a well-established market [Ali 1994].
-   Radical innovation appears when a new concept is a break-away from an existing one. Such radical innovation may lead to entering new markets (For example the DVD compared to the VHS video). A radical innovation is harder to discover than an incremental innovation because the market is not already known and the customer needs are most of the time confused.

In this research work, the word "innovation" is used for any type of innovation between incremental and radical one. These various kinds of innovation: incremental innovation and radical innovation are generated due to the trust between actors, to the behaviour of the participants within the company and to the way of managing projects.

3.1.2.4   Drivers to innovation

In the literature there is no existing generic formula to innovate in any situation; however some authors put forward recommendations to foster the emergence of innovation. [Legardeur 2001] proposes sharing information and knowledge, and managing the conflicts [Robin, et al. 2006] appearing between actors who are in favour or against an innovation. Most of the time actors' reactions depend on their own interest which can be close to the interests of the company, but sometimes not. The innovation of products or processes requires the creation of an informal network of actors in constant evolution to exchange points of view, information and to validate the progress of innovation [Boujut and Tiger 2002]. In this situation, cooperation in design is very important, because the different actors' points of view are formalised and exchanged then integrated in order to converge towards the development of the product.

Cooperation cannot be managed by the sharing of sequenced tasks and responsibilities; where the links between actors and design phases are made by documents in asynchronous

and distant forms. The main goal to foster the emergence of innovation is to support cooperation between actors and not to define of a sequence of design tasks. Thus, the result will not only be the sum of individual results of each actor; but the comparison and the negotiation between various actors' points of views to bring new skills learning and know-how sharing [Legardeur, et al. 2001].

A new form of actor could be used to foster these exchanges of actors' points of views and to manage the cooperation between actors: it is the "actor of interface". This actor of interface is not a project leader. A project leader is responsible for the definition of the coordination rules (scheduling, milestone, control, design activities) and can use his authority to take decisions, which is not the case of the actor of interface. He attempts to create a favourable situation to foster and manage the collaboration between actors [Boujut 2003].

In innovative SMEs, the flexibility in the product development processes is very important in order not to constrain actors in their design work and limit their design choices. Predefined processes (as is the case in routine design) are too restrictive for the actors, they prevent the actors from considering all the possible design solutions and then stifle the emergence of innovation (or new ideas) [Legardeur 2001].

The emergence of innovation could be fostered by various drivers. Drivers are processes or factors that help, encourage or foster the innovation process.

Various drivers can be quoted: reward systems, leadership, communications, organisational structure, empowerment and risk taking.

- Reward systems: reward systems motivate actors and improve the actor's capacity to innovate [Saleh and Wang 1993] [Angle 1989]. Nevertheless, an inadequate reward system leads to high turnover of staff with the loss of all tacit skills and knowledge. So their effectiveness as a driver of innovation is questionable.

- Leadership: leadership is an important cultural driver for innovation. Leadership aids and mobilises actors with their ideas [Kotter 1990]. For [Quinn, et al. 1997], leadership is the most critical factor which stimulates innovation. However a rigid leadership is perceived as a barrier to innovation. Because this form of leadership does not allow the use of flexible processes to adapt the operative tasks to each specific situation occurring during projects and thus, stifle the emergence of new ideas [Pol, et al. 2005c].

- Communication: on the one hand it is well established that innovation requires fast transmission of information and depends on the quality of the communication achieved through the informal networks of actors. According to [Lawson and Samson 2001] effective communications within the company and its network of firms is

necessary to achieve innovation and learning outcomes. It facilitates knowledge sharing by combining a wide variety of experiences, dialogue between workers, building on others ideas and exploring issues relevant to innovation. On the other hand, inappropriate communication leads to misunderstanding, loss of information and errors during design projects. Without efficient communication, managers depend on their own informal networks and networking skills to obtain relevant information.

-   Organisational structure of the company: a flexible organisational structure leads to an effective communication, greater responsibility, freedom in decision-making and cooperation between departments. This had brought multiple benefits that included a better understanding of the different work practices, exchange and sharing of information and access to expertise which resulted in shorter development times [Maira and Thomas 1998]. Nevertheless bureaucratic structures that create various management layers each with their own agendas, were barriers that especially affected radical innovation.

-   Empowerment: an informal network is essential in the emergence of new ideas; managers evaluate this approach as an unofficial way to use their own networks to drive innovation. The involvement of actors in the innovation process through empowerment, allows them to fulfil certain esteem and assessment needs. Empowerment is not only delegating work to actors, it also ensures that actors have the adequate autonomy and authority to carry out the tasks in the right way. It is based on a form of management where collaboration is a priority [West and Friar 1990]. However, a lack of empowerment can lead towards less involvement of actors in the projects, and decrease the level of collaboration and exchange between actors.

-   Risk taking: generally in an innovative company, risks are present, estimated and managed. It well known that risk taking is the behaviour for innovative firms [Saleh and Wang 1993]. However these firms do not take unnecessary risks, they must remain manageable. Nevertheless each mistake made allows actors to learn the lessons to not make the same mistake again [Lawson and Samson 2001]. It is an opportunity to learn and to improve.

Moreover, the notion of flexibility is important for the company to remain reactive in the face of any design change, to not stifle the emergence of new ideas and the possible initiatives of each actor, so flexibility is essential for the emergence of innovation.

More precisely, the aim of this research is focused on the analysis of the collaboration to improve various design coordination aspects. Thus the aim is not to focus on the processes of innovation. Nevertheless a better collaboration between actors fosters the emergence of new ideas [Legardeur 2001].

These drivers influence the emergence of innovation. Nevertheless, these drivers are used differently if the company is large or small. Thus, the main characteristics of SMEs are will be explained in the following section.

3.1.3 SMEs

SMEs and large companies are mostly different. SMEs employees work in an organisation of mutual agreement: there are small departments, the project team is often reduced to 2 or 3 people and the constraints of money and lead-time are not always known in advance. In this direction it is important to define the context of SMEs is, in order to define the scope of the study.

Moreover the actors of SMEs are multidisciplinary and they carry out various different tasks in their job. Thus, it is very difficult to directly "apply" any models, methods or tools from large companies to SMEs.

The small structure of SMEs allows them to be very reactive in the face of the unpredictable nature of the market. However these profits could become a barrier to innovation because it is more difficult for SMEs than large companies to find resources to innovate namely: money, organisational structure focused on innovation, and adequate skills. Large companies use their size to manage the risks of innovation.

SMEs use few design methods and formal processes, consequently they become more flexible than large companies. However, for SMEs what is lost regarding formal structuring is partially compensated for through a better reactivity.

[Filson and Lewis 2000b] present the difficulties encountered by SMEs in designing products. Their article deals with the analysis of various SMEs and shows that:
- Most projects are launched behind schedule,
- Many projects are in progress without supervision,
- There is a lack of structured communication between actors and departments,
- Often problems of resources occur during the main critical steps of the project,
- Each actor assumes his responsibility for the product specifications but few people are in charge of the product development processes.

After the identification of problems concerning the organisational structure of the company, or in project management, or data management, sometimes companies may want to make changes. [Filson and Lewis 2000a] propose that any change must be done gradually because various problems of corporate culture appear, namely:
- Mistakes are not permitted,
- Strategies focus only on the short term,
- Conflicts of objectives arise between actors,

- Problems occur in the review of incoming projects.

To conclude, all these elements demonstrate that studying design in SMEs is a specific and complex domain where few analyses and solutions taken from large companies are directly applicable.

The research context for this thesis is the innovative SME. Indeed, Ederena uses innovative technology applied on products. Thus, an innovative product emerged for each new type of product (using innovative technology) in a new field.

The main characteristic of SMEs, in this case, is flexibility in the design processes and a better control of these processes. Thus, this research study is focused on how the design processes can be better coordinated by including human aspects (i.e. collaboration). Consequently, the literature review now deals with sections on collaboration, coordination in design and on information systems for collaboration and coordination. These sections lead to the detailed presentation of the research context.

3.2   Collaboration in Design

The collaboration between actors in design fosters the emergence of new ideas via a mutual wealth. These ideas are better formalised, better shared and have more chance to become integrated in the design project and put on the market [Legardeur, et al. 2005]. However, most companies lack a clear policy on collaborative philosophy. Collaboration is a complex process, and the evaluation of different collaborative strategies is difficult [Kristensen, et al. 2004].

Sociologists have carried out various social studies of collaboration between human groups; some of them have studied the collaboration in design. Of course these studies have been used to elaborate the models and the results. Unfortunately, these social studies are often global and it is very difficult during this research to associate real inputs from social studies to the research. However, these social studies could be in the future a promising way to improve the results of this research.

3.2.1 Definitions

Collaboration in design deals with a mix of schedule, product development representation, and decision making, while taking into account the notions of: time, tasks, and resources [Pol, et al. 2005d]. Cooperation and coordination are not mutually exclusive, but they are complementary and collaboration can be defined as the complex combination of these two notions. So it is easier to define cooperation and coordination in order to characterise

collaboration. According to De Vreede and Briggs [De_Vreede and Briggs 2005] collaboration engineering is "an approach to the design of re-usable collaboration processes and technologies meant to engender predictable and transferable processes, successfully conducted by practitioners of recurring mission-critical collaborative tasks." Collaboration engineering leads to the re-use of collaboration processes according to the practitioners and design situations. Therefore, the analysis of collaboration will be able to foster the identification of these re-usable collaboration processes in order to orient and train actors to run these processes.

Cooperation is defined by The Oxford English Dictionary as "the process of working together to the same end". Cooperation is considered as an effective and concrete articulation among designers involved in a collective action (*working in practice towards a consensus end)*. In a given situation it is the cooperation between designers which will be effective in a collective action.

Coordination is defined by Oxford English Dictionary as "the harmonious or effective working together of different parts". "Coordination is the process that aims to plan and schedule different tasks, and to distribute resources" [Andreasen, et al. 1998]. This prescriptive process defines the designers' activities and their interrelations. This process can be considered as a management tool. However the coordination processes which can be formalised in procedures or informal forms (such as work habits) remains a predictive process where the activities of coordination can be anticipated and planned. Coordination is a guideline for action [Legardeur, et al. 2004a].
Coordination rules are often defined and proposed but following them in a design situation is difficult. The definition of rules for coordination is not enough in itself to be applied.
Coordination, as specified by organisation and schedule of designer's activities, is generally associated with a routine design process. Cooperation and emerging organisation are key factors for promoting innovative design, but the real design process is not only innovative or routine; it must be seen as a complex combination of routine and innovative operations [Legardeur, et al. 2001].

During a project, the project manager needs to act on various cooperative and coordinative levers in order to build a favourable collaborative situation for design projects [Girard, et al. 2003]. The model introduced by [Karsenty 1996] and interpreted with the previous definitions represents the relation between the concepts of collaboration, coordination and cooperation. The model is articulated around three levels in accordance with the distance from the action (Figure 6).

- The cooperation in action (interference management) deals with the cooperative activities linked to the management of the design objectives and procedures in the

implementation of the design tasks. This level characterises the cooperation between actors in design through their interactions in their own actor network.

- The medium term coordination concerns the activities to manage the shared framework, definition of schedule and allocation of roles and tasks. In design, this coordination level sets out to formalise the design processes, and information flow, where the design methods and tools are chosen. The shared framework includes a common way of communication with a common language, common device (telephone, mail, videoconference…), common technical vocabulary, to share knowledge whether formalised or not [Karsenty 2000]. This reference helps to make design decisions in accordance with the knowledge of the others [Loiselet and Hoc 2001]. In design, this shared framework is composed of knowledge and shared thinking, and is built and maintained throughout the collaboration.

- Meta-collaboration concerns the collaborative activities at a high level of abstraction which produces useful information for the other levels (coordination and cooperation). This level is composed of: tacit information, informal agreements, how the actors perceive themselves in the group, and the corporate culture.
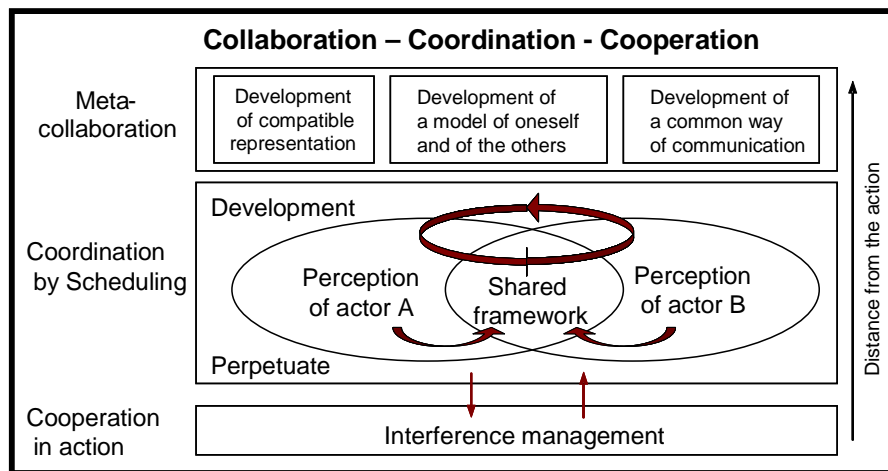
Figure 6:   **Concept of collaboration, coordination, cooperation**

Various cognitive processes as the "explanation" are used by actors to facilitate the construction of a shared framework [Boujut 2003], [Hoc 2001], [Takeuchi and Nonaka 1989]. This shared framework is used as a workspace by actors and improves the collaboration in their design work.

3.2.2 Shared framework in design situations

Many studies show that it is as important to share a framework of reference as to share the information itself in order to have successful collaborations between actors. Many works in linguistic psychology [Wilkes-Gibbs and Clark 1992], in ethnology [Heath and Luff 1994] and cognitive ergonomics [Karsenty and Pavard 1997] demonstrate that working in the same location, with the possibility of following the other actors' activities, fosters the creation of a shared framework to support collaboration between actors. These works show that this shared framework leads to a better communication and collaboration.

A shared framework is built between the "speaker" and the "listener" in order for them to have a shared hypothesis on a subject. Various misunderstandings result from incomplete representation of their shared framework. Sperber and Wilson [Sperber and Wilson 1989] reflect to the notion of "mutual cognitive environment", indeed that the transmitted information becomes mutual when the information is understood by the "speaker", the "listeners" and that each actor is aware that the information is well understood by the other actors. Information is called mutual when we can use a reasoning equivalent to the following: "I read the book X, I know that my partner has read this book and vice versa, my partner knows that I read the book X, but I also know that my partner knows that I know that he has read the book" and so on ad infinitum…

Thus, the provision of information is not sufficient to foster a mutual and shared framework; it also must provide indicators to be sure that the information is mutual and received by the other actors.

The implementation of a shared framework in a design situation is based on the analysis and the understanding of the design situation. The criteria which defines the design situation are [Eder 2003]:

- The actors, their specific roles, and know-how on similar projects, their knowledge and socialisation,
- The nature of the product [Suh 1990], the complexity, and the product state in the design process [Eynard 1999],
- The design process and the way to manage projects [Perrin 2001], the type of design (routine, innovative or creative design) and the form of collaboration used [Dameron and Fonquernie 2000], [Girard, et al. 2003],
- The financial and material resources (building, computers, software, budget…).

On the basis of this description it is possible to define the necessary parameters to implement a shared framework in a design situation:
- The guidelines for design:
  - Design objectives,
  - Indispensable skills,

·   Performance indicators,
·   Actors, resources, financial estimate…
-   The description of the design situation:
·   The product model and the design processes,
·   The organisational structure of the company,
·   The desired form of collaboration.

A shared framework is characterised by the combination of these parameters which evolve during the project. Various kinds of information about this shared framework are relevant to characterising the collaborative situation occurring in design. In particular, as we saw in this section 3.2.2, the design objectives, the skills and roles of the actors, the design resources and the nature of the product, project give information to describe a collaborative situation. When actors collaborate they build a shared framework to support their interactions. Thus the elements of this shared framework give pertinent information to characterise the form of collaboration used by actors during design projects and to be able to analyse it.

3.2.3 Skills

[LeBoterf 1998] gives two definitions of "Skill": The first defines the skill as a sum of knowledge, know-how and the implementation of theoretical knowledge. This definition limits the actors' skills to a list of possible actions. The second definition is based on the combinatory knowledge and on the individual himself [Micaelli 1997]. The individual is a "*builder of his own skills*", by combining his internal resources (knowledge, know-how, personal quality, experience…) and the network of resources in his environment (professional network, documentary network, Database…). The professional skill is **knowledge – in action – validated** in a specific **context** (constraints, human and technical resources, funding, logistics, scheduling…) with an **objective**.

The way the company is managed influences the way skills are managed; the more the management allows initiative and interaction between multidisciplinary actors in the design teams, the more the actor uses and trains his skills [Begin 2003]. Designers learn and improve skills during the design of products, and from project to project. The mobilisation of actors and strategic development of specific knowledge must depend on many factors (time, economic, technological, but also organisational, sociological and cultural), and on company strategy. Then, skills management leads to the formation of multidisciplinary teams made up of various experts in order to learn from each other and to improve particular skills [Batazzi and Alexis 2000]. The aim of management of skills is to improve the global level of skills in the company. Through "skill sharing" companies can promote collaborative situations that will foster the emergence of innovative ideas. The management of skills is an essential element in improving the performance of the team in design

processes. It is important to know and use the knowledge of each actor, then, it is also important to manage the learning process so as to improve the skills pool. This management of the actor's skills is one aspect of design coordination. During the project; the project manager assigns the right actors for each design activity according to the actor's skills, personality, knowledge… Thus the project manager needs to study how actors collaborate in design activities in order to take a decision on the actors needed for the design activity.

3.2.4 Communication

Most of the time, actors misunderstand the word "collaboration" and assimilate collaboration to "communication". It is easy to fall into the trap of thinking actors could have better collaboration if only the bandwidth were increased. Collaboration requires communication, but it is not only communication. Another confusion is often made between participation and collaboration. Participation is a means, not an end. It is needed to collaborate, but to participate is not sufficient [Chiu 2002].

In the coordination aspects the transmission of information or documents may be made through various forms of communication between actors. This communication could take four forms, as shown in Figure 7:

Distribution   Collection   Circulation   Exchange
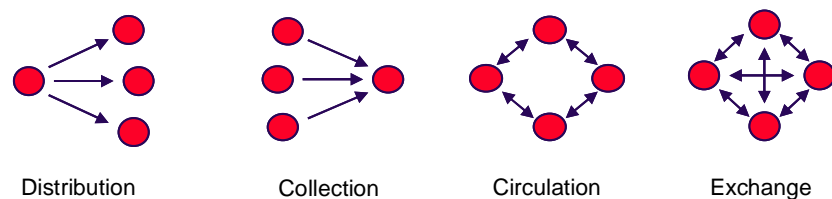
Figure 7:   Four forms of communication

These four forms of communication are used by the actors to collaborate in design projects. All these forms are complementary; each one is used in accordance with the design situation, the actors' way of working and the prescription of the project management. The "circulation" form is mainly used for validation, the "collection" is used to group information and build common information from various part of work, the "distribution" form informs the actors, and "exchange" is a group of the three previous forms in an informal communication.

The project manager must be aware of these forms of communication in order to foster an adequate form in accordance with the design situation [Sonnenwald 1996].

3.2.5 Individual person

According to [Cross and Dorst 2001]; designers interpret the same assignment quite differently, in awareness of their own design environment, resources and capabilities. The designer thus decides what to do (and when) on the basis of a personally perceived and constructed design task, which includes the design problem, design situation and the resources (time) available, as well as the designer's own design. Collaboration in design is thus influenced by all the individual persons included in the project team.
The personality is one of the main characteristics of the individuals. The model "Big Five" [Paunonen and Jackson 2000] defines the personality with five main criteria: sociability (dynamism), meticulousness, emotional balance, spirit opening (imagination), and awareness of the other actors. These identified criteria explain the main difference between individuals. The sum of the actors' personality influences the collaborative situation and must be taken into account in the definition of the coordination guidelines.

Motivation is often associated to the personal desire of actors to do their best. Motivation comes from various respectable or shameful sources, like fear, money, power, or an ideal… Motivation varies according to the individual, the context or the time. Between the actor who harms his or her company and those who belong to the company "body and soul" there is a large space. It is precisely in these two extremes that the project manager has to evaluate and drive actors. Therefore it is useful to have a scale to represent the various motivation levels and the related consequences (Figure 8). The goal is not to classify actors or to give a mark because motivation often changes and depends on the situation. Nevertheless, this scale can help a project manager to think about the motivation of his project team: what is the motivation level at this moment? During this year? What is the behaviour which reflects this level? What did actors say? What did they do?

Motivation scale		
Motivation Level	**Description**	**Comments**
1- Enthusiast	His mission is more important than his own life. He works nights and week end.	Risks for the actor and for his environment. More or less longer.
2- Involved	Work in an autonomous way, he tries to improve the processes and the relationships.	"Ideal" attitude
3- Motivated	Work in an autonomous way, by doing "just enough" in order to carry out the work	Acceptable attitude, but sometime it is not enough
4- Spurred	Act consequently of an external stimulus as a reward or punishment.	Common attitude, it must be a transitional attitude. The project manager can be exhausted if the situation continues for a long time.
5- Survival	Do the minimum to dodge problems.	Must be corrected

6- Demotivated	Do nothing in every situation	Must be corrected
7- Rebellion	Try to harm organisation	Must be corrected

Figure 8:   Motivation scale [Carré 2006]

This scale helps project managers to establish a constructive discussion with actors in order to find solutions; or it can be used by project managers to estimate their own motivation level.

All these factors involve the study of the interaction between actors during design projects. Human behaviour takes a significant role in the emergence of collaborative situations; in this thesis, it is considered that the individual is at the same time a resource for the process, but also an autonomous actor, who can learn, take decisions, create, and model this process.

3.2.6 Characterisation of Collaboration

Various factors are used to define different forms of collaboration. The combination of these factors could lead to the definition of a large number of collaboration forms. Thus, this section introduces the main factors from the literature; nevertheless more factors could emerge during the study in order to facilitate the characterisation and the analysis of the collaboration.

3.2.6.1   Time and location

The form of collaboration could be differentiated according the criteria of time and location. The difference between the forms of collaboration is shown in the 2-by-2 matrix suggested by Johansen [Johansen 1988]. The matrix has the dimensions time and space, which are distinguished in the categories "same" and "different" respectively. Thus this matrix represents four possible scenarios of collaboration. These are shown in Figure 9 along with examples.
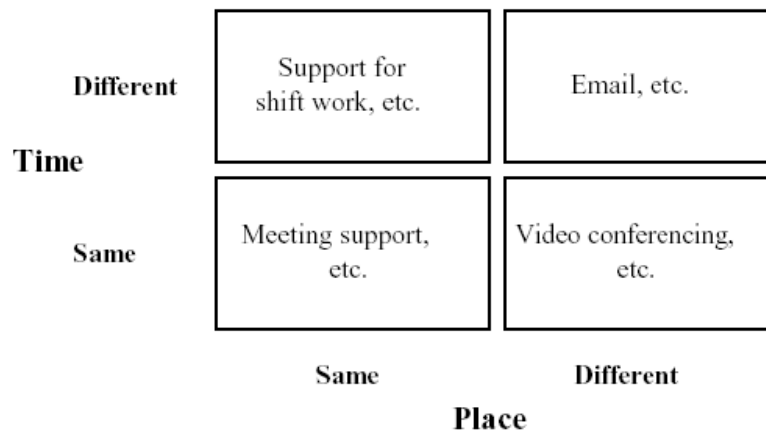
Figure 9:   Four scenarios of collaboration form.

According to the above Figure 9, four kinds of collaboration situations can be characterised:

- **Same time, same place**: Co-located people who have joined together physically, to, e.g., carry out a meeting, which could be facilitated by a so-called meeting support system, i.e., IT explicitly developed to assist people in the process of running meetings effectively [Nunamaker, et al. 1991].

- **Same time, different place**: Distributed participants cooperating synchronously, assisted by, e.g., a media space, i.e., a system that seeks to decrease the physical constraints experienced by distributed participants by enabling close and continuous audio and video interaction.

- **Different time, different place**: Distributed participants working at different times, supported by, e.g., an email application, which enables them to exchange messages with each other asynchronously.

- **Different time, same place**: Co-located participants working at different times, assisted by, e.g., a system supporting shift work (see, e.g.,[Johansen 1991]).

Johansen's 2-by-2 matrix suffers from the problem that it only states four potential kinds of collaborative situations, but nothing about how participants in these situations could be supported by IT. Thus, other factors are needed to have a better characterisation of the collaboration forms.

3.2.6.2   Formal and informal collaboration

The actors can work in a formal or informal way. Most of the time, their daily work is a mix of formal and informal collaboration. On this topic, various works [Crozier and Friedberg 1977] have defined the concept of "uncertainty zone", where all the effort of the company is oriented toward the control of the design changes. Thus, the responsibilities, the procedures, the specifications are defined in a formal way in order to make the future and the behaviour predictable. Nevertheless, design change happens every time in projects and cooperation processes are quite unstructured and the confrontation of the different actors' points of view leads to informal and unofficial information exchange. Consequently, this situation is favourable for interactions between actors where conflict could happen and "play of power" between actors could appear [Callon 1998]. The identification of these situations leads the determination of the zones where the actors elaborate alliances, resistances and negotiations in order to finally contribute to the progress of the project.

In contrast to that, various processes of coordination are more formal and define the actions of the project actors in detail. The formal aspects are more present in the coordination aspects and the informal ones are more used in cooperation between actors.

These two forms of collaboration (formal or informal) are necessary and must be used in accordance with the specific situation. Sometimes it is necessary to formalise thinking such as in a schedule, but other times it is useful to have an informal meeting at the coffee break to exchange extra information which cannot be disclosed during a formal meeting.

3.2.6.3   Degree of freedom

For decision-making, project managers need to identify effective action levers which will influence collaboration thus increasing design performance [Merlo, et al. 2005]. Those elements concern designers themselves, not just the product or the activities. So to identify them, previous works [Girard, et al. 2003] propose a taxonomy of collaboration (Figure 10). This taxonomy suggests taking into account: definition of design activities, freedom of relationships and collaborative experimentation between design actors.

Activity definition	Relationship freedom	Collaboration experiment
	Free	Established / Non-Established
Prescribed	Encouraged	Established / Non-Established
	Forced	Established / Non-Established
Collaboration		
	Free	Established / Non-Established
Unexpected	Encouraged	Established / Non-Established
	Forced	Established / Non-Established
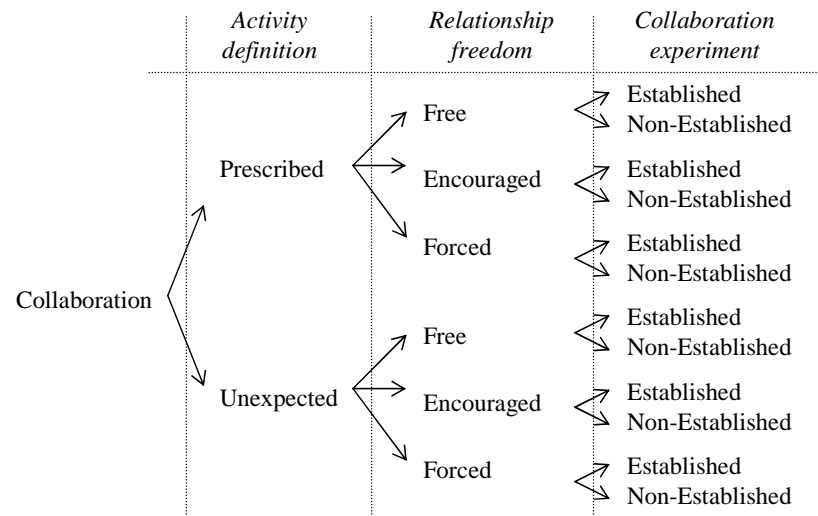
Figure 10: Twelve forms of collaboration

The activity definition concerns prescribed collaboration and unexpected collaboration. The degree of freedom of a relationship corresponds to the possibilities which are offered to the actors to collaborate. The degree of freedom can be "Forced" if managers define or impose rules to force actors to collaborate. Otherwise, if no collaboration rules are imposed, the form of collaboration is "Free". Between these two forms of collaboration ("Forced" and "Free") the collaboration can be "encouraged" where managers give advice to guide actors in their way of collaborating. Collaborative experimentation relates to whether workgroup members had relationships before the beginning of the activity. Finally twelve forms of collaboration are identified by taking into account these three criteria.

This taxonomy helps to characterise the form of collaboration used by actors during projects. This characterisation supports the project manager's decision-making process during the coordination of a project. Thus, the identification of the parameters influencing collaboration is facilitated. At the end, it could be possible to have anticipative control on the collaboration form and not just reactive in the face of the unpredictable nature of design.

3.2.6.4 Conflictive and consensual collaboration

In project design, actors are often confronted with problems that they cannot solve alone. Moreover, it is possible that a conflict appears during the design process, when the activities of various persons interfere on the same subject. In these situations, the actors have to collaborate in order to decide together what the actions are to solve the conflict and to reach the objectives of design without interfering with the defined design process [Rose 2004]. Thus, the collaboration between actors is set between conflictive and consensual. The conflictive collaboration is when the actors come into conflict and keep to their

position as opposed to a consensual collaboration where the actors are inclined to make concessions. These two extremes do not foster collaboration; nevertheless the conflicts or the confrontations are not bad if the dialog remains open and constructive between actors. In the same way, a form of collaboration where every actor makes concessions is not appropriate because everything could be accepted as a mistake.

3.2.6.5 Subjectivity and objectivity

In "The eye of the spirit" [Wilber 2001], knowledge about the world is explained as an integrated process. Wilber explained that any phenomenon can be looked upon in four ways. As displayed in the following Figure 11; in an interior and an exterior fashion, and in a collective and an individual fashion.

	Subjective	Objective
Individual	My work experience	Time used in experiment
	I	It
	We	Its
Collective	**Intersubjective**	**Interobjective**
	How we communicated and came to an understanding	How the parts of the experiment are connected
	Interior	Exterior
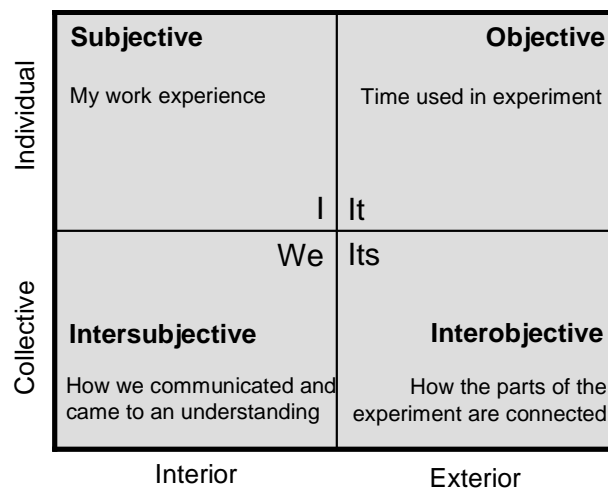
Figure 11: Four ways of looking upon phenomena

As illustrated in Figure 11, looking upon a phenomenon in 1) an internal and individual fashion is a subjective analysis, 2) as exterior and individual is an objective analysis, 3) as internal and collective is an intersubjective analysis, and 4) as external and collective is an interobjective analysis. As dispersed collaboration involves people, objects and relations between these, all four views are necessary to facilitate a full, comprehensive analysis of the different aspects of collaboration. In the collaboration analysis process, subjectivity is introduced in two main places: during the recording of data and during the analysis itself (these points are developed further in Chapter 7.2).

3.2.7 Synthesis on collaboration

In this thesis, collaboration means "work with other actors toward the same goal", and the consequences of such a definition are that actors must have the possibility to communicate

between them. However to communicate, actors must have a common space of reference in order to understand and exchange their thinking. Thus, actors build a shared framework in order to support the interaction between them. An uncompleted shared framework leads to misunderstanding and design errors. This environment is characterised by the actors themselves, the specific attributes of the product and the project, the design processes, the form of collaboration used, the resources (see Chapter 3.2.2).

Moreover, the notion of a goal is essential in collaboration; goals federate actors toward this goal and help to distribute work, to find compromises in order to reach the common goal. The personal thinking and the individual way of working play an important part in the effectiveness of collaboration. The involvement of actors is more efficient in the federated project if they find a personal benefit in collaborating. This benefit could be to help them in their daily work, to learn more in a specific domain or to find a solution easily. However if an actor does not find benefit in collaboration, he will be hesitant in participating in federated projects. Benefits motivate actors to make efforts in order to keep the collaboration in operation. These efforts must be made by the right persons, at the right time in the right place to do the right task; and this is possible only if each actor is aware of the other actors' actions.

In this section 3.2 about collaboration in design we have seen the description of various relevant aspects to support the characterisation of the collaboration. This characterisation allows the evaluation of the form of collaboration used by actors in design in order to know how the actors collaborate:

- In synchronous or asynchronous **time** and in the same **location** or distant. Each form of collaboration can be classified into four categories (synchronous / in location, synchronous / distant, asynchronous / in location and asynchronous / distant).
- In a **formal** or **informal** way. Each form of collaboration can be evaluated by a continuous scale between formal and informal collaboration.
- With which **degree of freedom** i.e. if the form of collaboration is closer to a "free", "encouraged" or "forced" collaboration.
- In a **conflictive** or **consensual** way. Each form of collaboration can be classified between these two extremes.

This is a first characterisation which comes from the results of existing research works. Nevertheless, this first characterisation needs to be expanded and linked with the context of research. Thus, this characterisation will be completed by the case study in order to add extra factors and to obtain a complete characterisation.

Moreover, this characterisation of collaboration will be the basis for the analysis of the form of collaboration used by actors in design projects. Thus this analysis of the form of collaboration will be a support to improve various aspects of the coordination such as skills management, definition of flexible and detailed design processes, a better understanding of the previous design activities…

3.3 Coordination

The coordination of design processes is not easy, but milestones or mechanisms can be set up in order to guarantee the progress of the project and to control the convergence of projects towards initial internal or external objectives. Project management involves organising the design project and coordinating the actors' activities in order to improve the performance of design processes. Milestone is a word commonly used in project management. In this thesis, a milestone is to be understood as a predefined design activity which is scheduled during the design process. When achieving the milestone the completed work is checked and the project manager can take decisions to modify the future design process according to several parameters such as time, costs, completion of task, extra milestones definition, or project team resources. These milestones are control points to ensure that completed tasks, generated documents, product or raw material definition are well matched with initial objectives.

Design coordination is not a tool to control the actors' tasks but attempts to anticipate the future and to adapt the design process to changes (which can appear during the design). Design coordination is ensured by the analysis of the design objectives in order to define an adequate mode of coordination, providing the necessary information to the actors at the right time and in the right format. The project manager has also to define performance indicators in order to control the progress of the design and to take corrective actions if necessary [Girard and Doumeingts 2004a], [Legardeur, et al. 2004b].

Therefore, two methods may be used by the project manager: either attempting to force cohesion and the gregariousness of the group and focusing on a predefined plan; or on the contrary working to encourage the emergence of shared collaboration spaces [Dameron and Fonquernie 2000]. On one hand, in the former method, the manager "forces the system" and the design process follows predefined activities; in this case the design process leads to a routine situation and collaboration is stifled by the design formalism. On the other hand, in the latter method, the manager can use an organisation based on autonomy, but such an auto-organisation presents obviously the risk of diverting energies, of not sharing any common objective and of generating situations of conflict.

The path for the manager is narrow: he must manage to combine the best elements of these two extreme types of organisation, one to structure design process, and another to keep enough flexibility in order to promote collaboration and to remain reactive in the face of changes in the progress of the design.

3.3.1 Coordination mechanisms

The coordination of the design activities is not only the scheduling of activities. During the project, actors make technical decisions (selection of materials, part dimensions, choice of processes, etc…) and have to choose a solution between various alternatives in order to solve design problems. The decisions deal also with the allocation of human and material resources. Moreover the design department often has not only to coordinate one design process for one project, but various design processes for various concurrent projects. Thus, the coordination mechanism must be defined to coordinate and run various activities and processes.

3.3.1.1 Design coordination Theory

"Design Coordination Theory" results from the studies of the work group ESPRIT, IMDEV and the program ESPRIT IiMB (Integration in Manufacturing and Beyond) [Andreasen, et al. 1994] [Duffy, et al. 1997]. The studies to improve the product design prove that design coordination is a way of optimising the design processes. This approach is based on various points of view to structure the design successfully. The coordination is assured by four main activities [Andreasen, et al. 1996] or four factors [Girard, et al. 1999] :
- Make decisions on tasks to carry out,
- Control of resources,
- Modelling of the job point of view,
- Scheduling of design activities.

Based on these activities or factors, eleven interlinked models [Andreasen, et al. 1998] have been described (Figure 12):
- Model of the **Product Development** cycle,
- **Decomposition** model is a multi-point of views model,
- Models of **Disciplines and Technologies** linked to the product. It is used to structure the design activities,
- Model of the **Product Life** Cycle in order to define each phase of the life cycle and the interactions between product and environment,
- Model of **Synthesis Matrix** describes the activities to carry out in order to assure the design and the manufacturing of a product sub-assembly,
- Model of **Life Cycle Phases System** completes the synthesis matrix in order to optimise the sequence of the life cycle phases,
- Model of **Goal / Results** describes the decomposition by objectives and the results achieved,
- Model of **Task** defines the tasks needed to develop the product,
- Model of **Activity / Plan** with the support of the model of Goal / Results and the model of Task defines a complete scheduling of the activities,

- Model of **Resources** defines all the characteristics, the structures and relations of the necessary resources,
- Model of **Design History** is the memory of the product development project by storing a record of the activities carried out.
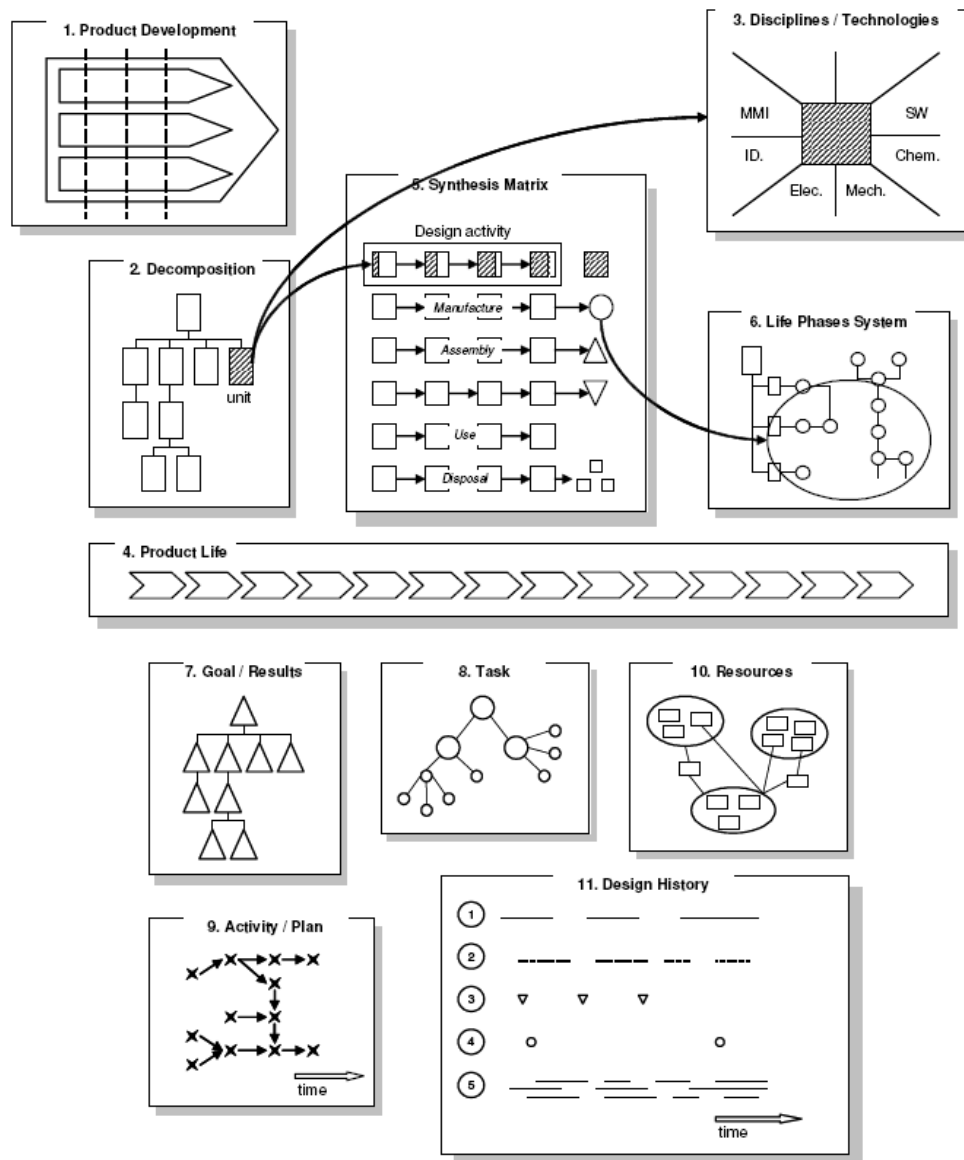
Figure 12: Design Coordination Frameworks [Andreasen, et al. 1994]

This theoretical model formalises the main concepts characterising the coordination framework in industry. Nevertheless, these studies based on the "Design Coordination

Theory" are not easily applicable in SMEs. For example, the model of **Synthesis Matrix** is not used in French companies. The models 7, 8 and 9 are not easy to manage separately when the workload is full: the **Activity/Plan, Task** and **Resources** are in reality closely interlinked. Moreover, no tool has been implemented in order to support the use of this model by companies. Finally this model requires a long term vision which few SMEs have the possibility of acquiring. The intent in this thesis is to improve design coordination in the context of SMEs and to propose a more adequate and flexible framework.

Other studies on design system coordination based on this theoretical work have been done such as the GRAI R&D model.

3.3.1.2   Design engineering model: from GRAI R&D to IPPOP model

The GRAI R&D model [Girard 1999], provides a framework composed of three main parts to study the design system (Figure 13) :

- The technological system transforms the input data (requirements) to output data (product definition),
- The decision system pilots the transformation of the technological system,
- The information system links the decision system, the technological system and the environment.

This design system model is based on system theory [Simon 1960], [Le_Moigne 1990], organisation theory [Mintzberg 1990] and the theory of hierarchical systems [Mesarovic, et al. 1970].
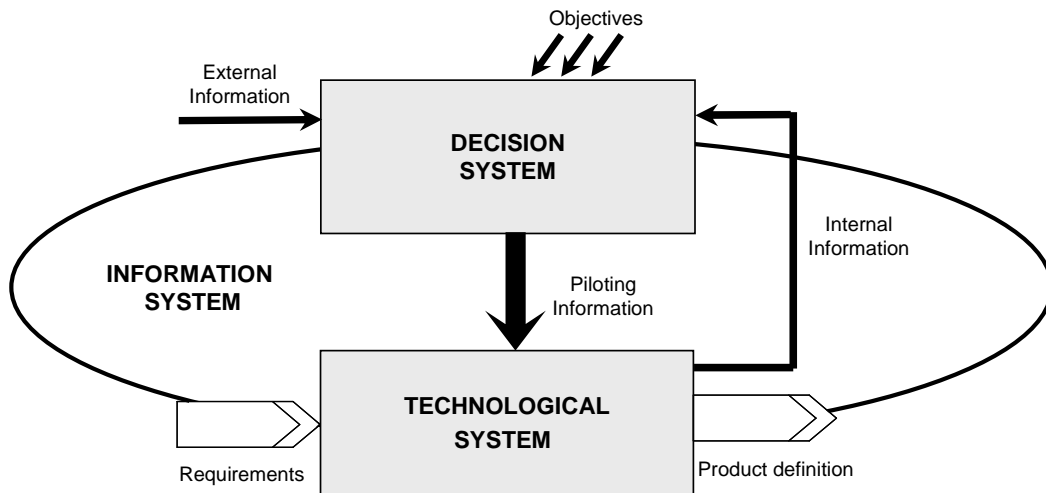
Figure 13: Design system model [Girard, 99]

The technological system describes the transformation of the requirements to the product definition and the processes of manufacturing. The technological system uses human, materials and information resources and is structured by "design centres" (Figure 14). A "design centre" is a group of actors carrying out design activities to reach specific objectives during the project.

The "decision system" ensures design coordination and is the location of decision taking. Decisions are then transmitted to the "technological system" in order to synchronise the activities in the "technological system". The "decision system" is composed of "decision centres" with various levels. A "design centre" is managed by a "decision level" which defines a design frame with design objectives, necessary skills, required resources (financial, human, material, and information), and the performance objectives in order to evaluate periodically the activities of the "design centre". The "technological centre" provides feedback to the "decision centre" on the evolution of the product knowledge and on the progress of the product development activities.
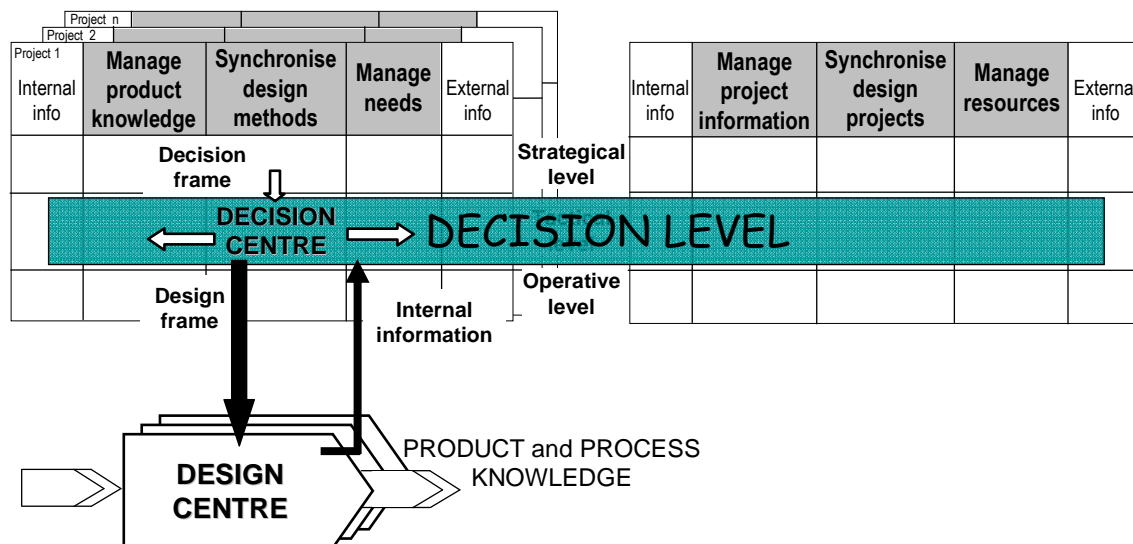
Figure 14: GRAI R&D model [Girard and Doumeingts 2004a]

In the GRAI method, the concepts of "horizon / period" group the "decision centres" into "decision levels" [Doumeingts 1984]. The "horizon" is the time during which the decision is available and "period" is the date until which the decision may be updated. This concept classifies the decisions taken with temporal criteria according to three categories:

- Strategic decisions (long term) deal with the policies and the strategies of the companies. They define the orientations and the objectives for the design,
- Tactical decisions (medium term) deal with the organisation and the resources to provide in order to reach the objectives,

- Operational decisions (short term) deal with the implementation of the design activities.

This time categorisation is completed by another criteria: the functional objective of the decision. Three functional objectives are used to improve the classification involving decisions on:
- Information flow,
- Management of capabilities (skills, resources, materials…),
- Synchronisation between information flow and abilities.

The "decision centre" is defined with a decision level and with a functional objective. For each decision level, six "decision centres" are identified in accordance with the functional objectives of the decisions. These functional objectives of the decisions are [Girard and Doumeingts 2004a] (Figure 14):
- Manage product knowledge,
- Synchronise design methods,
- Manage needs, manage project information,
- Synchronise design projects,
- Manage resources.

Decision centre: the various activities of the "decision centre" [Doumeingts 1984] are defined by the associated "decision frame" (variables and limitations of the decision), the result of each decision making process, and by the information used to take decisions. The concept of "decision frame" is used to coordinate the "decision centres". A "decision frame" is defined by:
- The decision objectives,
- The decision variables used to define the actions to carry out,
- The constraints linked with the decision variables,
- The criteria used to choose the decision variables.

The operational definition of these elements is defined at each decision level. The organisation of the technological system is closely linked to the decision levels. Each level coordinates a part of the technologic system, called a "design centre". The coordination is based on the decision making [Duffy, et al. 1997] by using predictive models of the system, in order to estimate the final "value" expected. It is necessary to evaluate the design performance to support the decision making [O'Donnell and Duffy 2001] [Haffey and Duffy 2001].

The main goal of the "design centre" is to reach the expected design objectives according to the "decision frame". The "design centre" is a space where the product knowledge is transformed from its initial state to the final state. This transformation is defined by a model of the design processes and a product model based on product knowledge [Eynard 1999]. The final state is reached when the objectives expected in the "design centre" are achieved.

The "design frame" which coordinates the "design centre" is defined by the following elements:
- The design objectives defined for the design centre,
- The skills including knowledge, methods, processes and technology needed,
- The performance objectives to check the progress of the project (like milestones, expected values),
- The resources needed to reach the objectives: human (designers), materials, founding, lead-time etc…

Designers are the human resources assigned to the design centre to complete the expected objectives. The human resources in the "design centre" could be a project team or a single person.

This GRAI R&D model is the basis for the definition of the theoretical aspects of a project named IPPOP. Thus, in the IPPOP project the specifications for a model of coordination are defined in order to implement a tool for project management based on Product, Processes and Organisation. The IPPOP project is based on an integrated model divided into three sub-models: product model, process model and model of coordination decisions [Nowak, et al. 2004].

As we can see in Figure 15, in this IPPOP Project, a product model (the left circle) is proposed to formalise the technological knowledge about product (function, structure, behaviour, expert view,). This model is related to existing CAD models, and can be used by the designers from its semantic definition level to its geometrical definition level.

A process model (the middle circle) is proposed to represent the activities of actors. This model ensures that the design logic is followed and stored for further use (both re-use and evolution) by the project managers when evaluating design processes.

Finally, the modelling of coordination decisions (the right circle) supports the structuring of multi-level projects with the external and internal objectives of the enterprise.

The models are implemented in a prototype which can be used by the designers (see in section 3.4.3 for IPPOP prototype explanation).

This work has been defined in a general context of design coordination. It must be adapted to SMEs but some aspects appear to be useful: for example considering that project evaluation is based on integrated aspects from product, process and organisation points of view; or process traceability in order to be able to evaluate and re-use it which is a key point for analysing collaboration and understanding how coordination can influence it.
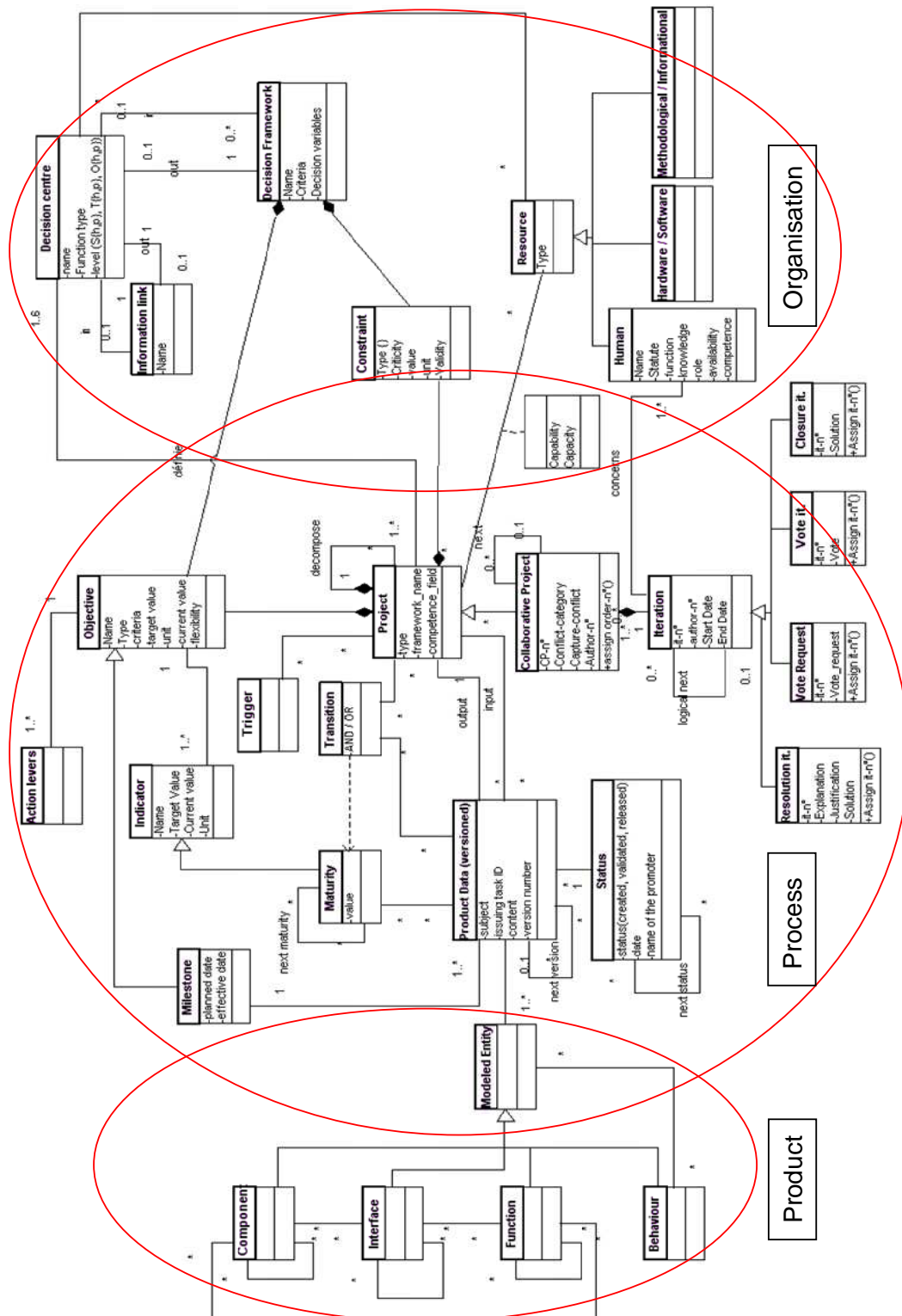
Figure 15: Integrated model IPPOP

3.3.1.3   Management of design projects

The global approach to managing design projects is based on the coordination of the main design situations which will occur in the project with a project plan. For each design situation, the project manger has to define the resources (human, financial and technical), constraints, objectives and performance indicators to reach the expected objectives in order to be reactive in the face of any design situation [Merlo 2003]. This approach is supported by various models with the main elements influencing the design in order to manage design projects. In this section 3.3.1, it has been seen that the model of "Design Coordination Theory" (in section 3.3.1.1) is very complex to support the management of projects in an SME, and that a more global model as the GRAI R&D model is more complete and easy to be applied for supporting this management. Indeed, the GRAI R&D model with the global (decision centre) and local (design centre) elements of the design system lead to the definition of different design situations in order to manage projects. And finally, the integrated IPPOP model with the process and product models help the project manager to have a global but pertinent view of the design results. Nevertheless, nowadays, design results alone are not sufficient to evaluate the performance of design. Indeed, design performance can be improved by the study of the interactions between product, processes, organisation and actors which do not have a direct impact on the design results. The GRAI R&D model aims to characterise the global framework of the design decision making, but the division into design centres is a macroscopic view of the design system and does not offer a detailed description of design activities. Thus, the GRAI R&D model must be enhanced to obtain one where all the factors influencing the collaborative activities and the design processes are included. These factors are:
- Factors from the global design context,
- Factors from the organisational structure of the company,
- Factors from the product definition stages
- Factors from design process progressing,
- Factors from the actors themselves.

All these models will be a basis for the description of the coordination mechanisms in design situations.

3.3.2 Project management by project leaders

In an SME, the main task of project managers consists of the coordination by organising and scheduling the project around an appropriate structure [Pol, et al. 2005b]. [Coates, et al. 2000] suggests that task management, and scheduling together with resource management are the most important issues when it comes to operational coordination. The project manager defines objectives and allocates resources (human and material) to the various

tasks. He defines milestones to synchronise the progress of each person's work. However, this implies that the design process can be rationalised and organised using a prescriptive approach. In an SME such a prescriptive approach exists at a global level, but, at a detailed task level, actors have only objectives and milestones and they manage their tasks by themselves. In this case, respecting deadlines is the main performance target. The project manager must ensure that the results of everyone involved in the design phase converge and do not interfere with each other. According to integrated design methodology [Tichkiewitch 1996] models, tools and methods must be developed to control the exchange and sharing of data during the design process in order to reduce risks of redundant or contradictory data and to facilitate effective collaboration.

The main ability of a project manager is leadership in managing design projects. In order to support the basic needs of a social system, three main types of requirements must be distinguished for leadership activities [Badke-Schaub and Stempfle 2004]:

- Content-related requirements (25% of time): encompass all activities to accomplish the task and to solve the given problem.
  - Goal elaboration: formalisation of goals and decisions related to goal and task clarification.
  - Solution development: Discussion and selection of solutions in a supervising function.
  - Analysis of failures: Diagnosis of sources of failures and development of alternatives.
- Process-related requirements (50% of time): In order to successfully solve a problem the leading function does not only deal with the design task itself, but must also direct parts of the leading activities to structuring and coordinating people and processes.
  - Scheduling processes: Scheduling activities related to the coordination of who, what and when.
  - Monitoring processes: procedures of monitoring and controlling processes and people.
  - Allocation of different kinds of resources such as money, people, material.
- Relation-oriented requirements (25% of time): Leading activities also concern aspects of goal attainment, that is to pursue goals with or without the support of others and ensuring the motivation of persons involved.
  - Interpersonal influence: Strategies influencing others pursuing own goals and/ or company's goals
  - Processes of detection, analysis and solving opposing positions.
  - Motivating and supporting, rewarding performance, and building identification for the company's goal.

Leadership is focused on a macro view of the company (human relationship, strategy, schedule), but at a micro level the information flow has to be managed properly.

3.3.2.1   Organisational structure

The organisational structure of a company is composed of individuals with responsibilities, where the relationships between actors are structured by various common actions. From this first definition it can be possible to explain in more detail what the organisational structure is. The actors involved in the organisational structure are supposed to converge towards the goals of the organisation; however the contribution of each actor is difficult to evaluate: sometimes, some of them could go against official and explicit goals of the organisation. So, the existence of an organisation is not based only on the involvement of each actor but also on the achievement of their work for the same official goal. The number of participants is not a criteria of existence; an organisation could be 2 or several thousand people. Of course, the behaviour of the organisation is different according to the number of actors. The boundaries of an organisational structure are not clear, it could have lucrative or non lucrative goals, could be official (as in a company) or non official (as with volunteer workers), and could produce concrete products or services.

Various forms of organisational structure are described. in the literature There are the five forms of organisation introduced by [Mintzberg 1982], or the four types quoted by [Blanchot, et al. 1999].

[Mintzberg 1982] proposes a classification of the organisational structure of companies. He identifies five mechanisms of coordination:
- **Mutual agreement** when the actors of the organisation coordinate their tasks themselves in an informal way via simple communications.
- **Direct supervision** of a superior on the actors. One person is in charge of the actors' work.
- **Standardisation of processes**, indeed, the detailed definition of formal rules on the processes of work.
- **Standardisation of results**, with the definition of objectives. The results are specified but not the method to reach them.
- **Standardisation of qualifications**, it is the use of specialist persons to complete a task in order not to standardise the processes and the results.

Moreover, Mintzberg describes five forms of organisational structure where, for each one, a mechanism of coordination predominates.
- **Simple structure**, based on **direct supervision**. It is mainly for small structures and supervised by the director.
- **Mechanist bureaucracy**, based on the **standardisation of processes**. It is principally found in old and large companies with a high level of formalisation of work. For example, large manufacturing units with an unskilled workforce are representative of this form of organisational structure.

- **Professional bureaucracy**, based on the **standardisation of qualifications**. It is the opposite of the mechanist bureaucracy, where power is given to the workforce because this workforce is qualified, and has responsibilities. Examples might be doctors in hospitals or professors in universities.
- **Divided bureaucracy**, it is based on the division of the company into departments where each department has autonomy and is managed by objectives.
- The "**adhocracy**" based on the **mutual agreement** mechanism. It is used mainly in complex and fickle environments, where standardisation is not effective. The structure of the authority is not well defined with a low level of formalisation, and with ad-hoc structure defined only to carry out a specific task.

However various other classifications have been proposed to define the forms of organisational structure, [Blanchot, et al. 1999] proposes four forms of organisational structure:
- Quality organisation, where Quality is used not as a tool but as the outline of the company management. This approach fosters the auto-responsibility and autonomy; it is opposite to the classical and hierarchical management.
- Partner organisation, it is an organisation oriented towards subcontractors in a context of "extended company" when the company involves its contractors, subcontractors, and partners in its processes.
- Network organisation, to foster the work in network between actors, teams, departments or companies in order to become more efficient and not to stifle emergence of innovation. It is, for example, present in the automotive field between manufacturers and their network of subcontractors, research laboratory and contractors.
- Skill organisation, this organisation is based on particular strategies to manage actor' skills in order to learn new knowledge or know-how through the network of actors.

These sorts of transversal organisations are usually used to manage the development of new products [Tarondeau and Wright 1995] with teams composed of multidisciplinary and autonomous actors [Clark, et al. 1988]. A transversal organisation is a group of actors from various departments, organisations or companies. Thus, most of the time, these organisations are composed of multidisciplinary actors. The transversal organisations used in projects often overlap with the global organisational structure of the company. Therefore, in transversal organisation, the final result will not depend on the skills of one person or a group of persons but will mainly depend on the quality of the interactions between actors. From this observation [Bourgeon 2000] defined a hypothesis and rules to assess the form of organisation used during design projects. [Brion 2000] demonstrates that access to information must respect these principles of autonomy and transparency in order to

establish mutual trust and understanding of the work to improve the individual involvement in the project.

Nowadays companies are reconsidering the organisation with fixed departments; this form of organisation is too rigid and cannot adapt products or services to the client's specifications. Now the "distributed company" (company which integrates client, contractors, partners, subcontractors in its product development processes) develops a new organisation named "transversals" based on the management of processes, and the management of networks of actors. These "transversals" organisations oppose the traditional notions of boundary between the forms of organisation. The company must become flexible, and adapt its organisational structure to manage skills and knowledge. This model of company is an idealised model, but it shows the evolution of the organisation in progress.

Consequently these new forms of organisation have a favourable impact in design projects because they foster multidisciplinary exchanges between actors, the relocation of the decisions from the director to the actors [Prasad 1997]. The main difficulty will be to organise actors and to use the right form of organisation according to the design situation.

Organisational structure is one of the main concerns of companies. According to [Blanchot, et al. 1999], there have been more and more organisational changes during this decade: It was observed on the one hand "the explosion of organisation boundaries ", with the end of the supremacy of the hierarchy and an opening towards the exterior. On the other hand "transversal management", with the creation of transversal functions, management by processes, and the coming of collaborative projects. Thus it was observed that there was a transition from "the pyramidal structure to a form of horizontal coalition" [Batazzi and Alexis 2000].

Two forms of organisational change exist [Derumez 1998]:
-    The brutal/prescribed change: with a clear vision of the future actions, a detailed definition of the element to change in the organisation, the key actors as leaders and heads who make adequate decisions are identified and involved in the project of organisational change,
-    The construct/progressive change: with an unclear vision of the future situation, with a framework to manage the changes, a real desire to have a new organisation, with freedom of action in order to foster creativity and autonomous behaviour.

Generally, concerning organisational change, actors accept a new form of organisation when they find a personal interest in it. As we saw in the section 3.2.2; an organisational structure accepted by actors is one of the main parameters to assure the creation of a shared framework to support collaborative exchanges. The involvement of actors during the

change process assures the elaboration of personal models and methods in order to collaborate during future projects [Franchisteguy 2001].

However to define the right organisational structure in a company, negotiation with actors about the project in progress is not sufficient; heads of the company must be involved in this process in order to link the organisational choices to the strategy of the company.

[Franchisteguy 2001] presents a plan with steps to manage the organisational change:
- Construction: To encourage actors to abandon their reflexes, forget their habits, modify their vision of the environment in order to become ready to consider new modality of organisation.
- Reconstruction: Apply the changes, test and adapt the change proposed. An external aid such as research laboratories could be beneficial to assist the organisational change.
- Stabilisation: To consolidate the modified state and the organisational strategy. This step is essential to perpetuate the new organisation.

To manage the organisational change, the objectives have to be defined for short, medium and long term, with accuracy to clarify the adequate resources. The reorganisation work must be organised as a project, with the definition of missions, multidisciplinary groups, and responsibilities (inside the group as well as between groups). The reorganisation could be followed by an external intervention in order to keep a new point of view on the reorganisation progresses, with neutrality in a framework of action-research. These three steps must be managed as a project with the same tools to manage a project. Heads of the company must drive changes, and verify that a shared framework with a common language and vocabulary is defined.

An adequate organisation is one that can handle the unpredictable nature of the design process. This adaptation is based on the autonomous constitution of transversal networks of actors through the company to collaborate together [Legardeur, et al. 2004b]. Moreover in order to organise a structured design process it is possible to use workflow and lifecycle tools. Nowadays all the classical forms of organisation seem to be replaced by transversal organisations managed by processes and actor networks without a fixed definition of the boundary between departments. Human factors with the notions of knowledge, skills [LeBoterf 1998], or actor network [Legardeur, et al. 2001] are essential to study and thus to improve collaboration in design projects [Dameron and Fonquernie 2000].

The identification of the organisational structure used by actors in a given situation is a factor for improving the management of the design project and collaboration [Girard, et al. 2002].

3.3.2.2   Design management concepts

Traditionally, the design process is carried out by a continuous and sequential transfer of information from the definition of the needs toward the detailed design. From this sequential process, errors can spread through the process. These errors are detected only in the downstream steps of the process, or even during the manufacturing. It is in this context of misunderstanding between design practices that the notion of concurrent engineering emerges. The main field of application of concurrent engineering is in the activity of product design [Tichkievitch and Brissaud 2000].

The main objective of the concurrent engineering approach is to reduce significantly the lead-time and the time to market of products [Whitfield, et al. 2005]. This approach takes into account, from the early phases of design, the whole lifecycle of the product. Concurrent engineering is based on the simultaneity and parallelism between the different steps of the product development process [Sohlenius 1992] with the desire to converge towards the same objective. This notion of concurrent engineering could be called "simultaneous engineering" or "integrated engineering". All through this thesis, "Concurrent Engineering" is used to refer to these three notions of simultaneity, concurrence and integration of activities in the product design project.

Nowadays, various authors from industry and research fields have studied this notion of concurrent engineering. Many more or less precise definitions have been put forward by authors [Clermont 1998], [Boudouh 2000]. From all these proposed definitions, a complementary one emerges:

Concurrent engineering is a global and systematic approach of the company, based on the simultaneous and integrated management of the product life-cycle, where multidisciplinary actors work together towards the same goals of cost-quality-lead-time. The main characteristics of concurrent engineering result from this definition:

- Achievement of design activities in parallel,
- Integration of the requirements of the downstream activities during the upstream activities,
- Setting up of multidisciplinary team involved in the product development projects,
- Optimisation of the existing processes of development, mainly in design methods and management of the manufacturing.

In this field of design, the main interest of the concurrent engineering approach is the cost saving, improvement of the product quality, and the reduction of the lead time [Dowlatshahi 1992], [Dowlatshahi 1994]. Indeed, the integration of the downstream activities with the early phase of design allows the early detection of errors in the product design. The qualities of products are improved, the supplementary costs due to modifications are removed, and the time to market is reduced. Consequently, the company

fulfils its commitments taken on in the specifications phases and decreases its global cost of production.

3.3.3 Synthesis on coordination

In this "Coordination" section, we have seen that the global approach to managing design projects is based on the coordination of the main design situations which occur in the project with the definition of a project plan and design processes. According to [Tarondeau 1998] processes in design are sequential or parallel activities organised in a network, where multidisciplinary resources, skills or actors are involved in order to manufacture an output which increases in value. For each design situation, the project manager has to define the resources (human, financial and technical), constraints, objectives and performance indicators to reach the expected objectives in order to be reactive in any design situation. This approach is supported by various models based on the main elements influencing the design in order to manage projects. It has been seen that models only based on design processes are too limited to manage projects, and that a more global vision is necessary to support this management, such as the vision given by the GRAI R&D model. The model of coordination presented in section 3.3 entitled the GRAI R&D model is based on the global (decision centre) and local (design centre) elements of the design system which lead to the definition of different design situations in order to manage projects. The process and product models help the project manager to have a global view of the design results. Nevertheless, nowadays, design results are not sufficient to evaluate its performance. Indeed, design performance can be improved by the study of the interactions between product, processes, organisation and actors which do not have a direct impact on the design results. The GRAI R&D model aims to characterise the global framework of the design decision making, but the division into design centres is a macroscopic view of the design system and does not offer a detailed description of design activities. Another model has been defined in the IPPOP project for implementing the main coordination principles from the global GRAI R&D model of the design system. In this IPPOP model, the main notions of the GRAI R&D model are used and adapted to the industrial context and these notions are integrated with Product, Process and Organisation notions. The IPPOP model leads to the implementation of a prototype to manage design coordination and project management. These models characterise the main notion of coordination used to manage projects. Moreover, these models can be adapted to this research context by adding a detail definition of collaboration aspects and improvements at the coordination level.

Nowadays all the classical forms of organisation seem to be replaced by transversal organisations managed by processes and actor networks without a fixed definition of the boundary between departments. Human factors with the notions of knowledge and skills [LeBoterf 1998], or actor networks [Legardeur, et al. 2001] are essential to study

collaboration in order to improve coordination in design projects [Dameron and Fonquernie 2000]. The main difficulty will be to organise actors and to use the right form of organisation according to the design situation.

In design coordination, design process modelling is essential to represent the process with the main activities, milestones, responsibilities and schedule in a context of concurrent engineering. This modelling formalises the design and allows the forecasting of future activities and problems in order to manage them earlier in the design process. However, it is possible to model the main activities at a "macro" level with the defined design team and fixed deadlines. Nevertheless it is very difficult to define in advance this process at a "micro" level, because the activities, actors and responsibilities depend on the individual characteristics of the product (materials, number of units, workload), client (specifications, norms…) and situation (financial, politics, partnership…). Thus at a "micro" level it is difficult to define the design processes in detail. In this domain, authors like [Van-der-Aalst 2001], [klingemann 2000] propose the use of local workflows to represent these "micro" activities by keeping flexibility in their management.

We have seen in section 3.3 that design processes need to be defined in detail, with enough flexibility to allow actors to collaborate and remain reactive to design changes occurring during the project. Thus coordination of projects needs also to take into account the collaboration aspects in order to understand how actors apply the prescribed coordination, to detect the design mistakes which originate from collaboration and to anticipate the future collaborative practices used in design activities.

3.4   Information systems for collaboration and coordination

"The lack of software usability and the poor design of programs are the secret shame of the industry" says [Winograd 1996]. Software design sits at the crossroads of all the computer disciplines: hardware and software engineering, programming, human factors research, ergonomics. It is the study of the intersection of human, machine, and the various interfaces (physical, sensory, psychological) that connect them.

In this research context, an information system is defined as every system which assists the actors of the product design to make decisions. In this section 3.4, an overview is made of the pertinent information systems used in product design. Thus, much research aimed at developing tools to support collaboration is described, such as CSCW (Computer Supported Cooperative Work), PLM (Product Lifecycle Management) tools [Johansen 1991], [Pol, et al. 2005c] or specific tools like IPPOP or ID². Such tools support coordination between actors in projects by sharing a framework composed of the same language, objectives, methods and tools.

Collaboration and coordination systems are used in all the states of the product life-cycle. The information flow is managed by PDM, PLM systems; the equipment flow is managed

by ERP (Enterprise Resources Planning) systems. All around the product, a simplified product life-cycle (Figure 16) begins with the definition of the customer's need and specifications, then the product design and manufacturing is defined and finishes by the end product and its shipping. CSCW systems may be used by every department and in every state of the product life-cycle. At a global view, the scheduling systems plan every step of the product development in detail in the global project plan.
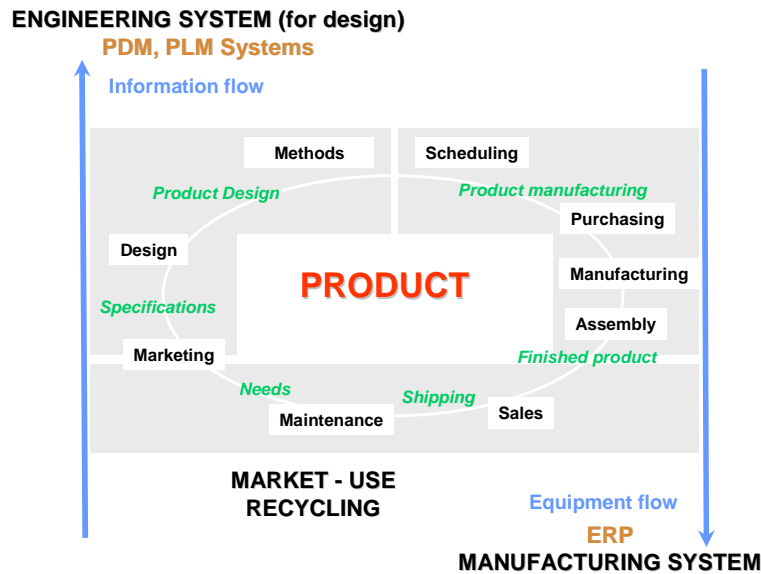
Figure 16: Product life-cycle with departments and systems

In the field of research prototypes, various studies intend to encompass all these system in a global one in order to limit the number of systems used and to improve the communication (information transfer) between all these systems. The prototype IPPOP prototype [Girard, et al. 2002] [Nowak, et al. 2004] is one of these types of system.

3.4.1 CSCW

CSCW means Computer Supported Cooperative Work. CSCW encompasses all software and hardware for shared interactive frameworks [Yoon, et al. 2004]. These systems build a multimedia environment to support cooperation within the engineering team [Gonzalez and Mark 2005]. The main tools of the CSCW domain are: web mail, discussion forum, shared database, information flow management, collaborative tools (Figure 17)… The main objective is to support communication, coordination and collaboration in projects.
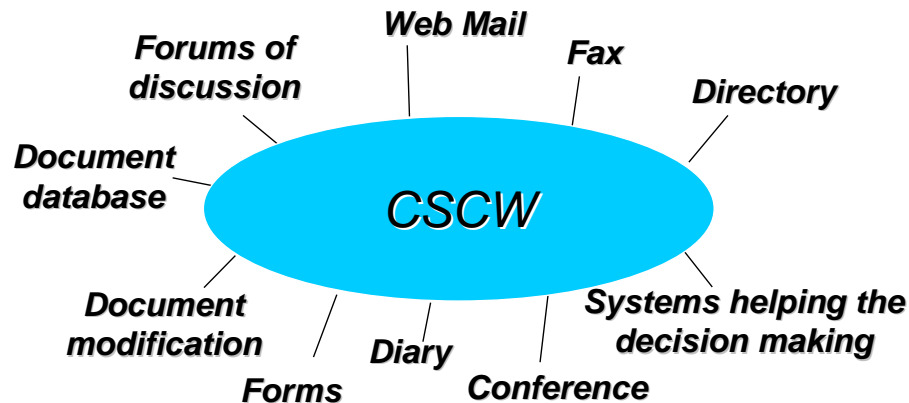
Figure 17: Main tools of CSCW systems

The main functionalities supported by the CSCW systems are [Johansen 1988]:

- Communication between actors: for the distribution, collection, circulation and exchange of documents (see chap 3.2.4, Figure 7);

- Coordination for scheduling: a shared diary enables every actor to be aware of the other actors' diaries; to allocate actors to a task, to book resources (room, computers…), to manage projects;

- Collaboration sets in place a shared framework to share objectives, to consider actor's interests, to inform each other on their progress [Ju, et al. 2004];

- Collective memory are databases used to store information for a long time, this information is semi-structured: part of it is structured for its categorisation and its reuse, and another part composed of the data formalised and shared by people is not structured;

- Automation of the administrative processes with the definition of the processes, objects, activities, actions and actors; the circulation of objects; and with the launching of actions or applications. These processes are the origin of the workflows concepts used in PLM systems [Rueckel, et al. 2006].

One category of CSCW systems focuses on the management of electronic documents; these are called EDM (Electronic Document Management). EDM systems are often used in administrative activities to manage documents. These tools store a large amount of electronic documents, foster re-use by sharing these documents, secure the access to the documents, and reduce mistakes in document management (copying, circulation, recording…). EDM systems are often integrated into the information system of a company to manage, store, search, display, and distribute documents. Thus, EDM systems ensure documents are up to date, classified, and unique. These CSCW systems are generally used in design to ensure the collaboration between actors as for video conference, mail or shared

diary functionalities… They help actors building a shared common framework that will facilitate collaboration during projects.

3.4.2 PLM / PDM systems

Nowadays, companies are focused on continuous product innovation and process improvement in order to reduce time to market and to decrease development costs. Ensuring the coordination of the whole development of a new product is a challenge for managers at the different levels of such kinds of projects, especially for SMEs [Filson and Lewis 2000a]. PLM (Product Lifecycle Management) systems support the management of product data and for a company the main issue is the implementation of such a system and the adaptation of such systems to the company.

Managers must take into account the mapping between industrial needs in product development process management and the available functionalities of PDM (Product Data Management) systems. A PDM system manages and stores product data and related documents according to the design, manufacturing and support phases of the product development process. Many other functionalities are available in order to take into account specific needs or viewpoints from the whole company (e.g. classification, integrated views of the Bill of Material, etc.) or to manage projects [Saaksvuori and Immoen 2004].

The management of the product definition lifecycle is not a new concept. Effectively, this concept has been around for many years. However, in industries this concept of lifecycle has been improved with the combination of various new technologies and approaches that facilitate the collaborative work in extended companies.

Historically, PDM has been the main technology using this concept of lifecycle. The aim of PDM systems is to provide an enterprise-wide infrastructure to support management of the product definition in design engineering.

In the 1980s, PDM was mainly used to manage the CAD files with a database, and was restricted to use in engineering departments. This first use of PDM systems for CAD file management led to the requirement of new technologies to manage data and communication. Thus, extra functions were added to manage data and communication in order to expand the initial capabilities of existing PDM systems.

Industrial evolution obliged PDM systems suppliers to expand their range of action from the engineering department to the whole extended company (including sub-contractors, customers, and suppliers). In the 1990s, more sophisticated functions are implemented to address new issues such as change control management, configuration management, and visualisation. During this period the PC became the main platform.

The advent of the Internet and Web-based tools has changed the use of PDM systems by enabling the implementation of new technologies and processes to facilitate real-time, synchronous collaborative working between actors in extended companies. With these

technologies, a full management of the product definition lifecycle in extended companies is possible.

In the 2000's the PDM systems evolved towards PLM systems. PLM systems are intended to support product data structuring and management throughout the product development process with additional functionalities and integration with other systems. According to [CIMdata 2001] they manage information through document management and especially product data evolution using predefined workflows [Liu and Xu 2001]. The previous PDM systems are the core of the new PLM systems and various new functionalities are integrated. Actually PLM systems are often based on Internet-based technologies and offer groupware-like functionalities [Eynard, et al. 2002] for collaboration between actors.

PLM systems can be characterised in terms of their main functionalities (Figure 18), generally achieved by integrating several tools [CIMData 2002]:
-   The PDM tools provide the possibility of generating customised views of product information for different users, enabling the definition, comparison and management of different product views (the so called Bill of Materials - BOM) and their related information, such as, for example., the BOM As-Design, BOM As-Manufactured, BOM As-Build and As-Maintained. Moreover, PDM systems include specific functions as the management of product data validation process, functions similar to collaborative tools (CSCW) e.g. emailing or conferencing, and internet-based portal functions (diffusion, internet, extended company and lifecycle management.
-   The Data Vault and Document Management provide then a mechanism for a secure storage and retrieval of all the product definition information, whilst the Workflow Management controls the interactions of people with this information: in fact, this automatically routes work from one stage to the next. In PLM tools, the workflow techniques enable the management of the ECR/ECO/ECN (Engineering Change Request/Order/Notice) processes.
-   The Project Management tools coordinate the framework of a project that deliver a product to the market. It provides work breakdown structures and allows resource scheduling and project tracking.
-   The integration with common tools used in design and manufacturing such as CAD, ERP and office suites applications is generally provided by PLM systems. The quality of this integration depends on the relation between PLM system and these external applications. For example, a CAD system and a PLM system implemented by the same editor have a native integration (like Windchill and ProEngineer). Nevertheless, when the external application is implemented by another company, the integration becomes more difficult and requires extra IT work to make the connection between them.

- The expert tools can be implemented and linked with PLM systems in order to achieve a specific objective and share their own specific information. For example a CAM system is an expert tool that may be integrated to a PLM system.

PDM tools :
- *Configuration Management*
- *Document management*
- *Lifecycles / Workflows*
- *Product structure*

Project framework tools

Data vault

PLM

CAD, ERP and office suites integration :
- *Part management*
- *Visualisation*
- *Graphics services*

Expert tools
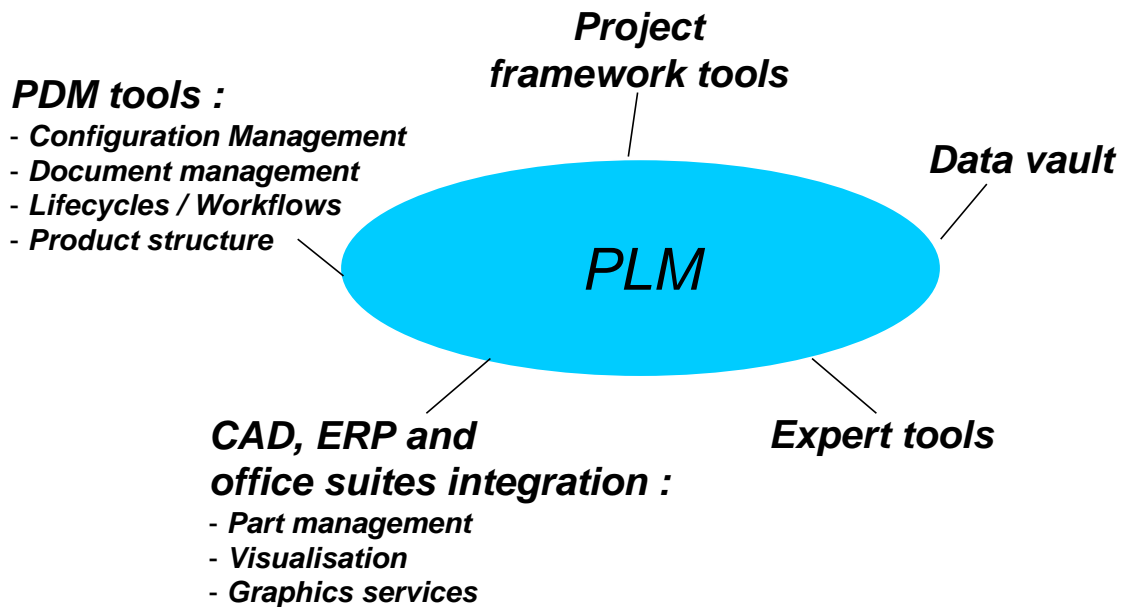
Figure 18: PLM environment

The management of projects and the necessity for traceability, standards, and other administrative requirements leads to a significant volume of document management activity. So it is almost unavoidable for a company to implement a tool in order to assist actors in data and process management. At this step the question appears of what sort of tool is more convenient for the company situation, a specific or generic one? A specific tool is burdensome in terms of resources: the IT skills must be present in the company otherwise the company must hire either a computer scientist or set up a whole IT department (according to the size of the company) to manage these systems. It takes a long time to implement such tool and people in charge of its maintenance are indispensable, both in order to solve problems which occur during its daily use and to customise the tool according to the specific situation of the company. However, such a specific tool must be configured to have its desired functionalities in accordance with the specific context of the company.

However, implementing a generic PLM tool is burdensome, difficult, and expensive. In the case of SMEs the costs may be reduced by a better data management and formalisation of the validation processes, but generally the match between company needs and the configuration of the PLM tool is not complete. Moreover, a PLM tool cannot manage the global process of a project because it only manages documents and their validation. It may

be possible to add extra specific tools which are integrated or at least can exchange data with the PLM tool.

Before any onerous PLM tool implementation there are prerequisites that must be addressed to create a favourable situation, to ensure a successful outcome [Pol, et al. 2005b] and to reduce significantly the cost of the implementation by reducing the implementation time and the number of testing iterations. These prerequisite tasks are focused on the organisational structure of the company, its design project process management and its product data management [Pol, et al. 2005a]. Most of the time the implementation of these prerequisites leads SMEs through reorganisation before the final implementation of an IT system [Crowder, et al. 2003]. Nevertheless, during the implementation of the prerequisites it is essential to keep enough flexibility in design processes to foster collaboration between designers in order to not stifle the emergence of innovation [Pol, et al. 2005d]. Flexibility can be introduced before and during the implementation of the prerequisites and later during the implementation of the tool. As an example; flexibility can be introduced by a PLM tool through management of the validation processes of documents [Gzara-Yesilbas 2005]. With this approach, some tools and methods aim to assist integrators in carrying out these prerequisite tasks. As for tools, the internal tool from PTC[1], named PDS assessment, uses interviews with actors to define the tasks to implement the PLM system in the company as well as possible. As far as methods are concerned, a methodology for PLM implementation is presented later in section 6.2.1.

3.4.3 IPPOP prototype

During the IPPOP project a prototype was implemented in order to test and improve the model presented in the section 3.3.1.1 The resulting cooperation and collaboration information system ensures internal integration (technological knowledge and coordination) and external integration (market software).
The description of the design process is based on a global description of the design system at the level of strategic decision making. Strategic project managers have to define the general functional structure of the product in order to identify which design departments have to work together. The global structure of the product depends on the decision and organisational structure of the company. The structure of the company is based on the definition of GRAI grids for each plant of the enterprise which is modelled in the IPPOP software (Figure 19). That permits the identification of relationships and influences between each plant and each department of them. So, the strategic decision level has to define global objectives of the design, interoperability and collaboration between departments. This step allows the identification of action levers that could influence the

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[1] **PTC:** Parametric Technology Corp with PLM (Windchill[TM]) and CAD (Pro/Engineer) systems.

system. Then objectives and performance indicators, deduced from action levers, can be deployed to the lower levels of decision [Robin, et al. 2005].
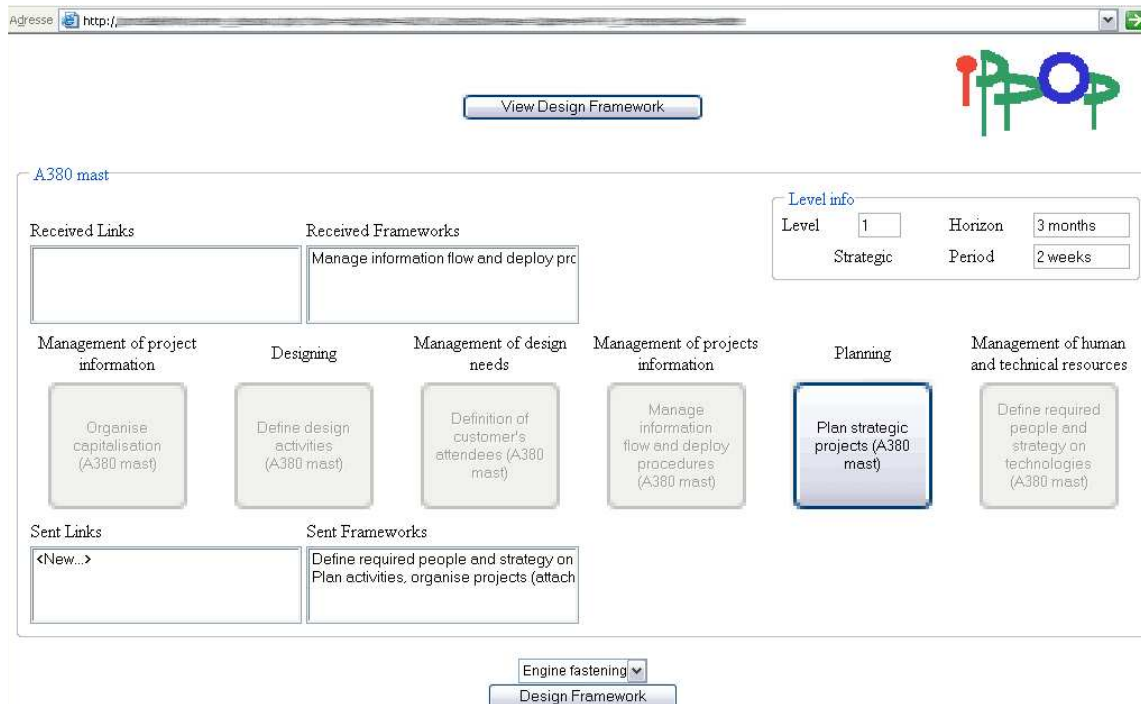
Figure 19: Example of IPPOP GUI on decision-making at a strategic level

Generally, CAD concepts originate in 3D solid modelling with geometrical functions. A direct relation does not exist between a product's geometrical descriptions (based on entities) and its functional, structural, technological or behavioural descriptions that are provided by the designers from design requirements. The developed demonstrator (implemented in the IPPOP project) extends the usual CAD modelling domain to that of modelling all product representations along its lifecycle [Charles and Eynard 2005].

The knowledge coming from either past projects or expert views has not yet been supported by operational software adapted to the practical work of designers. The IPPOP demonstrator may provide an answer by extending the current PDM tools.

In the IPPOP project the concept of collaboration is taken into account through the management of conflicts between actors [Lombard, et al. 2005], [Robin, et al. 2004]. This module is named Co^2med (an acronym for Collaborative Conflict Management in Engineering Design). When an actor detects a conflict, he creates a project (with the class "Project"); he describes the conflict, and invites experts to solve the conflict. By iterations (class "Iteration") each expert can propose solutions (class "Resolution it"), and can vote

for solutions (classes "Vote Request" and "Vote it"). When a solution is validated, the actor can close (class "Closure it") the conflict (see Figure 20).
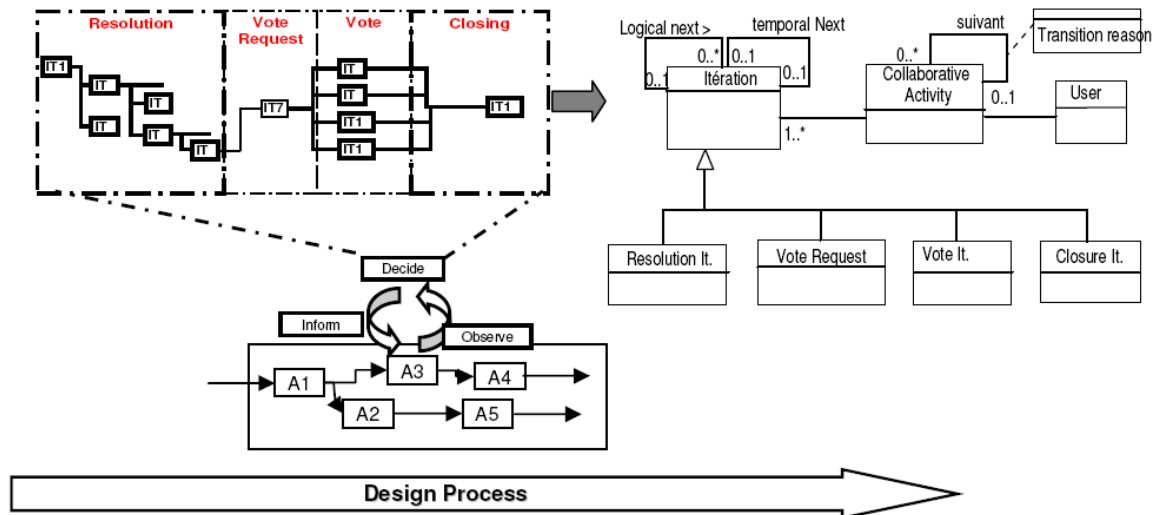
Figure 20: Static and dynamic specifications for conflict handling [Lombard, et al. 2005]

This Co²med module is useful in managing collaboration by conflict. However, this module is not sufficient to characterise every type of collaboration (as explanations, information requests, or technical decisions…) in project management.

3.4.4 ID²

Nowadays, one of the main objectives in design is to foster multidisciplinary collaboration among actors who have different points of view and build different representations of the product during informal phases. This point implies the development of new way of interaction between actors taking into account their differences of culture due to their domain of expertise (design, manufacturing, marketing, sales, etc.) [Legardeur, et al. 2005]. The literature study shows up a certain lack of tools offering help during these preparatory phases, however, a web-based tool has been developed by [Legardeur, et al. 2003] named ID² (Innovation Development & Diffusion) designed to be used with a view to improving the following points:

- Building a common representation of the new ideas,
- Setting up a network of actors,
- Distributing information in an informal context,
- Fostering interactions between participants for consolidation of ideas,
- Providing a project guide,

- Learning and recording experience during the project.

The general objective of this tool is to propose a support for the emergence of innovation within the organisation. More precisely ID² aims to support the strategy of a pilot actor in order to foster the development of new ideas and concepts. A pilot actor is an actor who has a new idea or concept in mind and who intends to evaluate this idea or concept with other actors. The pilot actor is the person who holds the new idea. ID² is not oriented towards the generation of new ideas but its use is complementary to creativity methods such as TRIZ [Altshuller 1999]. ID² is rather oriented toward the synthesis and the sharing of information about new proposed concepts and provides a support for new idea developments by proposing a platform for negotiation. For this aim, a web tool is proposed and designed to assist the pilot actor with his/her strategy by taking into account the different points of view, rationale and reasoning of the other actors involved.

The heart of a project on ID² is based on the Concepts and Criteria Table (CCT), see Figure 21. This table displays an example of a summary of all the information concerning a project. The existing solution, in the first column, is compared with the innovative proposals, in the following columns, against a number of evolving design criteria (rows). The pilot actor can invite a number of network actors with different expertise to help provide the data to validate the innovative proposal, so that the different points of view and areas of expertise can be compared. The idea is to provide a shared support tool enabling each actor to specify and explain his/her assessment criteria for the solutions. Thus, the structure of the table is dynamic and each actor can put forward new criteria (and thus new lines) as the project progresses. The criteria and information are therefore open to public viewing and discussion throughout the network.

Figure 21: The Concept / Criteria Table of ID² [Legardeur, et al. 2005]

ID² supports informal collaboration between actors during the early phase of design in order to discuss and promote the emergence of new design ideas [Legardeur 2001]. ID² obliges actors to have more informal exchanges and fosters a more informal form of collaboration. These informal exchanges are structured and recoded in order to promote new design ideas. The results recorded in this ID² tool have impacts on coordination aspects as for example [Legardeur, et al. 2001]:

- The selection of the project team. It is better to select actors who have already thought of and proposed solutions during the early phase of the project by using ID²,
- The attribution of project role to actors. This attribution can be decided in accordance with the comments or the involvement of this actor during the emergence of the project idea,
- The starting of a new project, the coordination of this project will be influenced by the information already recorded in ID².

Thus, ID² is focused on the management of collaboration with a large part of informal information in the early phase of design. The objective of the management of this type of information is to support the emergence of new ideas and to have an impact on collaboration by promoting the creation of new projects.

3.4.5 Synthesis on information systems

Various tools have been studied in this section 3.4 such as: CSCW, PLM, the IPPOP prototype and ID². These IT systems admit useful aspects to support this research study but they have been implemented for a specific context and have specific objectives.

Much research has been aimed at developing systems to support collaboration such as CSCW or PLM systems. Nevertheless these IT systems are generally used in design to ensure the collaboration between actors as for the Video conference, mail, shared diary. Nevertheless these IT systems do not support the analysis of collaboration in design for improving coordination aspects. In other contexts like in the sociological field, the analysis of collaboration is usually carried out with surveys, videos or interviews to understand how actors collaborate in order to improve the actors' way of working.

Thus the study of these IT systems leads to the definition of the necessary elements which must be tracked, recorded and characterised in order to understand collaboration in the context of this research. At the end, and based on these elements; a tool will be implemented to help the analysis of collaboration. The objective is to understand how actors collaborate during projects not only to improve the collaboration but also to understand the consequences of the coordination rules on the forms of collaboration. The understanding of these consequences permits the readjustment of the coordination rules. Moreover it permits the improvement of various coordination aspects of project design

management e.g. a more detailed formalisation of design processes, the introduction of flexibility in the design processes, or the improvement of project managers' skills.

With systems like CSCW, PLM and IPPOP the collaboration between actors is supported in projects by sharing a framework composed of the same language, objectives, methods and tools. However, the collaborative aspects of projects are not sufficiently taken into account by these tools. They act on "what, when, who, for what", but they do not define how actors work: are they in synchronous or asynchronous mode, in the same place, and with what degree of formality? In fact these IT systems do not address the operational functionalities for project managers which would allow them to coordinate and control collaborative design processes. Thus, before proposing such functionalities, the analysis and understanding of the collaboration in design must be addressed in order to see how a project manager might incorporate this aspect into the job of coordinating a project team.

3.5   Global synthesis

This research deals with the analysis of collaboration to improve coordination aspects in design projects for innovative SMEs. Indeed, in innovative design in SMEs, flexibility in design processes is very important to allow actors enough freedom to remain creative and to allow the company to remain reactive in the face of design changes. Thus, flexibility in the product development processes is necessary to avoid constraining actors in their design work and limiting their design choices. Predefined processes (as is the case in routine design) are too restrictive for the actors, they prevent the actors from thinking about all the possible design solutions and thus stifle the emergence of new ideas.

We have seen in this Chapter 3 also that, in order to collaborate, the actors have to build a shared framework to support their collaboration. An uncompleted shared framework leads to misunderstanding and design errors. This environment is characterised by the actors themselves, the specific attributes of the product and the project, the design processes, the form of collaboration used, the resources (see section 3.2.2).

In the literature, various relevant elements are used to support the characterisation the form of collaboration used by actors during design projects. This characterisation is based on criteria like: time (synchronous / asynchronous), location (same location or distant), formalisation (formal or informal collaboration), degree of freedom (free, encouraged, or forced), and more conflicting or more consensual collaboration. This characterisation comes from the literature, and will be completed by the case study in order to add extra factors and to have a complete characterisation.

The global approach to management of design projects is based on the coordination of the main design situations which will occur in the project with the definition of a project plan and design processes. This approach is supported by various models. It has been seen that

models with design processes are too limited to manage projects, and that a models of design systems provide more complete support. The GRAI R&D model based on design centre and decision centre structuring has been described and this leads to a more integrated model named IPPOP based on Product, Process and Organisation. These models characterise the main notion of coordination used to manage projects. The process and product models help the project manager to have a global view of the design results. Nevertheless, nowadays, design results are not sufficient to evaluate the performance of design. Indeed, design performance can be improved by the study of the interactions between product, processes, organisation and actors.

As described in the section 3.3; the notion of flexibility is very important in design. Design processes need to be defined in detail, with enough flexibility to allow actors to collaborate and remain reactive in the face of design changes occurring during the project. Thus coordination of projects needs also to take into account the collaboration aspects in order to understand how actors apply the prescribed coordination, to detect the design mistakes which originate from collaboration and to prescribe the future collaborative practices to be used in design activities.

The coordination of design projects can be lightly supported by various and heterogeneous information systems as CSCW, PLM or specific tools like for example IPPOP prototype and ID². In spite of all these systems, many problems of coordination remain. They are not sufficient to manage all aspects of coordination and of collaboration in design projects.

Based on this literature study, some fundamental concepts of coordination and collaboration have been characterised. The next step is to support this first characterisation with an industrial case study by adding extra criteria in order to represent the concepts of coordination and collaboration in project design by models. The description of these models is given in Chapter 4. Afterwards a tool to support the analysis of collaboration that occurs will be introduced.

4 Models of coordination and collaboration

The aim of this Chapter is to define theoretical models which, in later Chapters will be shown to be useful in assisting project managers in their work of coordination of design projects in SMEs. The definition of these models is supported by the literature and by an industrial case study in an SME. Thus, this definition is illustrated by various examples in order to make a link between the theory and the reality in SMEs.

The first section introduces the specifications for a model of design coordination in SMEs in order to draw the context of design coordination and to specify its requirements.

A second part is focused on coordination modelling and specifically aimed at showing how this modelling can help project managers in their work into SMEs. This model, described by class diagrams, characterises all the managed information to coordinate projects. The use of the model in a company and its limitations are detailed, the main limitation concerns the lack of input of collaboration aspects into the model of coordination.

The third part therefore introduces another model specifically for the analysis of collaboration in design activities in order to fill the lack of collaboration aspects in the coordination of projects. Thus, a model of collaboration is proposed with additional factors and concepts concerning collaboration. This model of collaboration characterises the collaborative mechanisms in design activities. Indeed, it represents the design activities with extra collaboration inputs. Moreover, the UML formalism used to define the model facilitates the implementation of a tool to support this analysis of collaboration. This implementation is useful for project managers who cannot use these models with this formalism easily. All through this Chapter, various examples from the industrial case study illustrate the demonstration.

4.1   Specifications for a model describing design coordination

In this part the specifications of a model describing coordination aspects are proposed. The specifications are focused on the coordination aspects in project design in SMEs. They are based on the literature review and on the work carried out in the SME partner Ederena where the company is fully involved in the definition and the validation of these models.

First, the actions of the project manager in SMEs are defined. Secondly, for each action, a list of information used is given and aggregated by categories and sub-categories. Based on this information, theoretical model of coordination is proposed.

The models are described by various intermediary diagrams represented in the UML formalism.

4.1.1 Design project management in SMEs

In design project management, the control of design processes can be defined as the understanding of existing design situations (in the real world) in order to evaluate them and take decisions that will modify and improve future processes, according to design objectives given by customer specifications or issued from the company strategy. The coordination problem here is a problem of decision-making to support designers in their activities [Girard and Doumeingts 2004b] in order for them to achieve an objective in a specific context (Figure 22). Each design activity has "input" and "output" information. Actors use the "input" in order to produce the "output", and they have "supports" namely: human and material resources, knowledge to help them in their work.
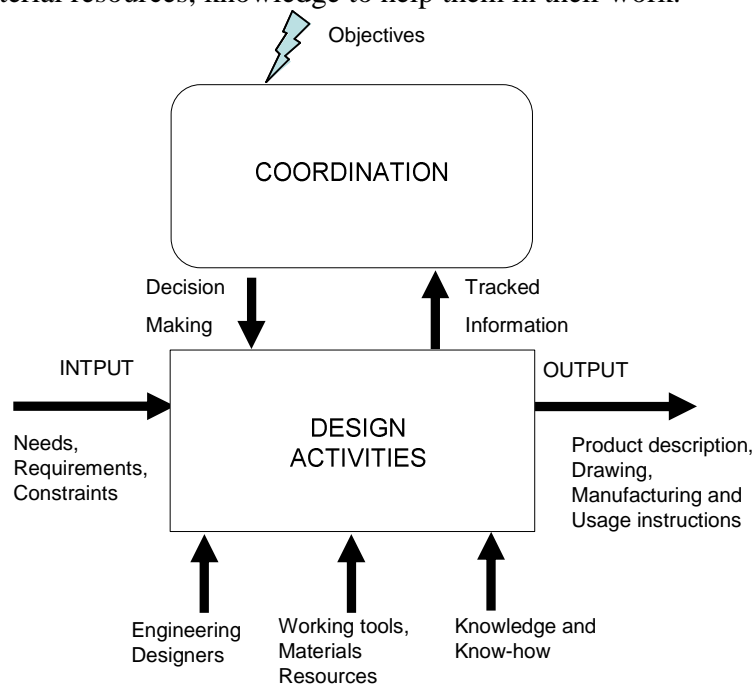
Figure 22: Coordination of design activities

For decision-making, project managers need to identify effective action levers to coordinate projects and control design performance. Those elements concern designers themselves, not just the product or the activities.

The project manager has to coordinate various elements in order to reach the objectives. The actions of project managers concern design coordination and process control.

Moreover the situation in many innovative SMEs requires a new analysis and study of the customer's needs for each project. Most of the time, the small structure of the SME does not ensure project management in a routine way and leads to the combination of various responsibilities. Indeed there are often not enough actors to be assigned to each design role, so most of the actors have various design roles in a project. For example the project manager can make calculations on one part and help in the design of the manufacturing tools in the same project. Consequently the role of informal relationships is very important in an SME in order that actors may help each other without rigid formalities. Thus, the combination of various responsibilities and the informal relationships lead to a high level of workload because informal tasks are added to the official ones. Accordingly SMEs have to manage deadlines by setting an order of priorities on design tasks according to the objectives. Another point specific to SMEs is their project structures which have a rigid formalisation of their processes at a macro level and a very flexible non-formalisation of the detailed processes which allows informal relationships into the project. The following analysis takes into account these specific points and leads to the proposal of models for SMEs.

> Example from the industrial case study:
>
> In Ederena, the main phases of the project are:
> · "Quotation": analysis of the customer's needs and definition of a technical quotation which leads to a marketing proposition.
> · "In order": If the customer accepts the marketing proposition the project phase of the project becomes "in order".
> · "In design": In this phase the engineer carries out a technical definition of the product and how to manufacture it.
> · "Manufacturing": In this phase the product is manufactured following the technical definition of the product.
>
> This macro structure is fixed in advance and is identical for each project; however the tasks inside each phase are defined at the beginning of the phase by the project leader. These phases are not necessarily sequential; one phase does not necessarily begin when another has stopped. Thus, when the project is "in order" it is possible to have a phase "design" or "manufacturing". This situation comes from a high level of informal activities in SMEs. Moreover, the phase "quotation" is included into the project for a better reactivity. This reactivity is an advantage of SMEs.

Project managers define actions for each phase of the design process. In these actions, they use "information input, information outgoing, support and control" to reach the fixed objectives. Thus, the management of projects is achieved with numerous actions by the project manager (Figure 23). These actions and the information used have been validated in Ederena.

The project manager analyses the requirements from the customer, after which he defines the project team, he then defines the sub-phases of the project plan and activities in each sub-phase, next he defines a plan to control the progress of the project and finally he applies this control plan and makes appropriate modifications in accordance with the results and the design objectives.
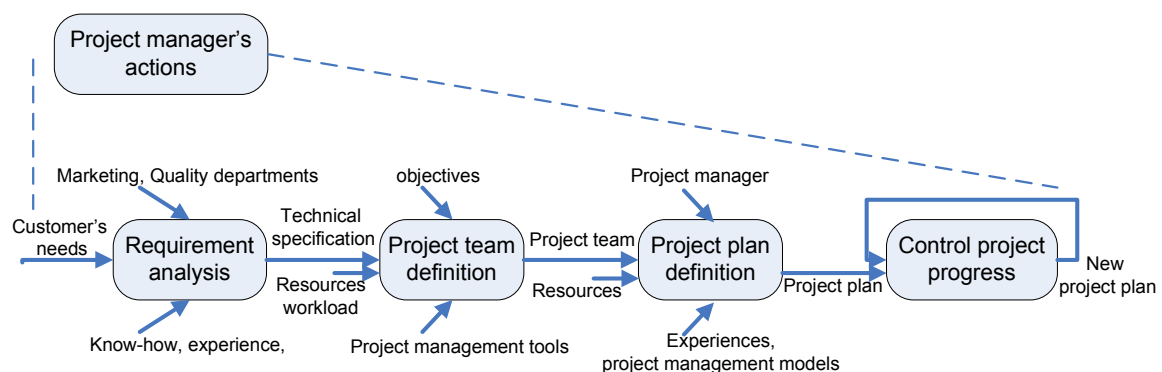
Figure 23: Synthesis of the project manager's actions

- "Requirement analysis": the analysis of the customer requirement is one of the first actions of a project carried out by the project manager. Its objective is to analyse the customer's needs and to evaluate the project in terms of feasibility, resources, profits and time.

> a) Information input:
> The in-coming information corresponds to the needs from the customer explaining what kind of product and which functionalities he wants. This definition is, most of the time, incomplete and requires an analysis to be made in collaboration between the project manager and the customer in order to merge the customer's requirements and the capacities of the company. This analysis is based on the identification of technical problems, deadlines and Quality standards.

> b) Information output:
> The out-going information is a technical specification document which is a description of the product requirements with the future functionalities of the product, with norms, test definitions and quality controls. This

document is used by designers to make a technical quotation with an evaluation of the cost and lead-time to produce the product.

c) Supports:

The analysis of the customer's requirements by the project manager is undeniably supported by his know-how and knowledge especially in relation to previous similar products Moreover the Quality standard is additional knowledge useful in analysing the requirements of the customer. The informal links between actors are often used by the project leader to confirm his decision making.

d) Control:

In this action of "requirement analysis" the project manager is the decision maker. The marketing department controls his task not from a technical viewpoint but in order to verify that the project matches the strategy of the company. The Quality Department also controls and verifies the quality of the customer's requirements and validates the feasibility in terms of quality for the project. Finally, if the project manager is at the same level of hierarchy than other actors, he needs legitimacy from the head managers to have the authority to coordinate other actors. The head managers have to transfer their authority to the project manager. This situation is common in SMEs where each actor can have various different design roles.

Example from the industrial case study:

The heads of the company designate Fred as the project manager. Thus Fred has to analyse the customer's requirements in order to carry out a technical quotation for the marketing department. Consequently the project manager analyses these requirements and structures the project to achieve the proposition. He identifies the technical problems, deadlines and quality standards. Then, he bases his actions on his experience acquired in previous similar projects. If there are two possible solutions to study depending on different hypotheses, the project manager can decide to separate the project into two with a second team to study this second solution.

This example illustrates the input (analysis of the customer's needs), output (quotation), supports (project manager's work), and the control (two possible design teams) during this requirement analysis action.

- "Project team definition": According to his analysis, the project manager defines the project team in accordance with the skills of actors, workload, objectives and the financial or human resources available for the project. For each main phase of the project, project managers have to define the team associated, because the team could

change between phases according to the evolution of the project and to the actors' workloads. The project manager defines roles for each team member and his level of responsibility and autonomy.

a) Information input:

A lot of information is used to help the project manager to choose his project team. The technical specifications from the previous action "requirement analysis" allow the identification of the main technical difficulties of the project. The "Resources" are divided into three parts: Information Resources namely specifications, Human Resources to define who is assigned to a task and Material Resources such as funds allocated to the task or available software tools. The list of actors with their know-how, skills, availability and workload is decisive in choosing the right actor for the team. The deadline of the project defined in the previous action "requirement analysis" affects the number of actors in the project team. Moreover, the larger the project team is, the more collaboration figures in the project's success or failure.

b) Information output:

Outgoing information is the definition of the project team by the project manager with all the information on the human resources such as: name, roles, skills, workload…

c) Supports:

Project management tools show to the project manager the workload and the scheduling of each actor and help him in his action of team definition.

d) Control:

The progress of the project and objectives are included to control the team definition. The human resources department of the company checks, for example, whether the workload of each actor is in accordance with the labour legislation.

Example from the industrial case study:

For a new project incoming the project manager has two engineers and a technician available. He chooses to assign to this new project: the engineer who is more available and the technician as a support to help the engineer in order to satisfy the customer's request. In this context the engineer is in charge of the technician to define his work. Moreover, adequate resources are assigned to the team in order to carry out the customer's request: CAD / CAM software, office software…

In this example of project team definition, the input is the actor's workload, the output is the project team definition, the supports are software and know-how, and the control is made with the workload.

-   "Project plan definition": the main objective of this task is to build an adequate environment to help the project team to reach the objectives of the project by for example; the definition of the coordination rules (direct supervision, mutual agreement or normalisation [Mintzberg 1990]), the kind of communication (meeting, knowledge sharing, … [Bareigts 2002]) and collaboration (level of communication, free or forced, synchronous or asynchronous, present or distant) aspects.

The project manager defines the phases and the sub-phases of the product development process as a project plan. He specifies this project plan in accordance with the specifications of the project and his analysis made previously. At each phase the project manager has to define: tasks, objectives, milestones, deadlines, resources, documents to fulfil and control actions such as task completion and document flows control. Control of document flows correspond to specific basic processes describing all interactions between actors and the document. Each actor involved in the project interacts with the right document in accordance with his role, skills and responsibilities… The automation of these processes requires a workflow engine which must have inputs from the project managers:

·   the pre-definition of processes with objectives, activities, actions, actors, group, rights;
·   the definition of the documents flows;
·   the possible activation of specific actions or applications.

Moreover, project manager schedules all the tasks[2] defined previously for each phase. The objective of this schedule is to define deadlines, due dates and corrective actions in the case of overrun. A schedule has three dimensions: "time", "space", and "resources". "Time" defines when tasks are planned in a global schedule which also represents the actors' workload. "Space" is to know where the task will be done, for example in a meeting room. And "Resources" as was presented before (in the "project team definition" part); resources could be Information, Human or Material.

In this action the project manager uses the following information:

a) Information input: the list of materials, informative and human resources.
b) Information output: a detail project plan with time (deadlines), tasks, responsibilities, objectives, milestones.
c) Supports: the information based on the experience and stored with model of coordination.

---

[2] The concept of task and activity is distinct, a task is prescribed for an actor or a group of actors (oriented toward a finality) and an activity is achieved by the same actor or group of actors. So a schedule is composed of various tasks, and each task becomes an activity when achieved.

d) Control: the role of each actor and the organisation of the resources involved in the project.

Example from the industrial case study:

In the continuity of the previous example, the project manager recommends to the engineer to check the technical progress of the activity (coordination aspect on scheduling) and for doing so to have a daily meeting with the technician (coordination aspect on collaboration). He recommends also to the engineer and the technician to be supported by actors who have experience with the same type of product and/or with the same customer to help them in their decision making (coordination aspect on collaboration). Faced with the deadline for this project, the project manager plans a meeting every day with the engineer and defines a deadline of three weeks for the quotation and four weeks for a marketing proposition (coordination aspects on scheduling). Moreover, he defines the objectives, the available resources, the tasks to do, the deadline for each task and the modality of checking for each project phase (coordination aspects on objectives, resources, scheduling and design control). This example shows that when coordinating, project managers may take into account the collaborative point of view.

This example illustrates the input (design team), output (project plan), supports (experience), and the control (daily meeting) in this project plan definition.

-   "Control project progress": According to the plan of the project, the project manager has to control the progress of the project. This control is achieved in three steps: the project manager identifies the gap between objectives fixed and the achievement of the activity, next he evaluates the achievement and finally he prescribes corrective actions to reach the objectives (Figure 24).
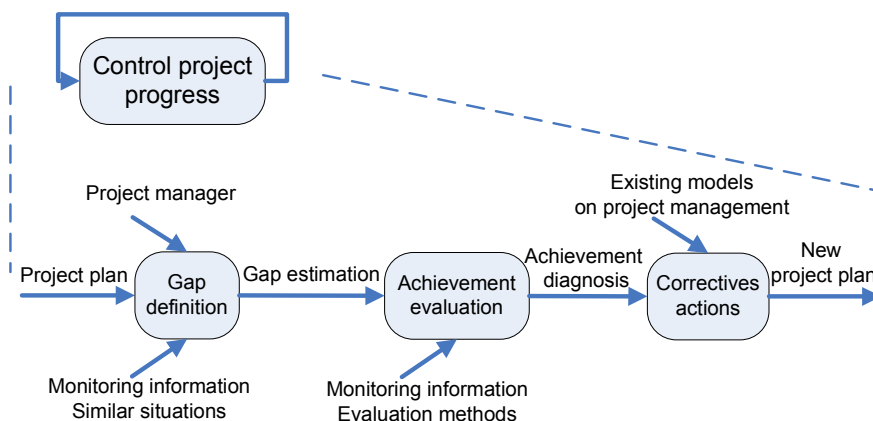
Figure 24: Project manager's actions in "control project progress" step

· **Definition of the gap** between objectives fixed and the achievement of the activity. The project manager consults the information describing the processes and the product, and evaluates the gap between the objectives fixed in the project plan and its achievement.

a) Information input: the project plan defined previously.
b) Information output: the estimation of the gap.
c) Supports: all project monitoring information and information stored on previous projects are used in order to identify similar design situations and thus drive the search for solutions.
d) Control: the project manager.

Example from the industrial case study:
During the meeting in the third week, the project manager notices that the quotation is not completed. The engineer estimates the lead-time to finish the quotation to be three more days. Thus the estimated gap is three days. This estimation will be the basis for the next step: achievement evaluation.
In this example of gap definition, the project plan as an input and the deadlines and lead-time as supports are checked by the project manager to evaluate the gap as output.

· **Evaluate the achievement**: it is the evaluation of the results with monitoring information in order to make a diagnosis.

a) Information input: The evaluation of the gap between objectives and achievement.
b) Information output: evaluation of the actual achievement by comparison between the objectives and the achievements.
c) Supports: the monitoring information to make a more detailed analysis, and also the methods of evaluation, if they exist.
d) Control: no necessary elements.

Example from the industrial case study:
A detailed analysis of the engineer's work by the project manager shows that the engineer has encountered a very difficult problem, and that the gap of three days previously given was based on an optimistic estimation. When the project manager defined the gap, he identified a similar situation solved by another engineer in the past. Thus from his diagnosis, the project manager identifies a lack of experience of the first engineer and he decides to assist him with a second skilled engineer in order to solve the problem and to acquire new knowledge.

> From the evaluated gap (three days), the project manager evaluates the achievement of the activities. If the result of this evaluation is not satisfactory then the project manager decides to apply corrective actions (add skilled engineer).

- **Corrective actions:** from the previous diagnosis, the project manager defines a new "Project plan" to redefine objectives, teams, tasks in order to bridge the gap identified previously.

a) Information input: the previous diagnosis.
b) Information output: a new version of the project plan.
c) Supports: no necessary elements.
d) Control: the existing project management models.

> Example from the industrial case study:
> The new project plan involves the second engineer in the project for 2 days in order to help the first engineer in his work of quotation. The only change in the new scheduling is the evaluation of the quotation after 3 days.
> This example illustrates the input (previews project plan), output (new project plan), and the control (project manager) in these corrective actions.

In each action, the project manager has to study a lot of information. The management of this information is essential for the collaboration and coordination in project management. Thus after defining the actions of the project manager, it is important to define the necessary information to be managed in each phase in order to construct the global model of coordination. A global and formal model of coordination can describe generic situations and thus be applied to more than one project. Moreover, of course, with a formal model of coordination (and later collaboration); processes and tools and even methodologies can be devised to support and improve these aspects of projects. The definition of these actions of the project manager is based on the literature survey and on the case study in Ederena.

4.1.2 Requirements for a model of coordination

The study made of the actions of the project manager allows the identification and characterisation of the information manipulated by him. Thus this synthesis leads to the definition of a model of coordination in order to help project managers in their work.
During a project, the project manager manipulates information such as: human (organisational) or non human resources, scheduling information, definition of control indicators and controlling the progress of the project. All this information must be included

in the specifications for the model of coordination. Based on the actions of the project manager, a list of the information used in each action is drawn up as follows:

- **"Requirement analysis"**: The information managed by project managers comes from various elements.
    • **Customer's needs** are documents provided by the customer in order to define the specifications of the desired product. Most of the time these documents are sent by e-mail and are incomplete. Thus, in this phase of "requirement analysis" the project manager has to complete the specifications in collaboration with the customer and skilled designers in the company.
    • **Previous work** done for the same or equivalent pairing of product/client. The storage of previous work is very important in this phase, because the project manager uses information from previous work to make his analysis of the customer's needs. The pool of previous work is the "know-how" of the company and avoids the need to repeat studies, tests and development already made for other projects.

- "**Project team definition**": The project team is defined by the project manager with information included in the organisational structure of the company. Indeed, project managers have to define the project team with the description of the actors' roles, their skills, and the specific information of the department and the site.
    • **Skills list** of each actor in the organisational structure of the company. The list of actors' skills is essential to the project manager in order to assign the right person to the right task and thus build the project team. These skills are in constant evolution and have to be updated after each project.
    • Necessary **roles for the project.** In the analysis of the project manager, he has to identify what the necessary roles for the project are. This list of roles is compared to the list of actors' skills to define the project team.
    • **Workload** of actors and departments. The workload is another factor to be taken into account in defining the project team. The assignment of a person to a role in the project is made according to the workload of the actor concerned and also the workload of the department.

- "**Project plan definition**": Project managers use a lot of information to define the scheduling, with process element as tasks, milestones, and triggers to launch a design activity. This information is essential to build a project plan with an associated schedule.
    • **Main phases of the project.** The project manager defines the main phases of the project, and their objectives. These phases and objectives are dependent on the nature of the project.

> Example from the industrial case study:
> If the client needs only a study on a specific part of the product, the phases will be a phase of quotation and a phase of design. However, if the complete manufacture of a product is needed, the phases will be: "quotation", "design", and "manufacturing" with loops between phases. After the production of the prototype it may be necessary to have another phase of design in order to make changes.

- **Tasks definition in the phases**. In each phase, the project manager defines the tasks to complete in order to reach the objectives fixed. For each task it is necessary to define the goal, the actor who is in charge of the task and who the participants are, the deadline and the resources available to carry out the task.
- **Objectives**: Objectives are defined at various levels. In the project plan action, objectives were defined at a global level for the project; and at a detailed level for each task in the project plan.
- **Milestones** are specific activities in the project plan where the defined objectives must be achieved. If the objectives are achieved the milestone is validated and the project continues to the next task, but if the objectives are not achieved, the project manager must carry out a control of the project plan. Milestones allow the validation of phases of the project and help to control the progress of the project.
- **Deliverables** are the documents which must be fulfilled at the end of the task.

- "**Control project progress**": A lot of information is also used to define the control plan to check the progress of the project. Project managers have to define performance indicators and timetables in order to compare previously fixed objectives with the achievements of the project phases.
  Furthermore, project managers must apply this plan of control throughout the project. This implementation of the control definition during the project leads to the creation of other information such as controls, reports, documents for validation…
  - **Objectives:** the project manager uses the objectives fixed previously to define the gap between achievements and objectives. These objectives are used to control the work carried out.
  - **Timetable** gives an overview of the progress of the project to the project manager with time, tasks, actors and resources allocated.

- **Indicators of performance:** the project manager defines, during the definition of the project plan, specific indicators in order to assess the performance of the project. These indicators are based on the objectives defined and are checked at each design stage in order to control the progress of the project and its performance. For example, the performance indicators for Production could be the number of products manufactured or the lead-time to manufacture one product. The performance indicators could be based on any other aspects such as: Quality (e.g. number of defects), Design (e.g. accuracy of the estimate of the workload) , Marketing (e.g. outcome)
- **Deliverables refer to** the validation documents fulfilled during the project by actors. Deliverables are used by the project manager to control the progress of the project. For example, the specification of the product is a deliverable fulfilled by the project team, validated by the project manager and given to the customer.
- **Information modified** defines all the information changes carried out by the actors. It is important in the control of the design progress to record all the changes appearing on information throughout the project.
- **Technical data** gives all the technical information on the project to the project manager in order to validate the work carried out in the project. For example, the quality standard for the design of a specific product such as, for example, a crane.

The project manager needs support in generating, storing and re-using all this information. This support should be based on a model of coordination in order to develop adequate tools to help project managers. The specifications of such a model of coordination for project managers have to take into account all the information associated with the project managers' actions.

In each design phase the project manager can use tools to assist him in his tasks. A list of several different types of existing tools which might support design activities in companies follows (see also Figure 25):

- **Project management tools** aim to schedule the project plan and to define the structure of the design processes. However these project management tools are mainly oriented towards scheduling but, they are not designed for managing documents or validating tasks according to objectives.
- **PDM / PLM tools** are mainly oriented towards the management of documents and less towards the management of projects [Pol, et al. 2005b] (e.g.: Windchill^{TM}). In industry, the use of these tools is mainly oriented toward the management of product data and processes. This assessment is based on experience in the industrial case study where a PLM prototype was implemented.

- **CSCW** tools are intended to support knowledge sharing and communication. These aspects are essential to coordinate projects. Thus, CSCW tools support the aspects of project management and are used by most of the project actors such as, for example, e-mail, fax, electronic directory, conferences, document sharing and forums. Nevertheless, CSCW systems are general tools and are thus not specifically focused on the design field. According to [Johansen 1991], CSCW tools are more aimed at structuring and controlling the information, which is also one of the main objectives of a project manager. Thus, some examples of CSCW tools can be quoted as: the shared electronic diary and the task manager. Nevertheless, the CSCW tools cannot be focused on design processes or project management without additional extensions (see Chapter 3.4.1).
- **Office** tools are mainly used to manipulate information and documents. For example, all the software included in the Microsoft Office or Open Office suite is included in this category. Sometimes such office tools are incorporated in CSCW tools and are used everywhere in the design process to create or modify documents.

To conclude, as shown in Figure 25, it is well established that there are no tools which support all aspects of project management in design. Thus a model of coordination is the logical way to construct and define the specifications for future tools which could bridge this gap.

Phase of project management / Type of information managed by tools	Analyse	Structure	Schedule	Control
Organisational & Human		Xxx		
Process	x	XXXX	Xx	XXx
Product Data	Xx	x	x	Xxx

X   Project management tools   X   The tool is focused on
X   PDM tools   X   The tool has some functionalities
X   CSCW
X   Office tool

Figure 25: Capabilities of tools to support project manager's actions

Thus, in summary, the project manager's actions begin with the analysis of the project requirements to define a project team, and the definition of the product development

process with tasks, milestones, objectives and documents. This product development process is the basis for scheduling tasks included in this process with time, space and resource aspects. Finally the project manager has to define a plan to monitor the product development process with control elements and to apply this plan during the project.

In all these actions, project managers use information to carry out their work and achieve objectives. Successful project management relies on the management of this information. Thus, the definition of a model with this information brought together and organised will help to formalise the main concepts which must be taken into account by project managers in their daily work. The objective of the following subsection is to introduce and propose such a model focused on coordination aspects in SMEs.

4.2   Design coordination model in SMEs

4.2.1 Definition of categories of information for coordination

In the previous section, the project managers' actions are defined. In this section based on the definition of these actions, a list of used information during these actions has been compiled and aggregated by categories and sub-categories. Thus, three main categories of information are proposed: a technical one, a process one, then an organisational and human one. This information can be often formalised by documents. Nevertheless in a SMEs context, where informal information is predominant, all the information is not necessarily formalised by documents. The identification of these categories comes from the literature survey and from the work achieved in the company. A detailed list of the elements of information is given and is collected together under these three category headings:

- **Technical information:** the project manager needs information on the work done by actors in order to review the progress of the project. He also has to be aware of any technical difficulties encountered by actors in order to take decisions in consequence. Thus he manages a category of information named "technical information" which is composed of:
  - **Customer needs** contains much technical information and is an informative resource for the task of quotation.
  - **Previous work** is a support in the action of analysis in order to re-use previous work done. Thus previous work must be recorded and linked to the process tasks and the actors who carried out the tasks.
  - **Deliverables** is a support in the action of control in order to compare the deliverables achieved and those demanded / expected.
  - **Information modified** is the output of the control phase and is included in the modified project plan.

- **Process information:** this category is composed of the main information used in the phase of plan definition and control. The processes are the basis of the definition of the project plan and are used to control the progress of the project, to manage the schedule, tasks, deadlines… This category is composed of the following information:
    • **Project phases** are included in the processes in order to know which one is activated and what the objectives are. This information is included in the output of the project plan definition action.
    • **Tasks definition** is also information included in the project plan.
    • **Milestones** are included in the project plan but milestones are also a support for the control of each phase and of the group of tasks included.
    • **Objectives** are outputs for the project plan definition and inputs for control phase.
    • **Timetable** is a support to create the project plan by project managers.
    • **Indicators of performance** are an output of the project plan definition where the project manager defines the indicators of performance for the project team's activities. The indicators of performance for the whole project are defined by persons external to the project such as: the customer for the lead-time, the final cost and quality requirement… Indicators of performance are a support to control the progress of the project. They are used in design processes and divided into expected indicators and achieved indicators.

- **Organisational and human information:** this category is composed of information used to set up a team, to manage actors' skills, or to define the organisational structure of the company. This category deals mainly with the project team definition, and affects all other actions.
    • **Skill list** depends on the organisational structure of the company and is a support to define the project team.
    • **Roles** are a support for the team definition by project manager. Roles define what necessary roles are needed in the project.
    • **Workload** is a support for the project team definition and must be updated regularly according to the actor's workload evolution.

From the definition of the project manager's action, the information used in each action and its categorisation; a model with these main concepts could be established to support the design activities of coordination in projects with associated information.

4.2.2 Design coordination model

The aim of this model of coordination is to help project managers in their management of design activities. This model of coordination is mapped to the specific context of this research work: coordination of design activities by project managers in SMEs.

The model of coordination is constructed with a logical and sensible analysis of this information and categories. Indeed, each category of information presented before is represented by classes, attributes and links and then all these classes will be compiled together to constitute the model of coordination. The associated links, cardinality and attributes have been defined to facilitate the studied actors' activities and project manager's ones in accordance with the information relationships.

4.2.2.1 Organisational and human information classes

The organisation of the design system of companies is formalised by departments, which are composed of actors (i.e. human resources) and corresponding functions. A function is an administrative name defining what the position of the actor is in the company. All the functions of the actors involved in the company are commonly represented by a functional chart. Independently, actors can have various roles in a project. For example, the actor Fred has the function "design engineer" in the company, and has in the project A the role of project manager, in the project B the role of drafter and so on. Consequently, role is dependant to the project, thus the attribute role is included in *Design Process* class which represents the project (design process is described in the next paragraph).

As synthesised in section 4.2.1 organisation and human resources are characterised by a skill attribute and a workload attribute. This skill attribute is a first approach to competencies management that can be specifically studied and implemented in the future (Figure 26).

At the beginning of a project, the project manager uses this information to define the organisational structure and to define the team (roles and selected human resources) of the project (design process).

The classes in grey (in Figure 26) represent the process aspects and the white ones represent the organisational aspects. The project (*Design Process* class) needs a relation with the classes *Function* and *Human resource* to characterise the actors involved in the project.
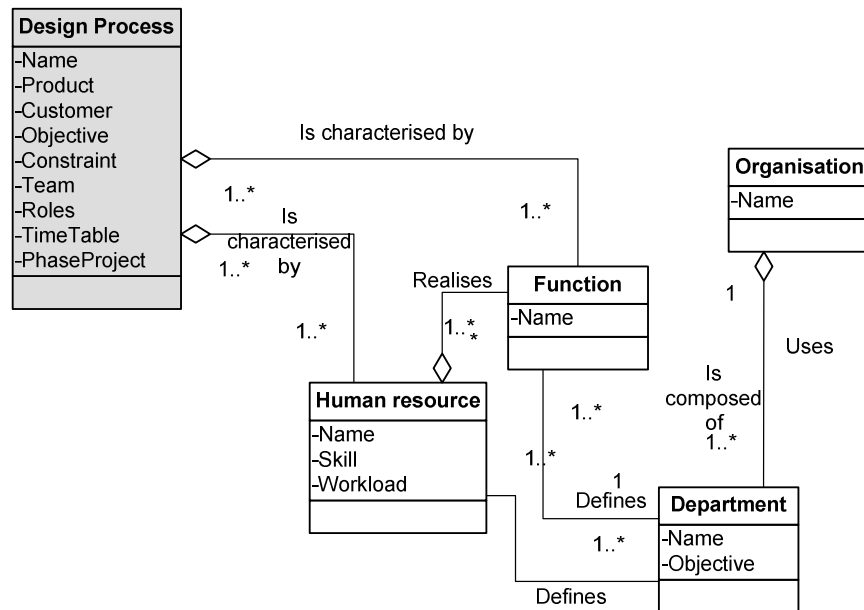
Figure 26: Organisational and human information classes

The links with the rhombus are links of aggregation. Aggregation is used to represent a link between independent classes. This information of independence is used in a future IT implementation to declare variables. The cardinality of the links represents the quantity of objects for each class. For example 1 organisation is composed of 1 or many (represented by *) departments.

4.2.2.2 Process information classes

As we have seen before, during a project, the project manager defines a schedule composed of tasks. As several different kinds of tasks can emerge, the class *Process Element* is used to formalise these tasks. The following classes are proposed (Figure 27):

- *Design Process* class corresponds to the project and is used to manage the information on the project like the <u>phases</u> of the project and the <u>timetable</u>.

- *Process Element* class includes the <u>indicators of performance</u> for each process element with the difference between the expected and the achieved indicators. The <u>objectives</u> at a global level (for the project) are managed by the *Design Process* class while at a detailed level they are managed in the *Process Element* class.

The study led in the SME partner shows that tasks can be divided into two types: traditional tasks focused on the implementation of the product definition and milestones that are tasks concentrated on decision taking:

-   *Milestones* and *Task* classes have a link of inheritance with the *Process Element* class, thus *Process Element* class transmits all its attributes to *Milestone* and *Task* classes. *Milestone* is a specific process element orientated toward the validation of *Tasks*, thus this class has specific attributes to manage this validation: the <u>expected</u> and <u>achieved decision</u> in order to manage the corrective actions and <u>justification</u> for a better understanding of these decisions.
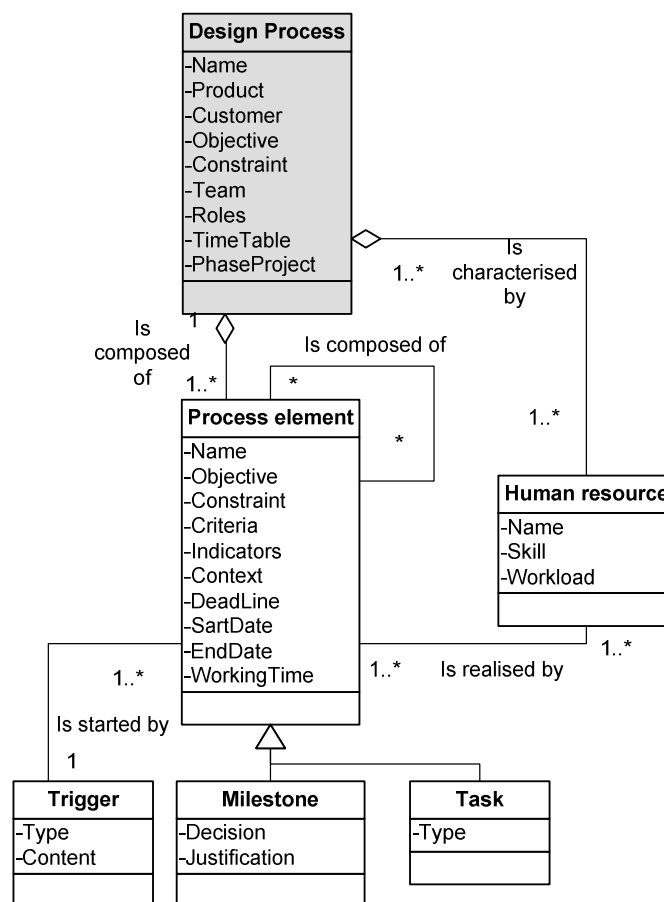
Figure 27: Process information classes

For each kind of task, the project manager selects the person according to the objectives, constraints, criteria and performance indicators that will be used later to control the

project's progress. For milestones the project manager must record the decisions taken in order to be able to improve them later:

- *Human Resource* class allows the linking of each actor of a process element to the project team where each project <u>role</u> is defined with actors' <u>name</u>, <u>skills</u> and <u>workload</u>.

Trigger class represents the elements which allow a *Process Element* to start. It can correspond to documents, tasks, or milestones. The trigger is defined by its <u>type</u> (document, activity, decision) and its <u>content</u> as a comment to describe why a process element is started.

4.2.2.3   Technical information classes

This category includes customer needs, deliverables, information modified and information on previous work, as studied previously. The organisation of this information in the model is managed by two classes (Figure 28): *Resource* and *Design Process* classes.

- *Resource* class manages the documents used or generated during tasks and that can be: the customer needs, deliverables, methods, tools and modified information. The attributes of the class are: the <u>Type</u> of the information in order to know what kind of information it is, and the <u>Associated document</u> to have a link with the real document.

This class *Resource* must be linked to the classes *Task* and *Milestone* to allow project managers to associate these resources with the right task or milestone. Moreover a resource can launch a process element as an activity, thus the *Resource* class is linked to the class *Trigger* which used the resource to launch the associated activity in the design process, as can be seen in the following Figure 28.

- *Design Process* class manages the previous work completed. This class stores the information from previous projects and the links between the *Process Elements, Function* and the *Human Resource* classes.
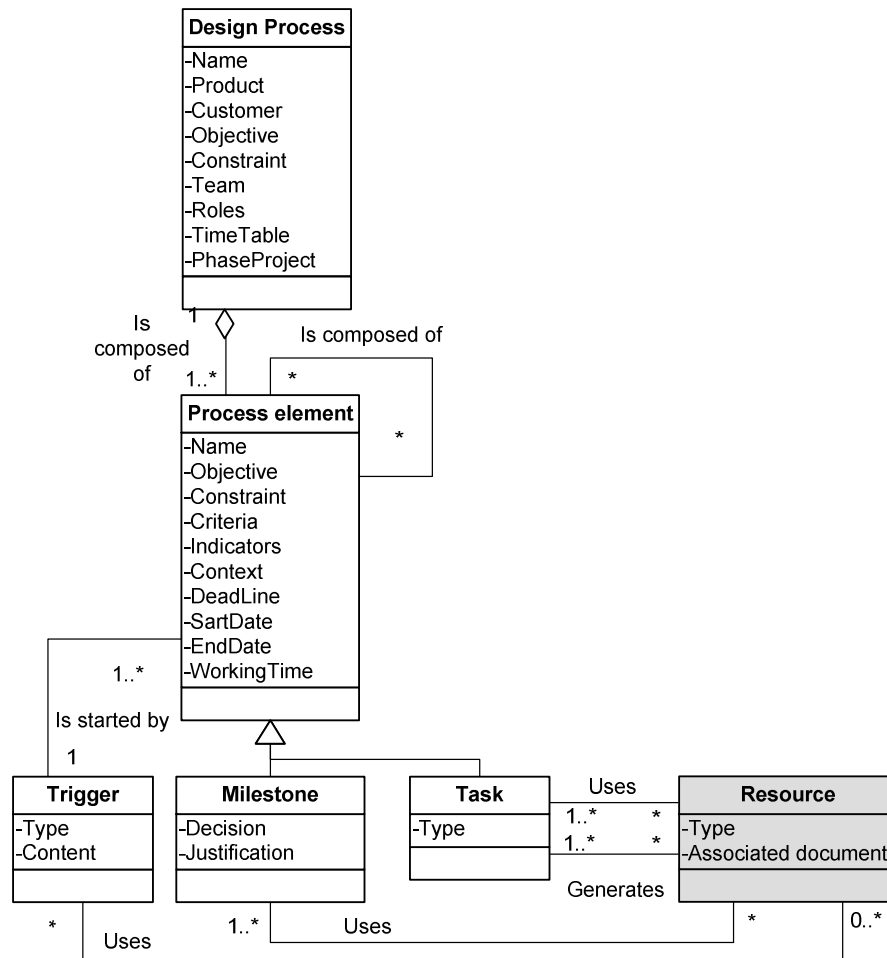
Figure 28: Technical information classes

The *Design Process* class has attributes in order that the project manager can define the context with the <u>name</u> of the design process, the <u>product</u>, the <u>customer</u>, the <u>objective</u> for the process to reach and the design <u>constraints</u>. Moreover this class stores the <u>team</u> associated with the design process, thus a link between *Function* and *Human Resource* classes exists in order to link the design <u>roles</u> to an actor and his function in the company. The cardinality between these classes are (1..*) because a design process must have at least one person with his function, and one actor can be included in one or various processes. Moreover, *Design Process* class is linked to the *Process Element* class in order to include tasks and milestones in the design process.

4.2.2.4 Conclusion

As a conclusion Figure 29 synthesises the model to give an overview of all classes and links between them.
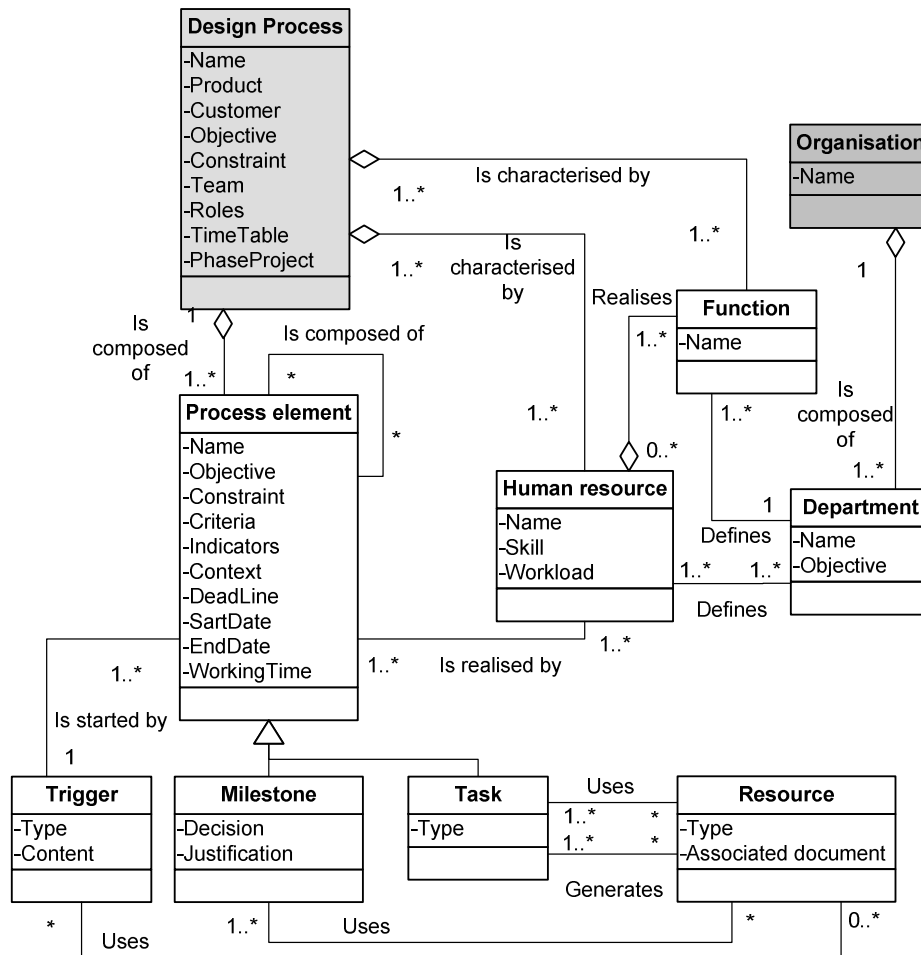
Figure 29: Conceptual model for Project coordination

The model, through UML class diagrams allows the identification of the necessary concepts for this SME to manage its design projects. In the company, the head of the technical department and the head of the company have contributed to make constructive comments on this model in order to validate it in their industrial context. Nevertheless the main problems still remain. The project manager must introduce flexibility into a predefined global design process by explicitly formalising constraints, criteria, objectives and indicators. Thus the project manager must capture project information and decisions to improve his own skills. This is a great challenge in the SME partner as the project manager

may be a young engineer. So the project manager must be helped in applying such a model. The next section will detail how such a model can be used and what problems still have to be solved.

4.2.3 Design coordination model in use

The previous coordination model provides a support for the project managers' work. In the previous section, both the actions of project managers and the model have been presented. In this part, the link between the actions of the project managers and the model is explained. Namely, how the project manager can use this model in the company to support his actions, and what the impacts on the work of the designers are.

- Requirement analysis: In this action the project manager analyses the customer's needs in order to identify technical problems, feasibility of the project, profits and time. Using the model he instantiates:
  - The *Design Process* class to store the phase of the project as "feasibility", the product and customer information.
  - The *Process Element* class to manage the information of this first task named requirement analysis.

Example from the industrial case study:
The project manager uses the model with classes, and attributes to organise projects. In this phase of "requirement analysis" he receives the customer need attached as a *Resource* for the analysis. From this analysis he notices that the project is a large project, the objective is to manufacture partition panels for trains. As a constraint, the production rate is fixed to two panels per week and without real technical problems (this sort of panel is often produced by the company). The performance indicators are the time to make this analysis and the level of accuracy of this analysis.

Instantiated object from class *Design Process*:
    Name = feasibility
    Product = partition panels
    Customer = Company A
    Objective = manufacture partition panels for trains
    Constraint = production rate is fixed at to two panels per week
    Team = not defined yet
    TimeTable = 1 month for this phase
    PhaseProject = requirement analysis

Instantiated object from class *Process Element*:
    Name = customer need
    Objective = analysis of the customer need
    Constraint = the constraint link with the rail domain (i.e.: smoke and fire norms)
    Indicators = time and level of accuracy to make this analysis
    Context = the project manager
    DeadLine = 1 week
    StartDate = 01/09/06
    EndDate = 01/18/06
    Working time = 4 days

-    Project team definition: This action is carried out by the project manager from his previous analysis of the customer's needs. The project manager defines the roles needed by the project in order to associate the right team in accordance with the project and the internal constraints of the company: workload, skills, timetable, deadlines…

• The attribute <u>team</u> in *Design Process* is used to manage the necessary roles of the project. The project manager defines the roles needed for the project (from the previous analysis).
• The model stores the information on each actor: his department, function, skills and workload with the classes: *Organisation*, *Department*, *Function*, *Human Resources*.

Example from the industrial case study:
From the analysis of the previews example, and for the first phase "quotation" the project manager notices that roles needed are a Marketing Department member to keep contact with the customer during this phase, an engineer with experience in this product, a technician to assist the engineer in his study and a Quality Department Member to respect the Quality requirements included in the customer's needs. From the information included in the *Human* and *Organisation* classes the project manager can find the right actor for each role. The Marketing Department <u>members</u> are available because the <u>workload</u> is not onerous for these roles in this project. Nevertheless, the only engineer who has the right experience has an onerous <u>workload</u>, thus the project manager decides to designate two technicians instead of one in order to decrease the workload for the engineer on this project.

Instantiated object from class *Organisation*:
    Name = Ederena Concept

Instantiated object from class *Department:*
   Name = Technical Department
   Objective = carry out the quotation

Instantiated object from class *Department:*
   Name = Marketing Department
   Objective = keep contact with the customer

Instantiated object from class *Function:*
   Name = Engineer
Instantiated object from class *Human Resources:*
   Name = Fred
   Skill = Rail specialist, designer, operator
   Workload = onerous

Instantiated object from class *Function:*
   Name = Engineer
Instantiated object from class *Human Resources:*
   Name = Filipe
   Skill = Project manager
   Workload = Medium

Instantiated object from class *Function:*
   Name = Marketing person
Instantiated object from class *Human Resources:*
   Name = Patrick
   Skill = Marketing
   Workload = onerous

Instantiated object from class *Design Process*:
Team = project manager, 1 engineer specialised in rail field and a Quality Department member

- Project plan definition: In this action the project manager defines the schedule by describing the phases of the project and the tasks included in each phase. Thus the classes *Design Process, Process Element, Milestone, Task and Resources* are used by the project manager to carry out this action.
  • *Design Process* class is used by the Project Manager to manage all the information on the project.

- *Process Element, Milestone, Task* classes manage the tasks and the milestones of each phase of the project with the associated resources

Example from the industrial case study:
The project manager defines all the phases of the project: "quotation", "design", and "manufacturing". For each phase he defines the *Tasks* involved. He defines the design phase "quotation" as activated, and specifies the product designation, the customer name, the deadline for the phase set at two weeks. All this information is included in the *Design Process* class. He also defines a *Milestone* two weeks later in order to validate the phase by validating the quotation made. This first process element of this phase is a task that analyses customer needs by the team in order to define the technical specification. The input data which is the customer needs is attached to this task by the class *Resource*. The project manager specifies all the information of the technical specification. The input data are the customer needs and is attached to this task using the class *Resource*. The project manager specifies all the information of the classes *Process Element* and *Task* where the objective is to define a technical specification, with a deadline of 1 week, the context of the task, and the indicators of performance (in this case the time to finish the task and the degree of accuracy of the definition). The second week is allocated for the second task, namely the definition of a marketing offer by the Marketing Department member based on the technical specification done previously. The project manager continues the definition of the other phases and tasks.

Instantiated object from class *Milestone:*
    Decision = validated quotation
    Justification = All the participates validate the quotation

Instantiated object from class *Task:*
    Name = Quotation

Instantiated object from class *Resources:*
    Type = Time, financial, person, material
    Associated document = Customer's needs

Instantiated object from class *Trigger:*
    Type = Manual
    Content = Comments

- Control progress of the project: the project manager follows the project and verifies the achievement of tasks and milestones. The main goal is to verify that the resources of the design activity (i.e.: actors) have carried out their tasks, fulfilled the deliverables, and indicators of performance.

- • The project manager recovers the deliverables stored in the *Resource* class and compares results and <u>indicators of performance</u> with the <u>objectives</u> predefined in the class *Process Element* in order to control the progress of the project.
- • Consequently to this control, the project manager takes decisions before defining <u>corrective actions</u>.

<u>Example from the industrial case study:</u>

At the end of the first week focused on the completion of the technical definition, the objectives are not completed because the engineer was not able to supply a price and lead-time for special material like aluminium and stainless steel (because the world economic situation on these materials tends to fluctuate greatly). Thus, the project manager defines corrective actions and new task and milestones. He plans a new task for the Marketing Department member in order to explain the situation to the customer and find a solution. The customer, usually a large company, may agree to order the raw materials in order to achieve better prices with his influence and network of contacts. In these conditions the project manager defines a new project plan with tasks and milestones.

All these examples from the industrial case study show how this model of coordination is used in the company. These examples represent the detailed interactions between the concepts summarised in the model of coordination and the practical actions of the project manager with the managed information.

4.2.4 Conclusion

In this section 4.2, a model of coordination focused on the project managers' view is presented with class diagrams. The objective of such a model is to group all the fundamental notions about coordination in order to help project managers in their work. The model is divided in three main parts to manage three groups of information: organisation & information: organisation and human information, process information and technical information. This model is based on the literature study and on the industrial case study in Ederena. Finally the use of the model of coordination by project managers was explained with practical examples from the industrial case study.

In Ederena, this model of coordination is used by the project manager in order to recall the main concepts in coordinating projects. Moreover, based on this model the project manager has elaborated personal documents with practical hints in order to summarise his way of project coordination with these concepts. These personal documents are elaborated by the project manager for himself in order to formalise his own project management approach.

4.3 Analysis of design collaboration

The coordination of design also deals with the identification of the main relevant elements for the characterisation of collaborative situations in design. Collaborative situations in design are defined, from a coordination point of view, with scheduling, formalisation, with the definition of milestones and activities. Alternatively, they can be defined from a human relationship point of view with the persons who are involved in the collaborative event, with their skills, their motivation, and their form of communication. In fact both these two points of view must be taken into account in several collaborative criteria to define collaborative events such as: do actors work in the same place or not? In synchronous or asynchronous mode? Do they use predefined tasks? And so on. All these factors must be included in a model which supports the analysis of collaborative situations that occur in projects. The UML formalism is used to describe the model of collaboration in design activities and this leads to its instrumentation and its implementation. From now, the word "analyst" will be used to refer to a role. This role could be held by at least three types of persons: project managers, researchers or consultants. In Ederena, the analysis was carried out by the researcher in close relation with the project manager.

4.3.1 From design coordination to design collaboration analysis

A model of coordination has been defined in order to help project managers in their coordination work of projects, processes and actors. Nevertheless, within the framework of industrial experience in design such as the European project IPPOP [Nowak, et al. 2004], the results of the GRAI engineering method [Girard and Doumeingts 2004a], and experiments in PLM implementation in SMEs [Pol, et al. 2005a] it is noticed that the use of such models is difficult for the project manager and especially for anticipating the impact of collaborative actions.

Moreover project managers can use their own industrial experiences in design, but only if they have already work for a long time as project managers in order to be able to characterise each kind of parameter mentioned in the model. However most of the proposed models propose to record a lot of information over the long term in order to re-use this

information and thus compensate for the lack of user's experience [Merlo 2003]. Therefore, project managers with a low level of experience, without "automatic reflex", and know-how can search similar design situations and re-use the "good practices" used previously. These "good practices" are only known by experienced project managers because the models do not identify "good practices". Thus, from this thesis, "young" project managers may be helped by using models (like these models of coordination and collaboration) and by being given extra tools to analyse the design situation.

The following Figure 30 shows the link between coordination and collaboration in the context of design activities. Actors during design activities use input information (such as: customer's needs, requirements, constraints…) and provide outputs at the end of the activity (such as: product description, drawing, manufacturing and usage instruction…). The actors use various forms of collaboration to transform input into output in design activity. The form of collaboration used can be controlled by specific guidelines defined by the project manager.
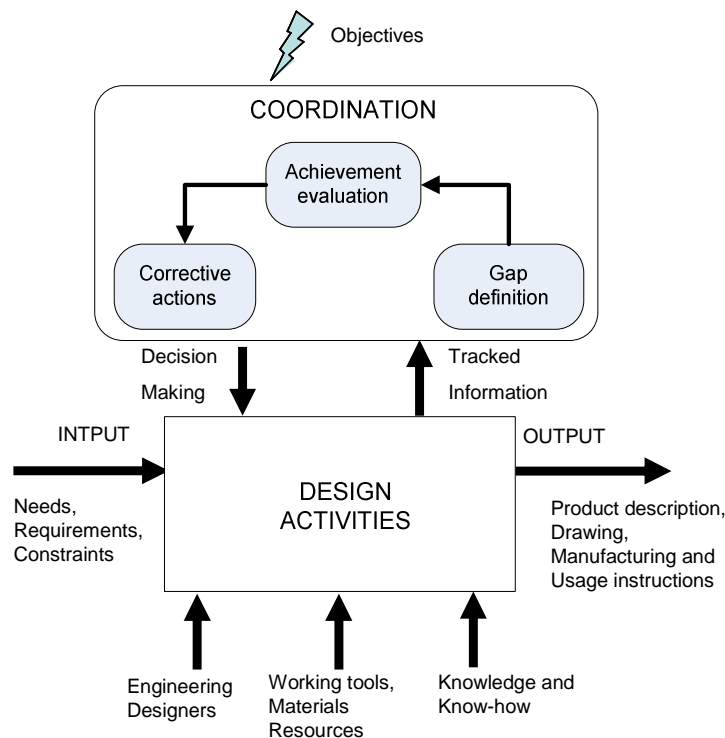
Figure 30: Description of coordination in design projects

In Ederena, it has been noticed that the model of coordination appears to be an accurate reflection of the actual practice. The elements well represented in the model and managed instinctively by the project manager are:

- In a context where project managers understand the organisational structure of the company, the definition of a project team based on information such as: workload, skills, know-how…
- The definition of the project structure with sub-projects, tasks and milestones. The detailed definition of the responsibilities, objectives, schedule, and their control.
- The customer's needs definition based on his experience. Nevertheless it is well known that project managers without experience or involved in large and complex projects often need to be assisted by specialists.

However, proposing a detailed definition of the elements to be included in the model of coordination is not the only necessary step towards a successful management of design projects. Many types of problems remain: delay, quotation mistakes, technical errors on the feasibility of a proposed solution, extra iterations in the design process… The causes of these problems come from the lack of experience and knowledge of project managers. The main question is how to define all these parameters. Some problems may concern: the management of the actors' skills (where the project team is defined according to the workload), problem of exchange or formalisation of the information (communication), it was not well defined who must contact the customer (form of collaboration), when a specification element that changes the entire design process is restarted (flexibility in design processes)…
All these problems are developed in the following points:

- Skills management: The definition of the project team is based on the skills and on the workload of the actors and not on the roles needed in the project. The first criteria of the project manager is the availability of the actors, while the logical way would be to first define the role needed for the project and secondly to find the actor for each role. Thus often the project manager allocates actors to the team who have only part of the skills needed for the project without adding other actors to compensate for this lack.
- Coordination rules: direct supervision, mutual agreement or normalisation [Mintzberg 1990]. It is difficult for the project manager to know which rule of coordination is adequate for each design situation according to the actors involved (e.g. individual, relationships, or workload), objectives (e.g. lead-time, cost, or quality), previous and similar situations...
- Kind of communication between designers: distribution, collection, circulation, exchange [Bareigts 2002]. The project manager has to define communication between actors during projects. He has to know which form of communication is adequate for

each activity. For example, when the project manager plans a meeting he has to encourage the exchanges between actors. In another activity, an email can be sufficient to inform the project team. For the validation of a document, he can define a process of validation in order to have a circulation of the document to validate it.

- Preferred form of collaboration: free, encouraged or forced, synchronous or asynchronous, present or distant, formal or informal. According to the situations and to the actors, the project manager has to define the form of collaboration between them. For example, this predefined form of collaboration can be free, encouraged or forced; if the project manager imposes two actors to collaborate then the form of collaboration is forced. The project manager can also encourage the collaboration between two actors by grouping them in the same team for example. And finally, the form of collaboration can be free if the project manager doesn't give any advice or order. The same reasoning can be made with the other criteria of the collaboration form (synchronous/asynchronous, present/distant, and formal/informal).

- Flexibility in the design processes: During the definition of the project plan, the project manager defines processes to validate documents or to reach objectives. During this definition various problems may occur. The processes must be fixed in advance in order to schedule the work but it is essential to keep enough flexibility in order to be reactive in the face of the unpredictable nature of the project. Since everything cannot be predictable, it is difficult to determine in advance which process will be the best. Thus the borderline between planned and flexible processes is extremely narrow for project managers.

- Design control: In the phase of control by the project manager, he has difficulties in evaluating the gap between the objectives and the results because he is not the only actor to work on the project; he has generally only technical documents to follow the progress of the project. Consequently, the difficulty for him is to act in the right way by defining corrective actions.

From this investigation in Ederena many problems remain for project managers. Project managers need tools; not only a model for coordination but all devices which could reduce the impact of these difficulties. Moreover the causes of these difficulties to coordinate projects are influenced by human factors which are included in the concept of collaboration. Thus, the collaboration aspects must be managed and included in the management of projects. However, no formal rules or theory is available to train project managers in order to predefine certainly and effectively the collaboration aspects during projects. Then, it is necessary to study the collaboration empirically in order to identify good collaborative practices. A good collaborative practice is a group of collaborative actions that solves a design problem and satisfies indicators of performance regarding the objectives. Consequently, the problem becomes: how good collaborative practices can be identified to include collaboration aspects in coordination of projects? To identify these

good collaborative practices, the first step is to be able to analyse the collaborative practices. With this in view, a framework for the analysis of collaboration is necessary:

-   The analysis of collaboration allows the understanding of how actors collaborate in their work and helps project managers to build the project team by assigning roles to persons and by managing the actors' skills.
-   By analysing collaboration, the relationships between actors are studied. Therefore, it is easier for project managers to set up coordination rules, to determine the appropriate means of communication, to evaluate the game of power based on the personal interest of each actor and finally to solve the conflicts occurring between actors during projects.
-   The analysis of the collaboration will help the project manager to define a project schedule. Indeed, the completed task will be more detailed and project managers will be able to compare the defined schedule with the activities actually carried out in order to better evaluate the gap between objectives and results. The additional input of collaboration in project management also allows the management of less formal events such as informal meetings, discussions in a coffee break or phone calls …

Thus, the project manager can use this analysis of the collaboration in order to prescribe and manage the project. Consequently the phase of analysis is essential to allow the prescription in the management of projects, because collaboration with a high degree of human factor depends on the specific nature of the project, the customer, the company, the actors… and so, collaboration cannot be properly prescribed without analysis. As a consequence the next section will focus on the definition of a model to represent the main elements for the analysis of the collaboration in order to include collaboration aspects in the coordination of projects. This model of collaboration leads to the implementation of the CoCa tool to support the analysis of the collaboration.

4.3.2 Proposed model of collaboration

The aim of a model of collaboration is to record information on the actors' tasks in order to support the characterisation of the collaboration and finally to include collaboration aspects in the coordination of projects. Thus, the model of collaboration must clearly represent the right information on the actors' tasks in order to support the analysis.

In the previous model of coordination, various actions remain difficult for the project manager to coordinate projects namely:

-   The definition of the project team based on the skills, workload and roles of the project,
-   The definition of the form of collaboration with the form of communication and the coordination rules associated,

- The definition of the project schedule where the project manager has to define flexible processes,
- Project schedule control where the project manager encounters difficulties in estimating the gap between objectives and results.

Nevertheless, for each difficulty, a great deal of additional information related to the collaboration aspect is required to help the project manager in these particular actions. The design process must be recorded with additional information on collaboration. Firstly, the context of the project must be recorded in order to define the specific situation of collaborative activities with the team definition, the customer, the company, the product…
Secondly, the collaborative activities in the project must be recorded with sufficient detail in order to be able to identify significant elements during 'a posteriori' analysis. This will facilitate for example the evaluation of the results achieved in the design process or the definition of the required flexibility of a project schedule. And thirdly, recorded information allows the assessment of the collaboration in terms of performance in order to anticipate and propose new forms of collaboration in future design processes.

The actual design processes are studied in order to know what has to be stored in correlation with the coordination tasks of the project manager.
Thus in the action of project team definition, the record of the actors participating in the project with the management of their skills is useful information for the project manager. Indeed the project manager needs to know which actor has the right experience and skill before allocating this actor to the right role in the project team. Thus archiving the pairing of team / project, with additional information such as skills, roles, characteristics of the project, is necessary in this project team definition action.

> Example from the industrial case study:
> From the example used previously, the project manager defines the project team with someone from the Marketing Department, from the Quality Department, an engineer who has an onerous workload and two technicians. To select the engineer and the two technicians who have the right experience, project manager examines the archives to see the project teams in previous similar projects.

During the definition of processes and the control of the project schedule by the project manager two keys points emerge. Firstly the project manager must introduce flexibility in the design process in order to become reactive to the unpredictable nature of the design project. Secondly he must monitor the processes closely in order to evaluate the gap between what has been completed and what was planned. Thus, for these two reasons, the project manager must understand the real process completed in the project in order to compare it to the theoretical process previously fixed. He must also analyse the problems that occurred during activities with their possible impacts on other ones. Thus, the record of

activity sequences is essential to define the processes of design activities carried out and to evaluate the gap between what was predicted and results.

> Example from the industrial case study:
> The marketing department transmits to the Technical Department all information necessary in order to carry out a technical quotation. The principal problem lies in the fact that the marketing department does not have sufficient technical skill to collect all the technical information. Thus, the Technical Department had to rebuild the customer's file and to contact them again in order to collect the correct information and to carry out the technical quotation. During this scenario, the marketing department is in charge of an activity which it does not have adequate skills. The initial schedule is outdated because the collaborative aspects have not been studied and the schedule has been defined routinely. Thus, it is useful for the project manager to notice the succession of activities carried out, with collaborative aspects in order to anticipate future projects.

It was seen previously that various human factors concerning collaboration are not included in the coordination of projects. Thus the notion of collaborative criteria will help the evaluation of the collaboration by project managers. This evaluation of collaboration now becomes the main problem of the project managers in the coordination of projects. The project manager must assess the collaboration in order to estimate if its form is suitable and if not, to find a better form.

> Example from the industrial case study:
> This example is the continuation of the previous example with the marketing department in charge of the quotation. The type of collaboration implemented during this scenario is called "free" because only the final objective was known in advance: to carry out the technical quotation. The responsibilities and the interconnection between actors had not been formalised in advance. Thus, after the analysis of the collaboration used in this scenario based on "free collaboration", the project leader decides to change the form of collaboration to a "forced" collaboration with all the relationships and tasks prescribed.

The analyst needs criteria to assess the collaboration used in his project. Thus, he needs to record and manage any on-the-spot analysis or comments on the collaboration made during the project in order to:
-   Recall his reactions during the project,
-   Review all this information afterwards with a global view,
-   Compile data with other information (from other projects, for example).

The project manager has two solutions to manage projects in the right way. Either he already knows all the subtleties of the job thanks to his experience and know-how, or he uses guidelines resulting from a model to help him in his work of coordination. Thus the model must be as complete as possible and therefore include collaboration aspects, elements for analysis and other elements necessary for coordinating projects.

4.3.3 Model of Collaboration for analysis

The model of collaboration is built to represent collaborative situations which occur during design projects in small companies. This theoretical approach is based on the capture of information describing collaboration between designers. This information may be used by the project manager to improve the way he coordinates design processes and actors. This characterisation will be based on the definition of collaborative events of the project. All these events are associated with contexts in order to understand and analyse the collaboration: both the global context of the project and the local context of a collaborative situation. Moreover, the model incorporates different kind of parameters (see Chapter 3.2.6), by capturing, for example, quantitative data such as time, activity type or problem solving as well as qualitative data such as quality of communication or interests of actors. The definition of this model of collaboration is carried out in closed relationship with the company where the head of the technical department, project managers and the director are involved in the use and the validation of the model. Thus, they are fully concerned by this sort of study and they understand very well the potential benefits. So, the company saw the models and made constructive comments in order to orient the definition of the models towards an industrial application.

4.3.3.1   Event

Firstly the fundamental concept of an event is introduced: an event defines a collaborative action which contributes to the progress of the project, this action can be of any type. As a consequence, tasks or milestones in the coordination model can be defined as events. The main interest of an event is to allow the definition of non-scheduled actions such as a discussion during coffee break or an important phone call.

Consequently, the first class defined in the model of collaboration is the *Event* class. This class characterises each collaborative event whether formal or informal at a detailed level of description (Figure 31).

The first level of description of an event is characterised by its activity type (such as report, schedule, validation, milestone, co-design…) and its subjects (such as meeting, discussion, videoconference, conflict resolution…) through the *ActivitySubject* class.
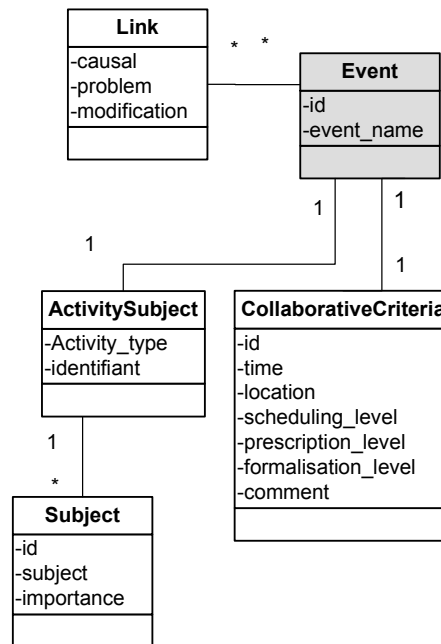
Figure 31: Class diagram of the event

When analysing events it is useful to detect problems or "good practices". As a consequence the class *Link* is proposed to group events in a non-sequential way according to specific points of view: not only a temporal mode, but also "causal links" or "problem links".

For example, non-formalised data could lead to time loss in later tasks: in order to collect this information, two events can be linked to show that one event will have a problem which originates in the other event; this function is named "Link Problem". Moreover, links between events can be also used to show that one event is the cause of another one. This is managed by the attribute Causal. Events stored may be scheduled tasks as well as un-scheduled events in order to identify formalised procedures but also real task sequences at a more detailed level. This information is generally useful to identify shortcuts or alternatives in the traditional process, then to analyse the parameters leading to these situations.

4.3.3.2 Context

The characterisation of events occurring in the project is strongly dependent on the specific context of the event. This context is defined on a global level and local level. The global level defines the context of the project in the company with elements such as: customer's name, product, project leader, project team… The local level defines the context of the event with elements such as: actors participating in the event, their expectation, outcomes, decisions made…

- Global context (Figure 32)

The *ContextProject, Customer* and *Project* classes allow the definition of the main information to situate the actor's tasks in the global design project of the company, mainly the attributes: <u>project_name</u> and customer's <u>name</u>. The cardinalities allow there to be various projects for one customer.

Various dates are used to record the evolution of the global context. Thus, the class *Project* has a date of creation, a date of end and a date of creation of a new context (a new project context is created for each important modification occurring in the project). Moreover the attribute <u>active</u> stores the status of the project to show if the project is started, ended or dormant.

The class *ContextProject* is focused on the storage of the main information which evolves during the project. The attribute <u>project_impact</u> represents the impact of the project on the strategy of the company.

Each event of the project is linked to the corresponding context of the project through the attribute <u>event_list</u> in order to be able to analyse them with the right context.

The context of the project is in constant evolution during its progress. Thus, the attribute <u>version</u> manages the version of the project context, by recording, for each version, the main information of the project in order to understand its evolution. This information is included in the class *ContextProject*.

It is important to know who is involved in the project and which roles are assigned to an actor, thus the attribute <u>actor_roles</u> stores the roles of involved actors. Moreover, the link with the *Actor* class gives information on the actors involved in the project such as function, name, address, phone… This information is essential in the management of the actors and workload.
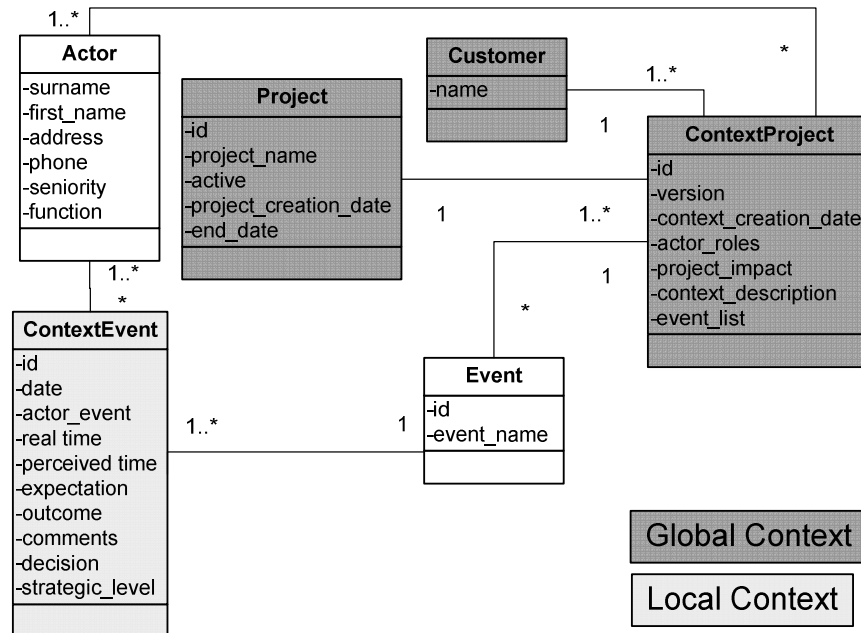
Figure 32: Class diagram of the global and local context.

- Local context (Figure 32)

The local context is composed of the class *Event* and *ContextEvent* with links to the *ContextProject* class and *Actor* class in order to define in detail the context of the event.

The context of the event is defined by a *date*, the *real time* (duration), *perceived time* by actor (which could be different from the real time), the *strategic level* of the event towards the project and the *actors* involved in the event. The *date* defines when the event occurs. The real time compared with the perceived time attribute shows if the actors have the feeling of wasting their time during the event or if they are productive. The strategic_level of the event represents the importance of this event in the project, in order to verify if the resources allocated for the event match up with its importance. The actor_event attribute stores the actors in charge of the event. These actors come from the list of actors available in the class *Actor*.

Moreover four attributes allow the comparison of the objectives of the event with the expectations of actors, and with the outcome produced: expectation, outcome, decision and comments. This comparison is useful for diagnosis of the project management during the evaluation of the gap between objectives and results. The quantity of result is evaluated by the attributes: outcome for the definition of the results and the resources of the event. Thus the project manager can evaluate the pertinence of the quantity fixed previously in the objectives. The decision and comments attributes give complementary information on the event and help to understand the progress of the event.

4.3.3.3 Characterisation of the collaboration

The characterisation of the collaboration is based on two types of criteria: quantitative and qualitative. Storing these criteria is carried out in the perspective of re-using this information to anticipate future design coordination.
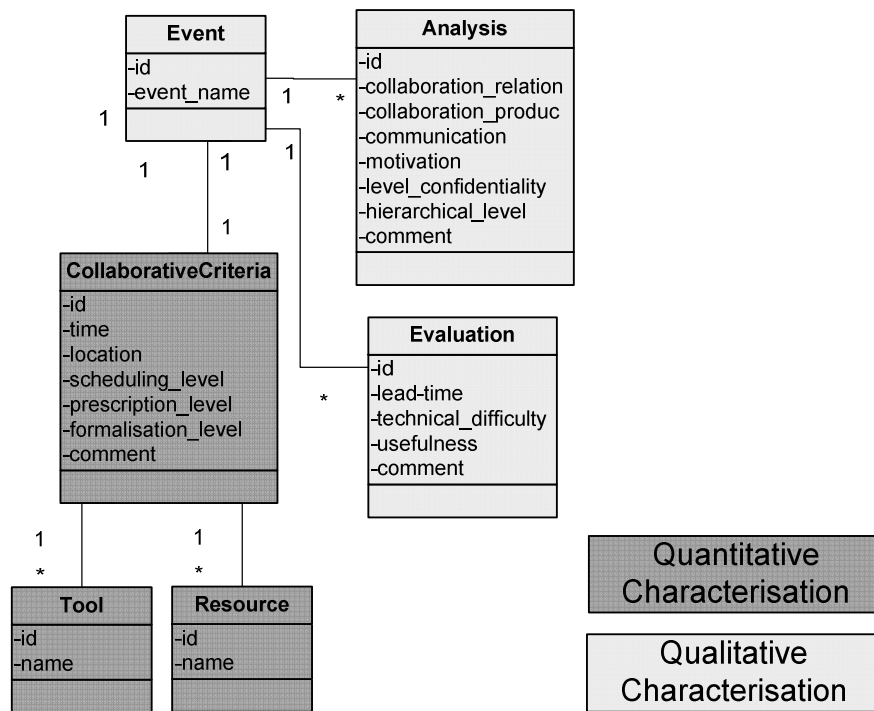
Figure 33: Characterisation of the collaboration

- Quantitative characterisation (Figure 33):

CollaborativeCriteria class characterises in a quantitative way the form of collaboration used in events by actors. These criteria are focused on the collaboration definition in order to differentiate the various forms of collaboration used during projects.

The attributes of the class are:
- Time: if actors work in a synchronous or asynchronous way
- Location: if actors work on the same location
- Schedule_level: if the event has been planned or emergent
- Prescription_level: if the event results from a prescription from the project manager or if actors were free to take the decision to collaborate
- Formalisation_level: if the actors' work during the event has been formalised
- Comments: allows addition of information on the collaboration occurring during the event.

Two other classes, *Tool* and *Resource* classes, store the specific tools and resources used by actors in their collaboration.

- Qualitative characterisation (Figure 33):

The collaboration is also characterised by qualitative criteria in order to help the analyst to evaluate the situation and introduce some on-the-spot analysis, evaluation and comments to prepare for future analysis through the A*nalysis* and *Evaluation* class.

In the *Evaluation* class, the project manager makes an on-the-spot evaluation of the collaboration. In this evaluation he estimates with the attribute technical_difficulty the difficulty of the event in reaching the expected objectives. The project manager evaluates the lead_time to know if it is urgent. Then, he evaluates the usefulness of the collaboration in the event. All these criteria of evaluation are made by the project manager from his own point of view.

In the *Analysis* class, the analyst makes a local analysis of the collaboration, on the spot, during the event. He estimates the productivity of the collaboration, i.e. if the results of the event are sufficient in relation to the stored situation with the attribute collaboration_produc (the label of this attribute is shorter because there is not enough space to write the full name with the software used).
The project manager estimates the motivation of the actors, if they have a same goal or personal interests in the work or are under pressure to finish (see Chapter 3.2.5)…
The forms of communication used between actors are quoted by the project manager to estimate if the communication used is productive or unproductive (see in the Chapter 3.2.4).
The attribute collaboration_relation is stored to know if the collaboration is more consensual or conflictive between actors.
The levels of confidentiality of the document achieved or the decisions taken are stored in the attribute level_confidentiality. The level could be "high" when only the heads of the company are informed, "medium" if only the project team is informed, and "low" if all the company is informed.
And finally to complete the local analysis the attribute hierarchical level is stored. In Ederena there are three levels: "high" when the two heads participated in the event, "medium" when there is only one, and "low" when no head was present at the event.

The local analysis and evaluation is used by the project manager to record his point of view during the project and help him for the future analysis of the collaboration.
A complete class diagram represents all aspects used in detail to describe a collaborative situation and understand the collaborative mechanisms in Figure 34.
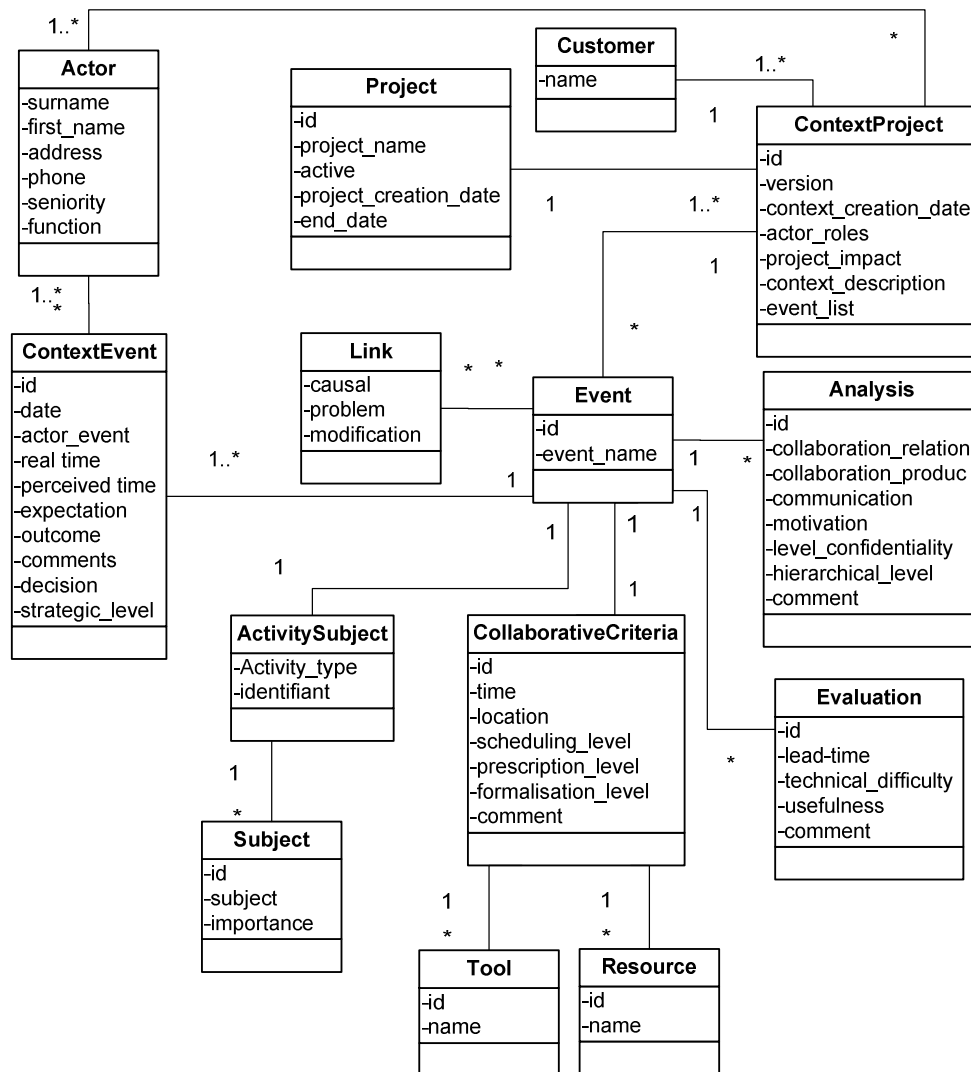
Figure 34: Conceptual model to characterise the collaboration

As we can see in the model of collaboration, various criteria of the classes *CollaborativeCriteria*, *Analysis* and *Evaluation* are not binary (black or white, true or false) but the real situation is situated between two extremes. The project manager, in his estimation, records a tendency of these criteria which could be more or less close to an extreme. For example, one actor has transmitted critical information to the other team members one day behind schedule. This delay leads to a global delay of one day for the whole project, which is not acceptable, but not a disaster according to the general lead-time. Afterwards, the project manager estimates the productivity of the communication used in

the event at 70% (100% is the percentage without delay and 0% when the information is not transmitted).

This global class diagram may be used as is by project managers but with some difficulties. These difficulties spring from the fact that no device supports the management of the concepts included in the model. As was noticed in the company, with the model, the project manager better understands the relation between the concepts described in the model. However, he does not have any tool or method to help him in the management of these concepts in his work of project management. Thus, this model of collaboration leads to the implementation of a tool in order to automate the recording, to re-use the data and support the analysis of the collaboration.

4.3.4 Collaboration model in use to analyse collaboration

The aim of the collaboration model is to support the analysis of the collaboration used by actors and to better understand design situations. It then helps the project manager to integrate the results of this analysis into his coordination actions in order to anticipate, coordinate and control the project. Nevertheless it is well known that such a model is not adequate for a daily use by a project manager. This kind of model is the first step of the approach leading to the implementation of a tool based on these models. At the end, the project manager will use the collaboration model through a tool in order to assist him in his daily work of analysis.

All these concepts included in the model are used by the analyst to drive his analysis of the collaboration. Currently, no method to carry out this analysis (in this context of SMEs and for the objective of improving the coordination) exists. So, there is no published method for analysing this sort of data. From Ederena, this experiment leads to the testing of various ways of analysing collaboration (Chapter 6).

The tool based on this model of collaboration must manage the analysis and evaluation, the collaborative criteria, the global and local context, and the links between events (Figure 35).

The approach to analyse collaboration begins with the study of the stored information of each event, especially the evaluation and analysis classes. The collaborative criteria and the global / local context then give additional information. At this stage the analysis is possible for establishing correlations between events. The links are used to represent the global sequence of design events occurring in the project from a specific point of view.
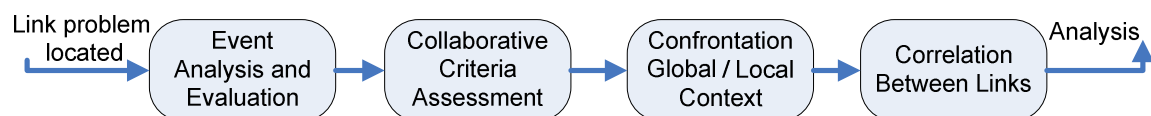
Figure 35: Approach to analyse the collaboration with the model of collaboration.

The main objective of this analysis is to identify problems / improvements / "good practices" in the design process in order to find adequate solutions. The complete analysis of the collaboration is not done by the tool; it makes available the main information to analyse the collaboration. Therefore the analyst has to study the sequence of events, make correlations between various attributes in order to carry out the analysis. This notion of correlation between attributes is illustrated in the two following examples:
- The notion of re-usability: if the project manager wants to re-use the collaborative process in similar situation. He has difficulties in identifying similar situations and defining the collaborative process used. Therefore, the classes *ContextEvent*, *ActivitySubject* and *Links* help the identification of similar design situations. And the classes *Tool*, *Resource*, *CollaborativeCriteria* help to define the collaborative processes needed for future scheduling during coordination phases.
- The notion of problem solving: during collaboration, it is usual to encounter problems, or conflicts. But these problems or conflicts could be positive for the progress of the project. Thus, the category "problem solving" helps the characterisation of the collaboration by defining if the problems (if there are any) were constructive or destructive. Hence, it is important to understand when a problem occurs: what the solution was, if the problem has led to the emergence of constructive knowledge, what the causes of the problem are… The classes *Link*, *Analysis* and *Evaluation* drive this "problem solving" assessment.

The analysis of the collaboration helps the project manager in the use of the model of collaboration and then coordination. Thus projects will be coordinated by taking into account collaboration aspects.
A deeper analysis with the tool and examples from the industrial case study will be given in the presentation of the results achieved in Ederena (Chapter 6).

4.4 Synthesis

Chapter 4 presents a model of coordination focused on the project managers' view to help them in their work of design coordination. The actions of the project managers in design coordination have been defined with the associated information. These definitions are the basis for the definition of the model of coordination. Afterwards, the model was presented with examples and uses. In conclusion a lack of human aspects management is noticed in this model of coordination.

Thus, this model of coordination is associated with a model of collaboration in order to evaluate the human aspects in design and to improve later on the management of collaboration between designers which lead to the improvement of this model of coordination. Then, the model of collaboration is provided to help project managers to analyse collaboration in order to identify good practices that will improve the way they coordinate projects by taking into account collaboration aspects. This model of collaboration categorises and defines the different forms of collaboration used during project with the objective of re-using them in future situations. This categorisation is made by the recording of the context, objectives of the project and events; and by criteria to represent the collaborative situations. This characterisation leads to the analysis of the form of collaboration used between actors in order to evaluate collaborative situations, to anticipate future design situations and then to improve coordination of projects.

Nevertheless, the model of collaboration formalises complex aspects and can be used by project managers but with difficulties (problems to record, to compare, and to analyse information required to use the model). Thus the model of collaboration requires a tool to support the use of this model.

The definition of these models was elaborated in collaboration with Ederena and was tested and used in projects. The feedback from the head of the company and the head of the technical department are positive: the models formalise the main concepts of collaboration and coordination used in their daily work, and help them not to forget any important concepts during the project.

At this stage, two models are defined to help project managers in design coordination then to store and analyse collaboration. The analysis of collaboration will be used to define guidelines for the project manager in order to take decisions in his coordination management (Figure 36). Therefore a software tool is necessary to support the analysis of the collaboration.

The UML formalism is suitable for the implementation of an IT tool to assist the project managers in the recording of the information of the collaboration model and to help them in their future analyses of collaboration. Thus, the implementation of an IT tool based on this model allows the collection of a large amount of data for the analysis.
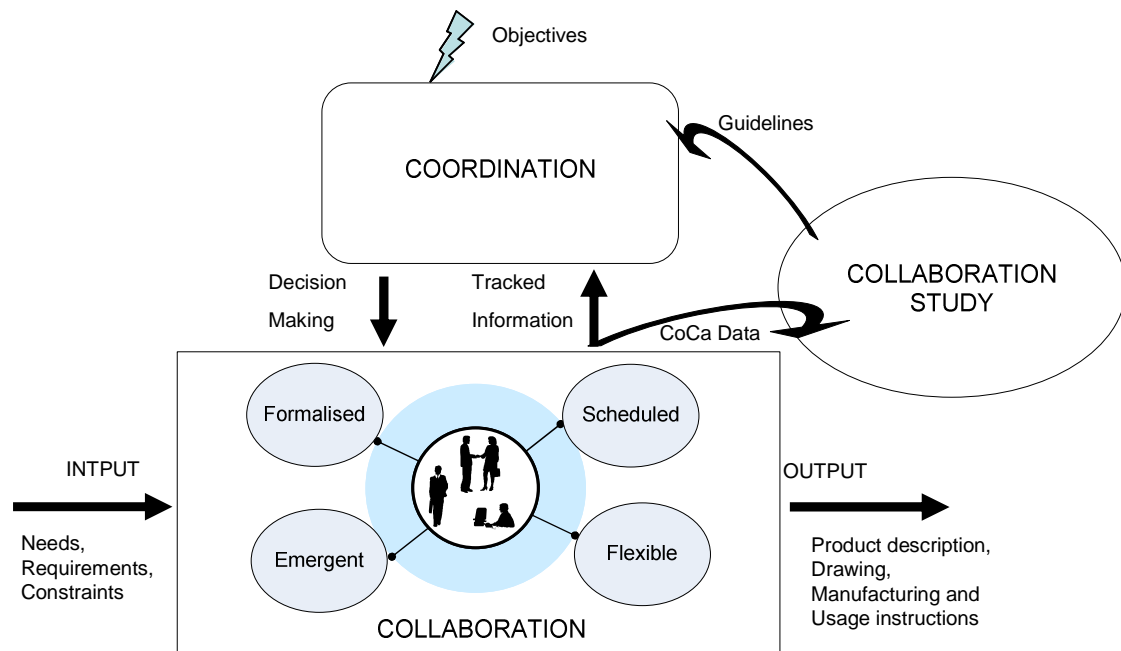
Figure 36: Coordination and collaboration in project management

UML models are useful to represent complex concepts such as coordination and collaboration in SMEs. At a conceptual level, coordination and collaboration aspects are based on complex mechanisms. These mechanisms and concepts need a specific methodological approach to be comprehended. Thus, the models are one of the possible specific methodological approaches. For example, the design events which occur in the design process (preliminary design, quotation, embodiment design…) are represented by the class *Event*, the links between them and the other associated classes like *ContextProject*, *ContextEvent*… This methodological aspect is presented through the implementation of the CoCa tool with its GUI forms, in Chapter 6 and in Chapter 7.

At an operational level, these models represent concepts and their links between them in order for a project manager to understand the consequences of his actions and to avoid neglecting important elements in his management of projects. One of extra benefits of these models is for young project leaders, with insufficient experience and know-how to manage these notions without support. Therefore young project managers could be given a sort of "check list" of the indispensable actions to carry out, a representation of the context of their management, and a better understanding of the consequences of their action. Thus, they would more quickly become experienced and more easily understand these notions of collaboration and coordination in their specific context. Furthermore, project managers have difficulties to use such models and the whole corresponding concepts directly during projects. Thus, the implementation of tools based on these models is helpful to facilitate the management of these concepts by the project manager. With such tools, the new project

manager has the possibility of capturing project information and decisions in order to improve his own skills, taking experience, improving the management of projects, defining standard processes, and helping to introduce flexibility in processes.

The notion of flexibility is important in design management in SMEs as was described in Chapter 3.2. Thus the introduction of flexibility in the design process is indispensable in order not to stifle the collaboration between actors. The strategy to manage this flexibility is helped by the model of coordination with a better understanding of the relation between the constraints, objectives, criteria and indicators on the design and by the model of collaboration which integrates the collaboration aspect into the management of projects.

In the next Chapter the implementation of the tool named CoCa, based on the model of collaboration, is presented. The implementation is described in detail from the approach to implementation of the tool, to the use of the tool. This presentation is illustrated by examples from the industrial case study.

5 "CoCa" tool: development and use in Ederena

The aim of the "CoCa" tool is to support the analysis of the collaboration occurring in design projects in SMEs. CoCa records the collaborative events in detail that occur in design projects by collecting such data as: projects, events, and collaborative criteria (time, location, tools, methods, level of formalisation …). These records provide the right data to the analyst, in order to analyse the collaboration and thus help the management of projects. This analysis enables design improvement by the identification of deficiencies in collaboration and in design events.

5.1 Introduction

The CoCa tool can be used by project managers, consultants or researchers.

Project managers can use CoCa to determine what form of collaboration produces appropriate results in projects and thus they can introduce flexibility in design processes in order to record and re-use improved forms of collaboration. Project managers need to have the perspective of a large pool of data to make the comparison between various projects and forms of collaboration. As we will see in the next Chapter "Results", the test of the tool within Ederena provides a representative pool of data, and these results can be correlated in order to validate the theoretical model and the tool.

It is well known by consultants that an implementation of an information system in a large company is completely different from one done in an SME. Indeed, in SMEs there are more design roles than actors available, thus actors have to accumulate roles. Moreover, each incoming project is managed differently according to the specific situation of a project, thus one part of the design process could be more important than another. Consequently SMEs need flexibility. If an implementation of an information system is done in an SME without a previous study of the actors' way of working, the company will lose flexibility in design processes, collaboration opportunities and emergence of innovation. Therefore consultants can use CoCa to specify the implementation of a PDM / PLM tool or an IT system in an SME. The main objective of this specification is to retain the necessary level of flexibility by studying the collaborative practices with CoCa.

Researchers can use CoCa in their industrial case studies in order to analyse the collaborative practices used by actors in design projects. The analysis of the collaboration can be useful in various fields as well as for a fine analysis of the collaboration or for an

organisational change of the company structure in order to match the organisation to the management of project with a specific IT system.

The validation of the tool and the theoretical model for researchers is achieved in the first instance by a case study of practice. However, for project managers and consultants other industrial case studies will have to be made in order to collect more results and to compare the analysis between projects.

This use of the tool is illustrated in the next Figure 37. Firstly, the analyst uses CoCa to record the information on the collaborative events occurring in projects. Secondly, the analyst uses CoCa to retrieve the information (recorded in a database) on the collaborative event to support his analysis of the collaboration. And lastly, this analysis of the collaboration leads to propositions, forecasts and expectations for the future projects and events in order to improve the coordination by defining guidelines for future events.
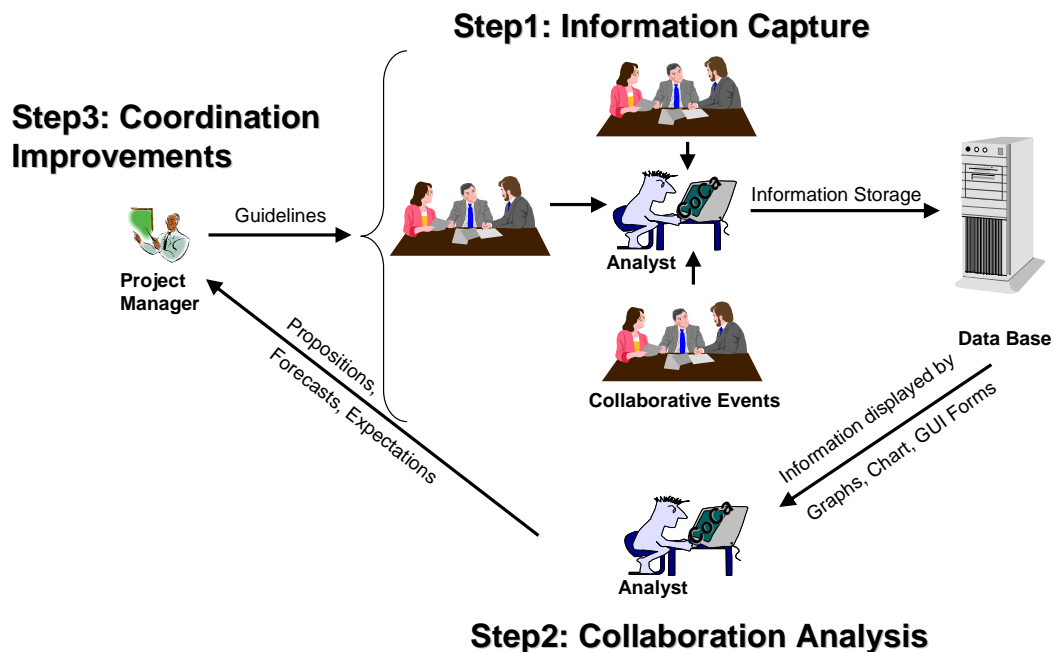
Figure 37: Use of the CoCa tool by the analyst

In the next section, the scientific approach used to develop the tool will be described to show how the tool was designed. Efforts were made to implement the tool on the basis of the theoretical work carried out in order to test and validate it. This description will explain how a theoretical model can lead to the implementation of a tool and why class diagrams must be created before the implementation.

5.2   Approach of the CoCa tool development

A tool has been developed named "CoCa" in order to support the model of collaboration presented in Chapter 4.

During the definition of the tool, UML is used to define the specification of the CoCa tool [Booch, et al. 1999]. UML is chosen because it provides an efficient language for modelling the architecture of the tool before its implementation. UML is an object oriented language, thus it provides a set of diagrams where objects can be defined and structured. These UML diagrams allow for the modelling of the entire system. Moreover, the UML structured notation is a generic formalism and is used as a common language providing a shared point of view between users and IT implementers.

The approach to the development of the tool is divided into three main steps: analysis step, design step then the IT implementation (see Figure 38).
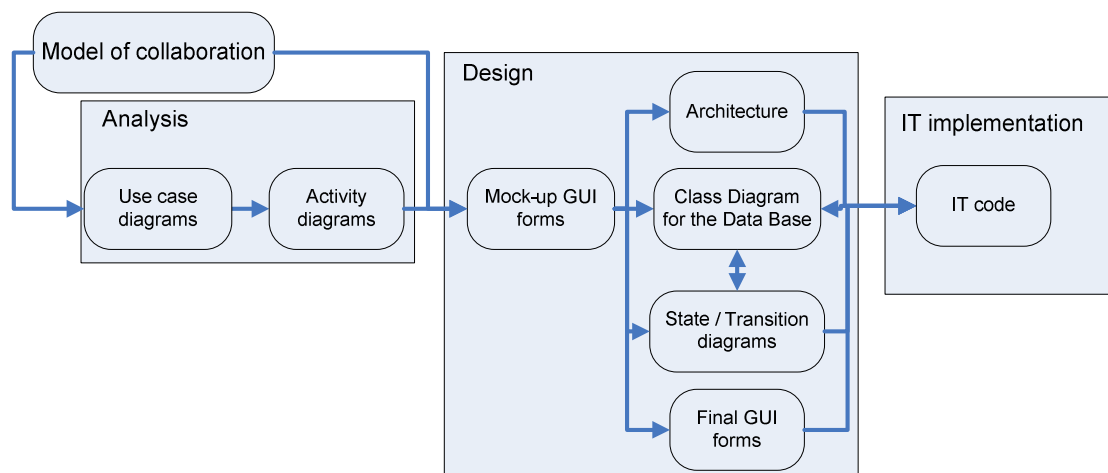
Figure 38: Approach of the CoCa tool implementation

Analysis step: is orientated toward the definition of the CoCa tool specifications. UML formalisms are used to specify the functionalities of the CoCa tool with:

- "Use case" diagrams describe the main and the sub-functions of the CoCa tool in order to define the objectives, the use and the constraints of the tool.
- "Activity" diagrams define the sequence of the forms and the action which causes the activation or the closure of GUI forms.

Design step: this step is concerned with the detailed definition of the tool with a functional study; the tool is implemented using Java technology.

- This step begins with a brief definition of the GUI forms as a "prototype" in order to gain an idea of the sequence of these GUI forms and the information included in each one. However, the detailed definition of the GUI forms will be given at the end of the design step; when all the necessary information has been defined as well at the level of the architecture as at the level of the state transition diagram.
- This design step defines the architecture of the tool in order to have the possibility of using the tool throughout a network and of choosing the software to manage the database and of supporting the IT implementation.
- Next, the GUI forms of the tool are defined in detail with the position of each button, colour, label, interface device. The definition of the GUI form is created with the UML formalism and leads to the definition of a class diagram for the IT implementation. Then a specific tool called NetBean is used to implement it.
- Another detailed class diagram is defined to represent the classes focused on the definition of the database with attributes, functions and links.
- In this step, a state / transition diagram is needed to describe the time-dependent behaviour of the system. Indeed, this diagram is an introductory picture to define the main states of a project (In Progress, Ended, and Dormant) and the transitions between these states.

IT implementation: this step aims to define the database, the class diagrams for the IT code and the IT code.

- The database definition is supported by the previous conceptual model of collaboration (Figure 34) and by the detailed entity / relation diagram of the data model (Appendix A, Figure 81). These two diagrams lead to the detailed definition of tables and the data stored within the database.
- Following that, another detailed class diagram is defined to group the IT classes, database classes, and GUI classes into the same class diagram in order to support the IT implementation (Appendix A, Figure 82).
- Finally, the IT code links the database and the GUI forms in Java language.

The description of this IT implementation step is not scientifically relevant because it is "traditional" IT work. Thus, this step will not be described in the thesis. Nevertheless, some elements are presented in the Appendix A in order to show an overview of the work completed in this step.

5.3 Design and implementation of CoCa

This section describes the main steps of the approach for the development of CoCa (analysis and design) with their sub steps.

5.3.1 Analysis: specification of the tool

The definition of the tool specification began with the definition of the main functionalities and constraints (Figure 39). The main objective of CoCa is to help the analysis of the collaboration in design projects by storing a large pool of data on collaboration and make it available to the analyst. Thus, the implementation of the model of collaboration needs to track the collaborative events occurring in many design projects with their contexts and collaborative criteria. This is the main function (Fm: Function$_{Main}$) of the tool: "Track the collaborative events". The achievement of this main function is achieved by primary functions (Figure 39).

The analysis of the collaboration requires the storage of information about the global context associated to the collaborative events: i.e. store the context of the project, the actors involved in and the events themselves.

Thus, the first primary function (F1) manages the data about the global context (i.e. the projects) in order to add, delete, modify or visualise the data items of a specific project context. This description of the project context is essential to understand the behaviour of project during the analysis of the collaboration. Moreover, this management of project context includes the management of the versions of a project, indeed when a modification is made to the context of a project the user may save the project as a new version in order to record the evolution of this project's context.

The information about the local context and about characterisation of the collaboration is managed by the second primary function (F2). This management of an event allows addition, deletion, modification and visualisation of data on the context of the event, but also description of the event with collaborative criteria, and with local analysis and evaluation on the form of collaboration used during this event. The local analysis and evaluation of the collaboration supports the later detailed analysis carried out by the analyst. For the first version it was not planned to manage versions of events. Indeed, in the first version of CoCa, only the versioning of the project context is supported. Thus, if a modification made to the information of an event is recorded, the old information is not kept. The analyst can modify any information on events but CoCa will not keep a history of modifications. With hindsight, perhaps in a second version of the tool, the management of versions of events should be implemented.

Moreover a function to manage "links" between events is implemented. This function will show if two events are linked by causality (if an event is the cause of the creation of another

one) or by a problem link (if a problem occurring in an event has an impact on another one).

The last primary function (F3) manages the actors involved in projects and events. This function will be used to add and delete actors in projects and in events, and also to store the information on actors such as: name, roles, seniority… This link between events or projects and actors is very important for a future analysis in order to understand the responsibilities of each actor in each event.

All these primary functions are represented in a "use case" diagram (Figure 39) which is used in the elaboration of the specification of the tool with UML formalism. Another detailed activity diagram defines the GUI forms used by the user to have an access to these functionalities (Appendix B).
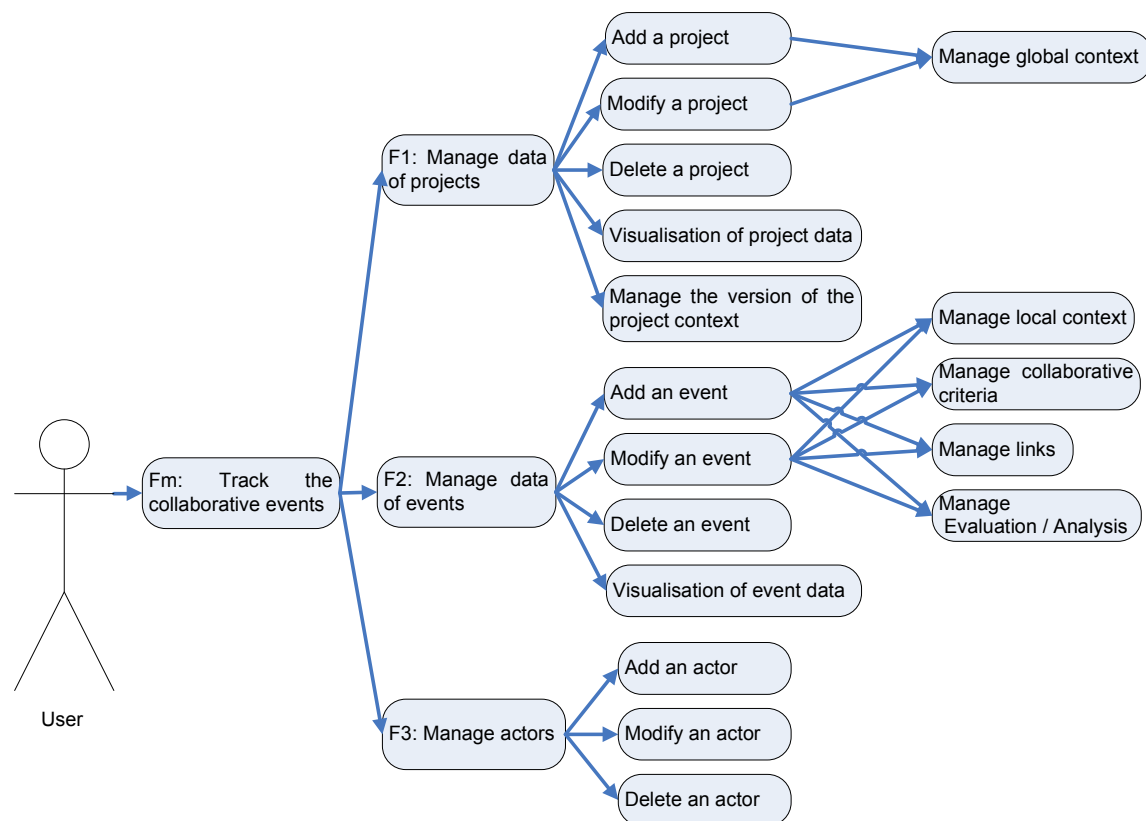
Figure 39: Use case diagram of the tool "CoCa"

This use case diagram (see Figure 39) shows a representation of the main functions of the tool, now the next step is to define the main forms and the sequence of these forms associated with each function. The sequence of these forms is represented in an activity

diagram (see Figure 40) in order to define the number of forms to be implemented, the links between them, and to verify that all functions are supported by the tool.

Firstly, the user has to login to the tool in order to manage the possible use of the tool according to the level of access rights given to him. Afterwards, a list of projects is provided, where it is possible to add a new project, to delete or to open an existing one. When the user is in the "project display" form, he can view all the information about one project, the list of events, manage actors involved, manage the version history and add an event to the project.

In the "event display" form, all data concerning the event is shown such as collaborative criteria, type and subject of the collaborative event. The user can manage actors involved in the event; add links between two events, and make a local analysis and evaluation of the collaboration used.
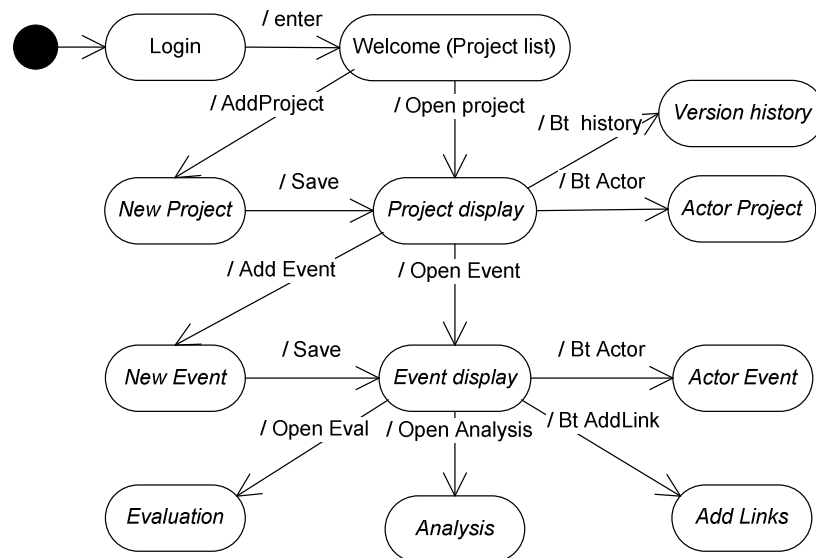
Figure 40: Activity diagram

Thus, the specifications of the tool with use case diagram (Figure 39) and activity diagram (Figure 40) result in the design and the implementation of the tool.

5.3.2 Design of the tool

On the one hand, this part deals with the design of the tool with "state transition" diagrams and definition of the architecture of the tool. On the other hand the three parts of the architecture are defined and implemented: the database, the GUI forms and the IT implementation.

5.3.2.1 Definition of the tool architecture

As has been seen with the functionalities of the tool, CoCa is not simply a data recorder tool or a project management tool. The main function of the tool is to help the analysis of the collaboration in design projects, to help the definition of the project management guidelines but CoCa is not a project management tool. Moreover it is not simply a data recorder, because the tool stores the data in a specific way (as could be seen from the class diagram of the database) and is orientated toward the visualisation of the data collected to lead to the analysis of the collaboration.

Consequently the architecture of the tool is composed of three parts: the **GUI forms** to collect and visualise data, the **database** to store the data and the **IT code** to link the database and the GUI forms (Figure 41).

Two possible architectures could be used to define the software: "one third" or "two thirds" architecture. The "one third" architecture integrates these three parts (GUI forms, database and IT code) in the same software and computer as a stand alone software. And the "two thirds" architecture has the database separated from the two other parts. The database is installed in an independent server. Thus, all the client computers (where the GUI forms and the IT code are installed) communicate with the server to record and get the information back. This is the traditional relation between "client / server" software.

The first version of CoCa tool is in "one third" architecture where the three parts are installed in the same computer and only one analyst uses the CoCa tool. However it is possible, for a next version of CoCa, to have a "two thirds" architecture by installing the database on an external server in order to have various analysts using a CoCa client software. All the CoCa client software will be connected to the same database in order to manage multi-user analysis of collaboration.

Figure 41 shows the link between the three parts of the tool.
- The database can be opened throughout the network where the address of the location of the database is stored in a text file named config.txt. The first implementation of CoCa is able to evolve towards a future version of CoCa as a "two thirds" architecture. Thus, the database of this future version will be based on a server, and every client version of CoCa installed on each analyst's computer will be able to communicate with the same database by using the information stored in the

text file. Moreover the database is stored in the freeware FireBird [Firebird 2006] and managed by IB Manager. As for the database management, the whole implementation of CoCa is completely done with freeware. Thus, CoCa may be installed anywhere, without the necessity of buying anything.

\- The GUI forms have been drawn up with the freeware NetBean V4.0 and are the interfaces between the users and the tool to record data or visualise data recorded.

\- The IT code is implemented in Java V1.5 language and leads to the processing of the data by linking the database to the GUI forms.
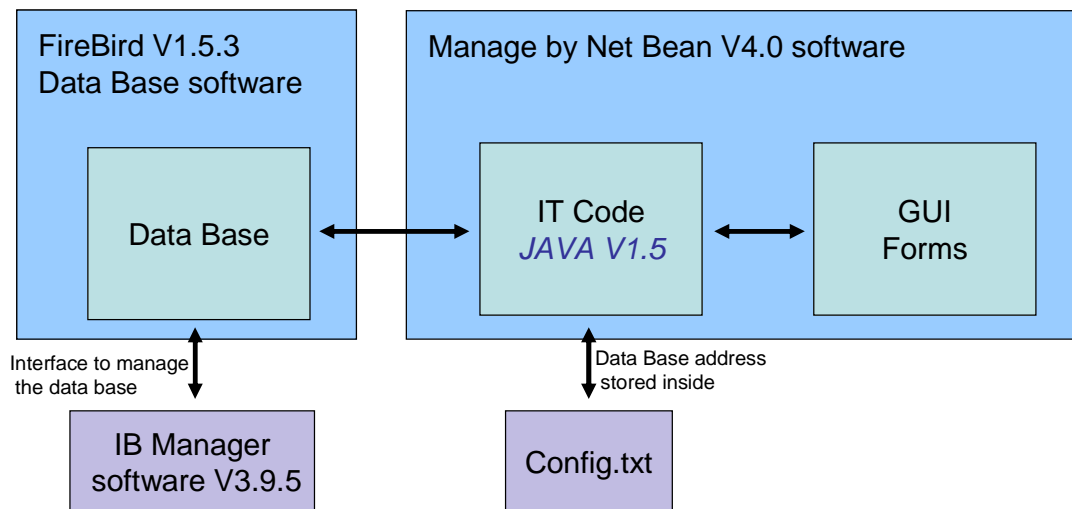
Figure 41: The architecture of CoCa tool

In this section, the definition of the architecture of CoCa with its three parts (GUI forms, database and IT code) has been presented. The definition of the GUI forms will be explained in the following section. The definition of the database is detailed in the section 5.3. The IT code in Java language is too long. This code is mainly focused on the management of recorded information and visualisation. Thus it is not presented in the study.

5.3.2.2 Definition of the GUI forms of the tool

The GUI forms have been designed and implemented in collaboration with IT engineers and ergonomists. These forms organise and display the information defined in the model of collaboration to be recorded by the tool. The three main parts of the model constitute also the three categories of main GUI forms: projects, project context, events. The forms are as follows:

\- Login form: The login step is very important to control the access rights of users. In the CoCa tool three levels of rights exist: user, project leader, and analyst. A list of

permissions is associated with each level of rights. This list of rights with associated permissions is described in the Appendix C. In summary, project managers, who have extended rights concerning their own projects; designers, with restricted rights to public elements of an event (i.e. no access to analysis elements); and finally analysts, with all rights on all projects.

-    Projects form (Figure 42): The first form after the login action lists each project stored in the tool with its version and its status (started, ended, dormant). Thus, the user opens "add", or "delete" project with this form according to his rights (only the project manager can delete a project). The "visualisation" button will be available in a future version of the tool to access to a form to manage data and advanced searches.
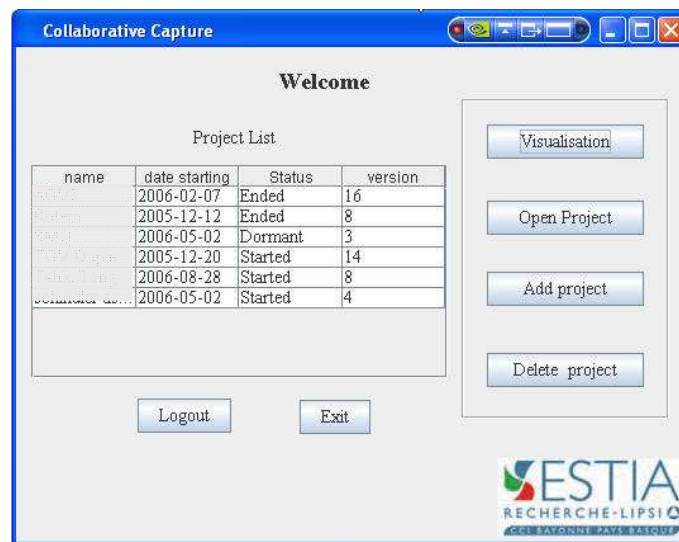
Figure 42: Projects form

-    Project context form (Figure 43): By clicking on "open project button" or by double clicking on the project name, the user opens the global context of the project. This GUI form of the project context shows various items of information which define the project: the name and customer, the starting date, who the project leader is, if the project has a small or big impact on the company's strategy, who the actors involved in the project are, the state of the project (ended, dormant, in progress) and a text field to complete the description of the project in a few sentences. The number of the version of the project context and its date of creation is recorded and shown in this GUI form. Moreover a "history" button shows and manages these versions. The user also has the possibility to add a new version when he saves the project context. The second part of the GUI form is used for the event presentation with a detailed list of the events included in the project with two buttons: "history all events" which

displays all the events of the project and the "list of event" which displays only the events of the last project context.

Figure 43: Project context form with the list of events

- Events form (Figure 44): In this form the local context is recorded and displayed, i.e. all the official or unofficial events which occur in the project. Various parameters are used to describe the event: the date, the name the strategic level of the project. But also the real time taken by the event and the perceived time[3]. The actors involved in the event are also tracked and managed; and three text fields are used to explain the

---

[3] Perceived time is a criteria used to evaluate the time perceived by the actors, which can be longer or shorter than real time depending on the interest of actors in achieving an event. Thus, perceived time can be compared with the real time during the analysis of the collaboration.

expectations, the outcome and the decisions taken during this event. All this information describes the local context and is intended to help in the future analysis by understanding the design situation.

Figure 44: Event context form

Three other tabs record extra data on a collaborative event of the project such as the type of activity occurring during the event, or evaluation of the form of collaboration used or to make an evaluation or an analysis of the collaboration on the spot. This evaluation or analysis on the spot is used by the analyst to record extra information to assess the form of collaboration used in each event. All these tabs are mainly used to analyse the collaboration. These analyses and evaluations on the spot are fulfiled by the analyst during the event in order to record his first thoughts about the collaboration of the event. In a

second step, these evaluations and analyses will be used and correlated with other evaluations and analyses from other events by the analyst to support the detailed analysis of the collaboration. They will be presented in detail in a later section 5.4 with examples from Ederena.

5.3.2.3   State / transition diagram

An illustration of "state /transition" diagram (Figure 45) is also presented in the particular case of the project.
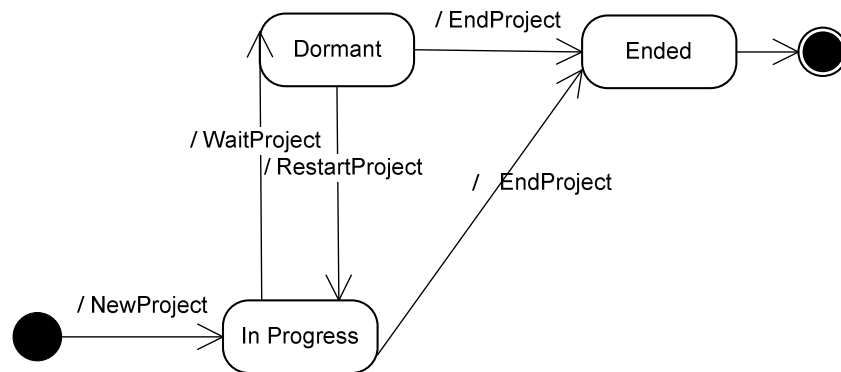
Figure 45: State / Transition diagram for the project

In CoCa, a project can be "in progress" when the actors are working on it and when it is active. However the project can also be "dormant" if it is in standby. For example if the project team is waiting for an answer from the customer after an offer, then the project is dormant until the customer answers. The project can also be "ended" if the product is delivered and if the customer has paid.
These three states are managed in the tool to contribute to the definition of the global context of the project.

5.4   Main functionalities of CoCa used in Ederena

The previous section described the design and the implementation of CoCa. In this section all the main functionalities of the tool are presented and examples are described from Ederena to show how the tool was used in an industrial context. The analysis of the data recorded will be seen in the next Chapter.

- Context of the project: This context ensures the capture of the global view of the project in order to facilitate the interpretation of the various collaborative practices occurring. Information about actors, customer, and any other data like the impact of the project in the strategy of the company, or any text field to refine the description of the context of the project are included.

The evaluation of collaborative events by the analyst depends on the context of the project. For this reason, this tool manages the versions of the project context in order to have a history of the modifications done on the project context and the event list during the project. For each version of the project context (see Figure 43) a comment field is filled in to give to the user the opportunity to explain why modifications have been made.

> Example from the industrial case study:
> Every Monday there is a global meeting to present the incoming projects and to review the projects in progress. Thus, during this meeting a selection of collaborative incoming projects is made to follow their progress with the CoCa tool. The project AGV7 is selected and is added in the tool by the GUI forms. This addition is done by the Project manager or analyst and begins by the definition of the context of the project (see Figure 43).

- Event: This context of project recorded previously, shows the list of the events occurring in the project with the links between them. Thus, CoCa ensures the capture of detailed information from the local context of collaborative events included in the project. Events are contextualised with a specific project context. For each new event occurring in the project, a new event is created in the tool with the fulfilment of the criteria, links, analysis and evaluation (if the user has the right to do it).

> Example from the industrial case study:
> Most of the time this meeting is the first event of the project, because an explanation of the incoming project is drawn quickly with the definition of the needs and a project leader is defined. All the information on event is recorded: dates, times, actors involved in the event, expectations, outcome, decisions and comments (see Figure 44).

- Links (Figure 46): Events can be linked by two types of link: "problem" link and "causal" link. The "problem" link refers to a problem occurring in one event which has consequences on another event. The user can explain what the problem was and the consequences were in a text field in order to improve the future analysis of this problem. The "causal" links are between two events where one event implies the creation of the other. Most of the time it occurs when the conclusion of one event leads to another action which must be carried out in another event. This type of link

allows better follow up of the progress of the project and its main decisions. For a future analysis it is essential to know the causes of the emergence of the event in the project.

Figure 46: GUI form of the tab "Links"

> Example from the industrial case study:
> In the same project AGV7 and in the first event "Need definition" a problem occurs (Figure 46): the actors don't have enough time to carry out the tasks required. Consequently the tasks will be done but not in detail, the quality may not be good enough. Thus the link "problem" alerts the analyst by showing where a problem appears; afterwards he has to understand why this problem occurred by using the other information provided in the tool.

-   Type / Subject and Collaborative Criteria tabs:
The tab "Type / Subject" records the type of the event (business visit, meeting, discussion, mail, phone…) and the subject of the event to store what happened. It could have only one type and various subjects for the event. The subjects are the

actions carried out during the event: decision, design, explanation, schedule, validation… and each subject is completed with a criteria of importance, in order to know if the subject is done, in progress or only planned (Figure 47).

Figure 47: GUI form of the tab "Type / Subject"

CoCa implementation was based on the theoretical model of collaboration shown in the Chapter 4.3. Thus, the collaborative criteria of the collaboration model have been introduced in CoCa to differentiate the collaborative practices occurring in events. As was presented in section 4.3.3 ("Model of collaboration for analysis"); these criteria are used in the tool to describe the form of collaboration used, so the analyst can know whether the actors worked at the same time, in the same place, if the event was planned, prescribed or formalised, if the actors used specific tools, or information resources to carry out their work (Figure 48).

Figure 48: GUI form of the tab "Criteria"

> Example from the industrial case study:
> In this event "need definition" the actors worked in the same time and place. The event was planned (every Monday), the form of collaboration is "forced" because the head of the company chairs the meeting, and the collaboration is mainly formalised because documents have been completed. At this stage no tool is used and the customer needs document is used in this event. A comment from the analyst gives extra information on the form of collaboration used in this event.

- Evaluation / Analyse tabs: The attributes of these tabs are available for the project manager but not for the general user because the information included in these tabs is sensitive. Thus the project manager can make evaluation and analysis during an event in order to begin an on-the-spot evaluation and analysis of the collaboration.
The Evaluation / Analyse tab show the list of evaluations and analyses made. In the evaluation, the analyst assesses if the actors collaborate under time pressure (no

deadline or urgent), if there are technical difficulties, if the form of collaboration is useful (see Figure 49).

Figure 49: GUI form of the tab "Evaluation /Analyse"

The analysis form (Figure 50) is more geared towards the assessment of the collaboration by quoting the level of confidentiality, hierarchical level and by various criteria to evaluate the quality of the collaboration: conflicts, motivation, communication and production.

> Example from the industrial case study:
> In this event of "need definition", the project manager makes a first analysis and evaluation of the form of collaboration used. He concludes that there is no real technical difficulty because Ederena has experience on a similar project named CAF, the lead time to finish the work is short and the customer needs specific quality requirements. In the collaboration analysis, he notes that the form of collaboration is practically appropriate because the

actors are motivated, communicate in a constructive way, and find consensus; but they are concerned about taking more work on. Consequently the analyst does not put the sliders to their maximum.

Figure 50: GUI form of the Analysis form

The collaborative criteria are quantitative and qualitative (see section 4.3.3.3 "Characterisation of the collaboration"). In CoCa the qualitative criteria are recorded by sliders in order to represent a trend and not a fixed value. This mechanism representing qualitative criteria by sliders is close to the Likert type scale [Likert 1932], [Edwards 1957]. Nevertheless, in CoCa the definition of the scales is inspired from traditional French software development rules and have ten pips and not five as it the case in the Likert type scales. Moreover, in terms of improvements, a deeper study of the Likert type scale will lead to a better characterisation of the qualitative criteria in CoCa. For example, one of the improvements will be to orient the questions (or the labels) alternatively on a positive and a negative way as it is the case in the Likert approach. This approach could lead to the statistical study by weighting of the answers. This statistical study is not explored in this thesis, but it will be presented as a further work in Chapter 8.

5.5   Synthesis

This Chapter has dealt with the development of the CoCa tool. The approach to this implementation was presented in the three main steps: Analysis, Design and IT implementation. The presentation was carried out with diagrams based on UML formalism. These diagrams were used to define the architecture, GUI forms, database and the IT implementation for the tool. Lastly a section has set out to explain how the tool is used by project managers in an industrial context.

- Implications for the approach:

The approach is divided into three main steps: "Analysis", "Design" and "IT implementation" step. The "Analysis" and "Design" steps of the approach were accomplished in collaboration with two IT engineers specialised in Java language and database. The "IT implementation" step was carried out by an external company. This company used the information achieved in the two first steps of the approach without making any changes to the analysis and design made previously in order to carry out the IT implementation quickly. The "Design" step was very detailed; the database and the GUI forms were completely defined. This detailed definition decreased the time to implement the IT code.

The multiple UML diagrams lead to the definition of scenario to describe the use of CoCa. These scenarios contribute to a better understanding of the needs of the company for the implementation of CoCa. This approach is "user-centred", indeed the "Analysis" step begins with the definition of different types of users with scenario for each one. In this approach, the main rules of collaboration described in this research work were applied. The development of CoCa is based on the UML formalism for a generic representation. The use of UML contributes to building a shared framework easily understandable by all the actors of the project.

- Implications for the tool:

After the implementation of the tool, it was noticed that the tool is close to the theoretical model of the collaboration defined in the previous Chapter because there are no extra GUI forms which distort the ideas included in the model. Every GUI form in the tool is based on aspects included in the theoretical model of collaboration. Thus, after the implementation of CoCa, no additional iteration was needed to improve the models: this is a confirmation of the successful definition of the models.

The CoCa tool is used by analysts to capture information, with the GUI forms, on collaborative events occurring in design project. The tool stores this information in the database in the right place thanks to the IT code in Java. Afterwards, the analyst analyses the form of collaboration with the tool using GUI forms and makes propositions, forecasts and anticipates the future collaborative situations. Thus, for the analyst the main issue is to

find enough information in order to analyse the collaborative practices used in the company and to improve design coordination. Thus the tool needs firstly to provide a search by keywords and attributes to find main text data. Secondly in the final version of the tool, a graphical visualisation of information will be implemented to represent and compare various forms of collaboration with common criteria.

Lastly, the tool will provide a specific form of output to visualise information from large databases [Melançon, et al. 2001]. The visualisation of data recorded will support the analysis of collaboration and allow the establishment of a memory of design projects viewed from the perspective of collaboration.

In the next Chapter "Results", CoCa tool is tested in the industrial case study in order to validate the models, the use of the tool in an industrial context, and to explore the possible improvements in the design coordination due to the analysis of the collaboration.

6 Results for collaboration analysis and coordination improvements

As described in Chapter 2 "Research methodology", an industrial case study has been carried out as part of this research study. The method of experimentation is based on a socio-technical approach [Boujut and Tiger 2002]. The author's role was to participate in a company workgroup and thus to introduce an external point of view. This industrial case study took place in an SME based in the south west of France named Ederena. Thus, a link is maintained between the theoretical work carried out in the laboratory and the reality of industrial life in design.

Re-organisation & Process Re-engineering for Coordination → Product Data and Process Management → Analysis of collaboration with CoCa tool → Coordination improvements
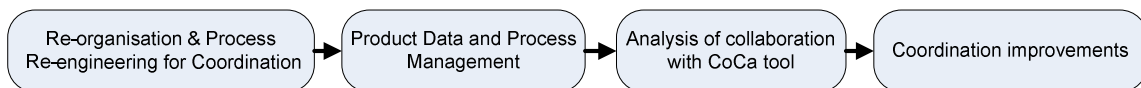
Figure 51: Description of Chapter 6

Thus this Chapter first presents work on the formalisation of the organisational structure of Ederena and of the roles for the coordination of design processes. This work leads to the implementation of a PDM tool to support this formalisation. Then, the analysis of collaboration using the CoCa tool helps project managers to take into account collaboration and informal aspects in project coordination. The final section examines the results of this analysis on coordination and especially the possible improvements in design coordination and in project manager's activities (Figure 51).

6.1 Re-organisation & process re-engineering for design coordination

This section deals with the evolution of the approach to design coordination of the company. The project manager takes decisions on scheduling or on coordination rules in order that actors apply them during their design work. Thus, an IT system like a PLM system can be implemented in order to support these coordination rules during the operational design work of actors. This section is divided into three parts:
- The definition of a new organisational structure based on departments, the links between them and the actor's roles.

-   The evolution of the way of managing projects in the company: the approach was initially to have one person in charge of each project named "chargé d'affaire" and it evolves toward a design project manager for all projects and a specific team for each project.
-   The re-engineering of processes: it must be implemented in order to formalise the product development process and to support the management of projects.

6.1.1 Organisational structure

Due to the growth of Ederena and the consequent large increase in the number of employees, it is necessary for the company to manage the integration of new people into their new functions in a short time, and to match their skills to the needs of the company. So, in this context, actors need to have clearly defined roles so that they can contribute to projects efficiently.

The company is made up of 7 departments: marketing, technical: in charge of the product development (design and industrialisation), logistics, buying, manufacturing, quality, and financial. Although informal definitions of functions within the company were established, actors needed a more precise definition of the departments of the company, the functions within each department, in particular within the Technical Department. The goal of this definition of the organisational structure was to formalise the general organisation of the company and to allow the positioning of each actor clearly according to their skills and the tasks that they must carry out. This definition leads to the management of the workload at the company or department level. It would also lead to the definition of the department, the users, the functions, the responsibilities, the future organisation, data and process management tools according to the specific needs of the SME. Consequently, through successive iterations, the study allows the organisation to evolve and adapt and changes the project management toward a better coordination of projects by project managers. The overall objective for the company is to become more effective in order to not lose its new markets and to retain its dominant position in Europe.

Thus, for the purposes of this project the organisational structure of the company must be defined in order to support the further work on project management, processes and product data management. The definition of the organisational structure was divided into two sub-steps: definition of the departments' function and identification of each actor's roles.

-   The function definition includes the characterisation of tasks which must be carried out. For example an organisational chart represents the place of each person within each department. For each department the internal links (with other departments) and the external links (with suppliers, partners, customers, sub-contractors) are defined.

- The main roles included in each department are defined: for example in the technical department the main roles are: "manufacturing responsive", "design responsive", "designer", and "materials strength responsive". These roles are used to assign roles to the design activities identified in the project plan definition. The links between employees' names and roles are defined by the project manager when defining a project team. Consequently, actors involved in the project are defined in the project team and not in the project plan itself in order to have the possibility to change actors without changing the whole project plan.

- The role identification allows also actors to know their place in the organisation accurately. Then the internal organisation of each department is formalised with the internal formalism of the company. This internal formalism is the first step before the definition with IDEFØ or UML formalism for a better communication towards external partners.
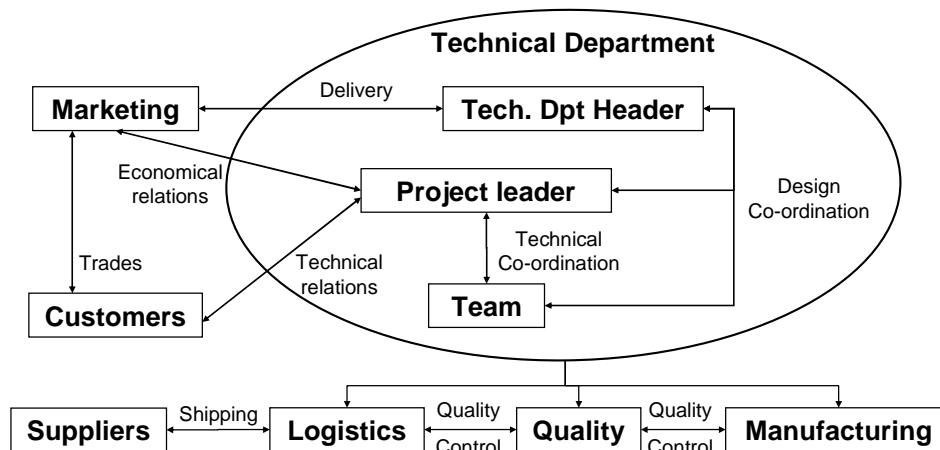
Figure 52: Organisational structure of the Technical Department

Thus, for example the Figure 52 represents the organisational structure of the Technical Department: the main roles involved and their associated responsibilities. The ellipse represents the boundary of the technical department; outside of the circle are the other departments of the company and the links between them and the external services i.e. the exchanges between them.

6.1.2 Project management

Historically, projects in Ederena were managed by a "chargé d'affaire", a single person in charge of a whole project: from the order from a customer to the shipping of the final product. However, following the growth of the company and the taking on of many new projects, this method of management was not suitable, if only because there were more

projects than people to manage them. This kind of management may be appropriate within a small company with few projects, where the "chargé d'affaire" can ensure a reactive link between the customer and project. He can work with all the other people in the Technical Department in a context of "mutual agreement" [Mintzberg 1990] where actors help each other in order to satisfactorily complete work through informal collaboration.

There are now too many projects to be managed, the deadlines are increasingly tight, the number of employees has increased. Thus, many breaks have appeared between the "chargé d'affaire" and the customer and also within the Technical Department due to these increased activities: e.g. problems of technical aspects under evaluated by the "chargé d'affaire", problems of communication between people who are too busy, problems of technical analyses which are too quick implying financial underestimations or overvaluations. Such problems of communication emerge between actors within projects and are prejudicial to deadlines and the image of the company. Hence it became imperative to rationalise project management and the design processes. Moreover the "chargé d'affaire" often does not have enough technical knowledge to work alone on large and technically difficult new projects.

Thus, these observations demonstrate the necessity to define the way to manage projects with project leaders. The goal is to identify the operational responsibilities and roles that will be used throughout the design project. For example, as previously stated, project management was based on the concept of a "chargé d'affaire": who in fact always belonged to the marketing department. These "chargé d'affaire" interacted with the Technical Department to obtain technical data when required. As a consequence, the role of each person was predetermined and did not evolve. With the evolution of the company, this context became ineffective, consequently, a transfer of responsibility from the Marketing department to the Technical department with the concept of project leader was proposed. A project leader belonging to the Technical Department is assigned to be in charge of a project's progress, a specific team is selected for each new project, and during the design process tasks are delegated to members of the team. The next step is to define how the responsibilities are shared, assigned and built upon from one project to another. This step defines the early phase of a project as building the appropriate organisational structure before its launch. So, when the order for a new project comes into the Technical Department, the head allocates names to roles: the project leader and his/her associated team according to the complexity of the project and the current workload. So, using a project leader orientated organisational structure, the project is managed by defining tasks and objectives controlled by milestones.

6.1.3 Project process management definition

The organisational structure of the company (internal departments and external partners) and the characterisation of the project management context (from "chargé d'affaire" to

project leaders) were defined. Consequently, this study is oriented toward the management of the project at a global level in order to coordinate the whole design process. Initially the coordination was managed by the "chargé d'affaire" who scheduled design tasks in an informal way and without milestones. Nevertheless in the new context of the company, the "chargé d'affaire" is not going to be in charge of coordination, this responsibility will thus fall on the project manager from the Technical Department. Thus, a study to formalise and represent the project processes is necessary in order to work in a project management way with a project leader and a project team.

Consequently, the main phases of the project development process are defined which correspond to the definition of the product life cycle phases: for example, a standard lifecycle in the company is "feasibility", "design and manufacture definition", "prototype manufacturing", and "production", as shown in the following Figure 53.
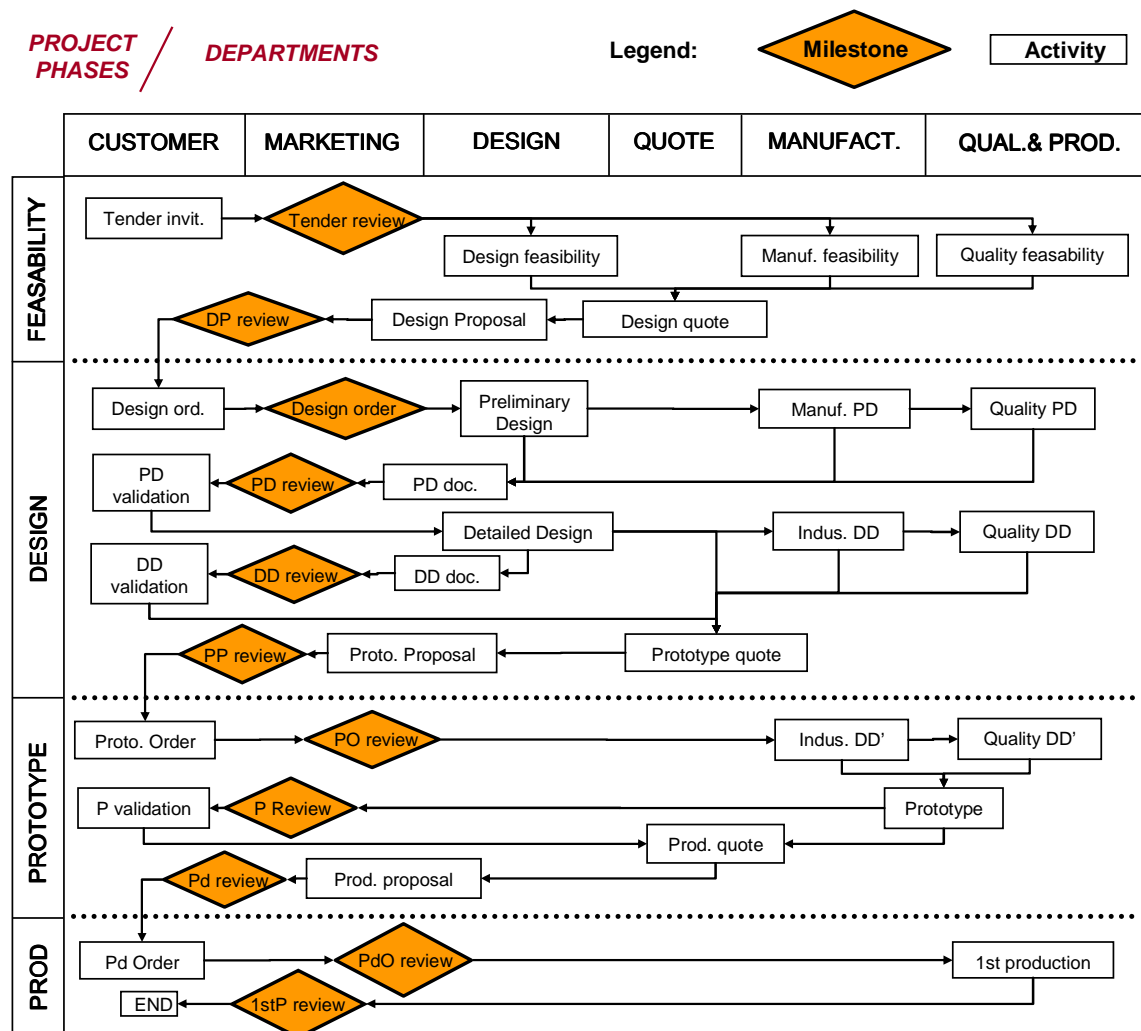
Figure 53: An example of the product development process

This decomposition of the development process into main phases is followed by the definition of the sequence of the main tasks for each phase. This leads to the definition of the whole project management process. This process is fixed for any incoming project. Nevertheless, this process is defined by the quality department and is based on previous standard projects. Thus, in practice, the projects can diverge from this strict representation; "shortcuts" are possible according to the characteristics of the project. For example, the process followed for a product and an already known customer will not have a phase of feasibility and will be shorter than the process of a project for a new complex product. This generic product development process is a support for project managers in order not to forget any activity, but according to the experience of the project team, some "shortcuts" can be taken.

Indeed, the task is carried out by various departments, but the responsibility to reach the objective and to complete this task is given to only one department. The goal is to define the succession of tasks by considering the different departments and the different phases, in order to identify more easily the different milestones that control the progress of a project. In Ederena, the internal quality standards are based on a global formalisation presented in the previous Figure 53. This representation of the main concepts of the formalised design process is followed by the definition of sub processes which detail who is involved in a task, which documents are used and produced, and what decisions are taken for milestones. During, these milestones, the project leader may define extra tasks not already planned in order to adjust the project process when a problem occurs. Thus, milestones may control the achievement of several tasks and introduce some predefined flexibility for the following tasks. Some milestones may control the achievement of a complete phase.

The definition of the product development processes with tasks and milestones is essential to manage the whole product development. Indeed a detailed development process is the basis for controlling the progress of the project by the validation of the previous tasks during milestones. During milestones, if some previous tasks are not validated, then corrective actions can be defined to reach the objectives.

After the definition at a global level of the project process management, the project process management is refined at a micro level. Guidelines are set out for the execution of each task in the project process. These guidelines define the implementation of the tasks planned in the global product development process by specifying sub-tasks or sub-objectives. This task sub-sequence is not really scheduled, but proposed to project members as a generic "good practice". The definition of these guidelines is not easy because they are specific to the company. So, each guideline is tested in order to compare them with the day-to-day operational work. Several iterations are made for defining and validating the guidelines. Indeed, these guidelines define the relation between actors with a suitable form of collaboration, a definition of milestones and tasks management.

At this micro level, an actor is assigned to each activity to implement it with total autonomy for its achievement, and with the possibility of asking for assistance from other actors.

However the person in charge must reach his objective which was predefined during the last milestone, and produce documents for the next milestone. The progress of the project is thus based on the management of milestones, objectives and deadlines. The management of milestones requires extra work. Actors have to communicate with all the people involved in the milestone in order to put the relevant documents at the disposal of the other actors about the work carried out before this milestone. This preliminary work is necessary before every milestone in order that all actors are informed about the work done and can take an adequate decision during the milestone. This extra work is a work not planned in the design process because it is included in the information management rules but it must not be forgotten by the actors. Then, during the milestone, the person in charge of the following tasks must evaluate the work carried out previously. The milestone is either validated and the following activities are launched, or it is refused and corrected tasks are defined in order to solve the problem.

6.1.4 Information flows

At a micro level, the product development process and project tasks are coordinated by the project manager. Thus, various internal tools are needed in order to help the project manager in this task of coordination. Initially, summary tables (like the PAT document Figure 54) record the documents which must be created for each state of the product life cycle. This first tool looks like more a check list than real software for the project manager. Although this check list is useful to remember a document; nevertheless, it does not take into account the responsibilities, the tasks, the lead time and the delay. Therefore, a new sort of document is drawn up: the PAT, it is an internal acronym for Project Administration and Tasks. This PAT is a form based on the new product development process (more detailed than the previous one) and allows the management of the tasks for each step of the process with associated documents, responsibilities, roles, departments, lead time and delay. The interest of this new PAT document (see Figure 54) is that it records all tasks that the project manager and the actors have to do. Nevertheless this document has limits: it does not take into account the collaboration aspects. Indeed it is only orientated toward coordination (who, when, for what …) but not about how the actors carry out tasks, with what supports (CAD systems, norms, specifications, previous work), resources, who is the specialist in this activity, etc… Moreover this document summarises all the planned documents and does not include the extra documents created in an informal way as mails, telephone meetings, or customer visits. Thus the PAT is not sufficient to manage project whilst taking into account collaboration aspects.

					AOC State	Order state	Responsible	Lead time expected	Lead time done	Delay
10	Contract Definition		101	Technical specifications of the Needs (TSN)						
		Clause by clause	102	Amdec, Charter 4P, …						
			103	Contract						
			104	Logistical specifications						
			105	Quality specifications						
		106	List of contractual documents							
		107	Schedulling for the study							
		108	Schedulling of the							

Figure 54: Extract of the PAT on the Contract definition phase

An example of the complete document is in Appendix D.

After the identification of the pertinent information which must be managed through the design process in the PAT (Figure 54). The life cycle and workflow specifications need to be addressed in order to implement them in the future PLM system. This specification is formalised by state/transition diagrams to describe the future life cycles and prepare the definition of future workflows. These state transition diagrams are based on the product development process (Figure 53). The next Figure 55 shows an example of a state/transition diagram for the validation of the design report.
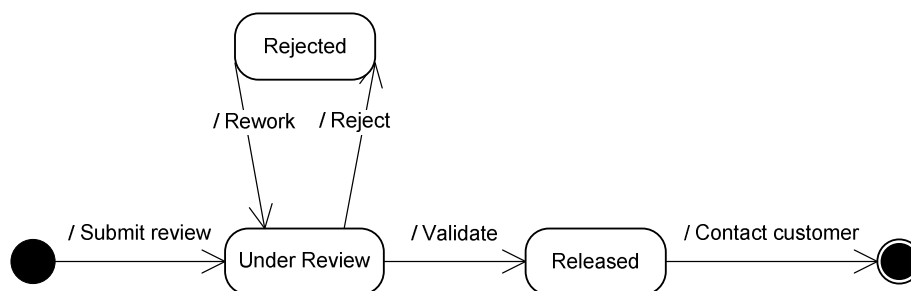
Figure 55: State/transition diagram of the "design report" validation

In this state/transition diagram (Figure 55), three states (under review, rejected and released) can be taken by the design report. Between each state activities need to be carried out to pass from one state to another. The definition of life-cycles and workflows is easier and more understandable with this sort of diagram. Effectively, the states of the life-cycles

are already defined in the state/transition diagrams and the activities of the workflows are also partially defined. The corresponding workflow will be described in section 6.2.2 (Figure 60).

6.1.5 Detailed processes

The first activity in the PAT is the technical specification of customer's needs through interaction between the customer, the Marketing Department and the Technical Department. The goal of this activity (called CND for Customer's Needs Definition) is to define the needs of the customer well enough in order for the Technical Department to carry out a technical quotation and be able to generate, at the end of the activity, a financial proposition.
Nevertheless, the definition of this CND activity in detail is not easy; the project leader can use several processes in order to define the inter-actor exchanges. So, several scenarios were observed which represent different processes in carrying out this first activity.

Example from the industrial case study:

- 1st scenario:
Initially it was expected that the marketing department would transmit all necessary information in order to carry out a technical quotation to the Technical Department. The principal problem of this scenario lies in the fact that the marketing department does not have sufficient technical skill to collect all the technical information. So, the Technical Department had to rebuild the customer's file and to contact the customer again in order to collect the correct information needed to carry out the technical quotation. During this first scenario, the marketing department was in charge of an activity for which it did not have adequate skills. Moreover the responsibilities and the interconnection between actors had not been formalised in advance. After this first scenario the project leader decided to change the scenario.

- 2nd scenario:
In order to force the collaboration between marketing and Technical Departments a document template was defined where all the technical information required to carry out a technical quotation was collected. The Marketing Department member had to fill in the document template and transmit it to the Technical Department in order to make the quotation. In this case the main problem lies in filling in the document template, indeed the document was often left incomplete and thus some information was not

processed. This was because the Marketing Department member did not have the necessary skills to adapt to each new quotation that asked for technical and specific information about the product, or about the customer. The template is only an appropriate response for a routine quotation where the information to be collected is always the same. Furthermore, most of the time, at least in this SME, quotations are specific to a product and / or a customer. At the end of this scenario the project leader tried another scenario.

- 3rd scenario:

The project leader proposed that the technical person responsible went to the customer with the Marketing Department member to collect all information necessary to carry out the technical quotation. However, this process was too constraining. Indeed, the technical person had to be present for many operations which did not concern them such as, for example, the marketing presentation. Thus the technical person could carry out the quotation successfully, but lost a lot of time in travelling and "passive presence". This scenario thus also increased the problem of the workload of the Technical Department.

- Last scenario:

This scenario is a blend of these previous processes. A first visit to the customer was made by the Marketing Department in order to establish the feasibility of the product at the marketing level, and then, if it was necessary, the responsible technical person had a meeting with the customer to collect all the technical information necessary to carry out the technical quotation. The meeting could have been a physical one or by phone; with or without the Marketing Department member according to the complexity of the case. In this scenario the Technical Department had the responsibility of discovering the information necessary to carry out the quotation with a formal coordination by mutual agreement with the marketing department.

The last scenario is currently applied usefully in the daily work of the company. In Ederena, it was observed in non-routine activity that the project managers prefer to maintain flexibility by using encouraged collaboration in order to let actors be reactive.

This example shows how the first task of the development process is now carried out in projects. Moreover, such a study demonstrates that the level of granularity is not detailed enough to coordinate every task in only one way. Thus, a similar study must also be carried out for all the activities of the product design process in order to redefine the processes in detail.

Nevertheless, the main problem is for the project manager to choose the right sequence or process to be reactive in the face of any situation by keeping enough flexibility in these processes. We are going to see various other aspects of this problem through this Chapter and possible solutions in the Chapter 7 "Discussion".

6.1.6 Conclusion

This section 6.1 has introduced the work of characterisation carried out in the company partner about:

- The organisational structure of the company with the definition of the departments, functions, roles and actor's skills.
- The project management approach with the management of project by a project manager, a project team constituted according to the available and necessary actors.
- The definition of project processes at a global and detailed level in order to schedule and manage the design tasks.

All the improvements in design coordination are based on this characterisation. Consequently a new organisation and a formalisation of the product development process were proposed, implemented and observed. All these observations show the need to structure the project processes and product data management. Moreover, a recent partnership with a customer in the field of rail transport has encouraged Ederena to evolve toward a rationalisation of its organisation in order to achieve quality and design standards. However this formalisation must not strangle innovation. So, it is necessary to study how this new organisational structure and project processes can retain enough flexibility in order to allow actors to keep the necessary amount of freedom to collaborate.

The next section outlines a global methodology, based both on that existing and on this experience with an SME. This methodology aims to prepare the company for the introduction of a new information system. It is then applied and the results are developed for Ederena, the company studied.

6.2   Product Data and Process Management: toward PLM tools

At the beginning of the study, the Technical Department at Ederena used 3D CAD, 2D drafting and a small ERP (Enterprise Resource Planning) software system. All these systems were used by different actors according to their own skills and knowledge. Indeed, actors do not use the same system (for example, one designer works with 2D software, and the other uses the 3D CAD system). No structured approach to the use of these systems existed: this leads to difficulties in transmitting, sharing and accessing the information. The

company wished to define such an approach and train its employees in order to rationalise information management. Again, the increase in the number of employees highlighted the need for the better management of the files created by actors and all technical documents, in order to reduce misunderstandings and time wasted in searching for information. The objective was to be able to identify each element of information, its support, its scope and the person responsible for its validation.

This industrial objective is closely linked with the aim of this research: improving the coordination of design projects by project managers. Thus, after the study of the organisational structure of the company, the reengineering of its design process and the formalisation of its information flows, the company needs to find an information system to support this approach and to assist project managers in their work. Moreover, the coordination and collaboration aspects were defined in models, the tool CoCa was implemented to support the analysis of the collaboration in projects, and then, the next step is to study how the coordination can be supported by taking into account the results of this collaboration analysis. The PLM systems are mainly used in companies to manage the product data, and to support the management of design processes (with many coordination aspects). Thus, these PLM systems are logically studied in this research in order to see how these systems can support the management of the coordination when taking into account the results of the collaboration analysis.

Thus, the company wants to implement a product data and process management tool which would be well-adapted to the company setting. This implementation started with the definition of a prototype implemented through a PLM tool named "Windchill^{TM}". This prototype formalises the study carried out on the coordination of design projects and the possible experimentations of solutions to support the work of project managers. These solutions are based on definitions of project plan, workflows and activities. Moreover the implementation of this prototype led to the definition of a methodology specifically for the implementation of PLM system in an innovative SME.
The description of such a methodology is now introduced and then the prototype will be described.

6.2.1 Methodology for PLM implementation

In the proposed new organisational structure the level of formalisation is increased and implies a more meticulous approach to achieving the administrative tasks carried out by actors including storing documents in the right place, scheduling design tasks and validating the finished work.

Thus, it is necessary to use a tool to help them in the completion of these extra formalised tasks. Hence, the company management chose to test PLM tools to help actors in the management of data and projects.

In Ederena, it was observed that a PLM tool cannot be implemented without prerequisite steps being carried out in order to adapt the tool to the company [Pol, et al. 2005b]. In this section a methodology is synthesised to support the achievement of these prerequisite steps before the implementation of a product data and process management tool. These steps focus on the organisational structure of the company, its design project process management and its product data management.

The methodology details the several steps initially identified in Ederena and attempts to generalise them for SMEs developing manufactured products.

The prerequisite steps, which lead in to the implementation of a PLM system, are divided into two main phases: analysis phase then specification phase.

The analysis phase is based on the study of the existing organisational structure and process of design, and the Specification phase corresponds to the definition of the new organisational structure and process.

The "Analysis" phase is composed of three main steps:

1. Definition of the organisational structure of the company (departments, roles, internal links). Generally, the representation of this structure is based on the IDEFØ formalism in order to characterise the functional view of the company in terms of departments, persons, roles and information exchanges. The analysis of the organisational structure is divided into two sub-steps:
   - Internal structure: as achieved through the case study with the description of the departments (as shown in Figure 52) and with the functions, roles and names of each person (with an organisational chart to represent the tree of departments and persons).
   - External structure: in order to take into account collaborations inferred by strong partnerships (links with suppliers, customers, partners, contractors).

2. Definition of the existing design process: Often both following models are based on the IDEFØ formalism in order to have a shared framework between the company's employees, but here Ederena formalisms are specific.
   - Modelling of the product development process composed of design tasks. In Ederena this product development process was defined with an internal formalism as is shown in the Figure 53.
   - Modelling of the project management process with coordination aspects and control tasks. In Ederena, the project management process is based on the combination of the Figure 54 (the PAT) and the organisational structure (Figure 52). The PAT is used to define the phases of the project with the

documents to fulfil at each phase of the project. The actors' roles in the project are defined in the organisational structure (Figure 52). This is due to the Ederena way of project management based on the achievement of the main documents/deliverables.

These models include the identification of information used during the project: transformed information, support information as well as control information.

3. Identification and characterisation of the information flows: UML formalism is used to describe in detail the information flows with class diagrams for the product and project data structure, and state-transition diagrams for life-cycle description. Thus in this step, two main sub-steps must be carried out:
   - Synthesis of <u>information used</u> as product and project data, and identification of their respective structures.
   - Characterisation of existing <u>life-cycles</u> (states and actions) for product and project data.

The "Specification" phase is composed of four main steps:

1. Definition of the future organisational structure including:
   - <u>Internal</u> structure.
   - <u>External</u> structure.
   - Definition of the <u>organisational roles</u> using UML use case diagrams to characterise actors' needs and tasks that must be characterised before the starting the project, as proposed by [Eynard, et al. 2004].

2. Definition of the future global design process:
   - Global definition of the <u>product development</u> process.
   - Global definition of the <u>project management</u> process.
   An IDEFØ model is defined that characterises the different phases, activities and milestones of the project.

3. Definition of the information flows:
   - <u>Identification</u> of pertinent information to be managed through the design process and definition of its structure, using the UML class diagram formalism.
   - <u>Characterisation</u> of correlated life-cycles using state - transition diagrams in order to specify tasks, responsibilities, resources, and validation processes.

4. Detailed definition of the product development process based on UML sequence diagrams. These diagrams include the information flows and human activities

previously defined in order to specify detailed activities for team members upon identified information. The aim is to specify the future functions that will be implemented through a PLM system. In this step 4, the definition of the processes is carried out at a detailed level, indeed for activities of short duration (in Ederena some hours), whereas in the step 2, the global definition deals with activities of long duration (in Ederena some days). This detailed definition leads to the prescription of the future possible forms of collaboration applied in the activities and also to the definition of the form of collaboration desired in the design activities.

These prerequisites are summarised in the following Figure 56 with the main phases and sub steps.
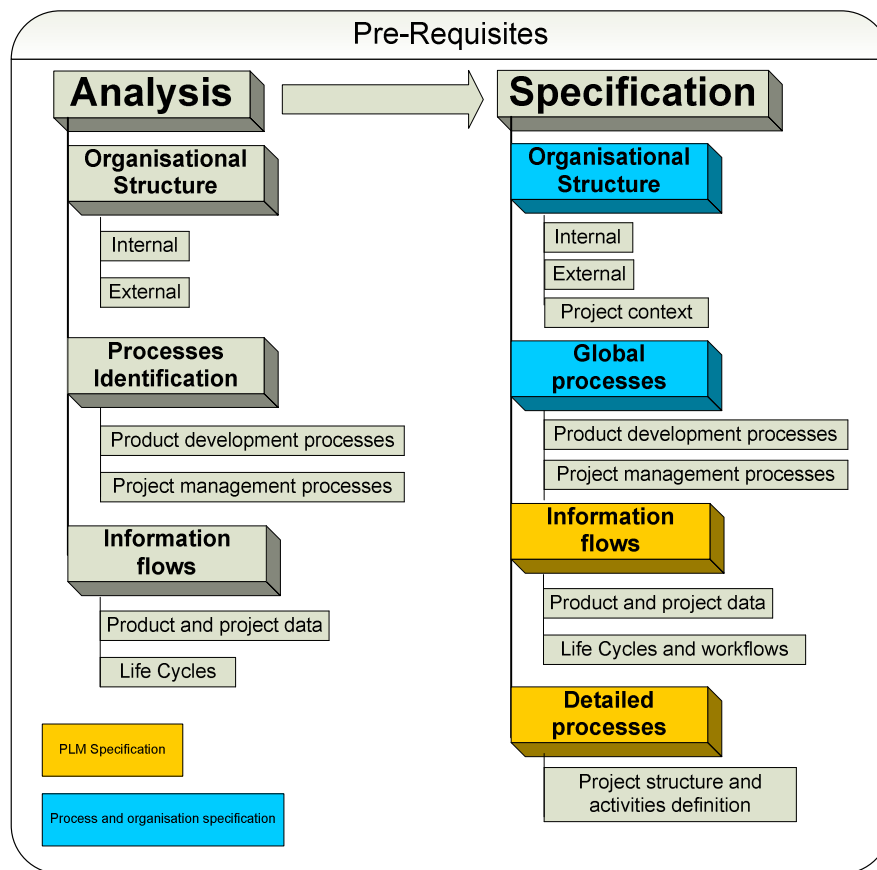
Figure 56: Prerequisites for the implementation of a PLM tool in SME

This methodology is based on the work carried out in Ederena (presented in section 6.1) in order to implement a PLM system in the company.

6.2.2 The PLM prototype

Based on the methodology just described, a prototype was implemented in order to evaluate the appropriateness of a PLM solution for the management of product data and management of projects in Ederena. The PLM prototype was implemented with Windchill[TM] ProjectLink software from PTC (Parametric Technology Corp).

In this section 6.2.2 the correlations between the coordination frameworks presented in section 6.1, the methodology just described and the functionalities of the prototype are explained. Then, the prototype is introduced in a practical way with a description of the implementation and examples to illustrate the management of data and projects (which is the main need of the company in terms of IT system). And finally, there is a discussion about the benefits and limitations of such a tool.

6.2.2.1   Toward PLM implementation

It has been stated previously that it is essential for the company to study: its organisational structure with the definition of departments and roles; the management of the project process; and product data management in order to be able to implement a PLM system. This study of the organisational structure of the company is necessary to adapt the PLM system to its organisation. Moreover the organisational structure of the company can also be influenced by the use of PLM system. Much of the **Analysis** and **Specification** work described in the methodology has already been done during the study in Ederena and has been presented in the Chapter 6.1. The relation between the concepts developed in previous study and the concepts existing in PLM systems is now described.

Considering the **organisational** aspects in Windchill[TM] ProjectLink systems, "users" (i.e. human resource) are members of an "organisation". An "organisation" means a company (or company site for an extended company) and allows the management of "products" and "projects". A "project" is a concept that allows management of documents and parts in a traditional way. A "project" is characterised by a team, i.e. a list of "roles" and associated "users" and also a "project plan".

However, the concepts of "skill" and "function" do not have equivalents in PLM systems. "Skills" are not mentioned in PLM systems (Figure 57). The "function" in the model of coordination is the position assigned to the actor; it is unique and defined in the organisational chart of the company. Unlike "function", the concept of role is the same in PLM and in the model of coordination. An actor can have various different roles in different projects. For example an actor might have the function of "designer" in the company and has the role of "project manager" in project 1, the role of "draughtsman" in project 2 and the role of being "responsible for structural calculus" in the project 3.

Concepts from coordination model	Concepts within WindchillTM for organisational aspects

Actor	User
Role	Role
Organisation	Organisation
Project	Project
Function	N/A

Figure 57: Relation between coordination model and PLM concepts for organisational aspects

In Windchill[TM] the **project** plan is composed of "summary activities" i.e. activities containing other activities, "activities" i.e. basic activities and "milestones". The two types of activities can be correlated to the event concept, but only the "activity" can be associated with a "deliverable" (i.e. an output methodological/information resource). A milestone can also be linked to a "deliverable". Figure 58 represents the separation between the concepts from project management and from product data management because these two categories are implemented as two separate domains within Windchill[TM]. The only interaction between them exists when an information document is defined as a deliverable in the project plan.

Concepts from coordination model	Concepts within Windchill[TM] for project management	Concepts within Windchill[TM] for product data management
Project	Project	NA
Project phase	Summary activity	NA
Task	Activity	Workflow activity
Milestone	Milestone	Workflow activity
Deliverable	Deliverable	NA
Design process	Project plan	Workflow
Team	Team	Team
Resource (as an input of a task)	N/A	NA
Trigger	N/A	NDA
Decision	N/A	NDA
Justification	N/A	NDA
Indicators	N/A	NDA
Objectives	N/A	NDA
Constraint	N/A	NDA

-    NA means Not Applicable (the concept does not exist in PLM systems).

-    NDA means Not Directly Applicable (the concept has not directly correspondence but it is possible to find a way to combine various PLM concepts to define a closer concept).

Figure 58: Relation between coordination model and PLM concepts for project processes and product data management

The "design process" concept from the model is managed by the "project plan" in the PLM system. The "project plan" is a succession of "activities" or "milestones" to represent the evolution of the project. This concept of "design process" can be mapped to the "workflows" in PLM systems concerning the processes of document management. A "workflow" is a predefined sequence of activities to manage the validation of a document. The main limitation of this workflow notion is that a user-created-workflow cannot manage a project, only documents.

The "resource" is described in the model as an input to support the achievement of an activity. In the PLM system this concept is used in the project plan to attach a deliverable to an activity; it is an output created during the activity.

In Windchill^{TM}, it is not possible to define "triggers" to launch design events in the project plan. These triggers are usually used in design to define conditions for controlling the start of design events. For example, these conditions could be "when a specific event is completed" or "when the project manager authorises the launching of the event". Nevertheless in workflows (which manage documents) it is possible to synchronise activities to manage the starting of activities.

Moreover the "decisions", "justifications" or "indicators" of performance taken during an "activity" or a "milestone" cannot be formalised and stored in Windchill^{TM} during a project. However "decisions", "justifications", or "indicators" can be stored in variables defined in workflows managing documents. Thus the proposed status and level of achievement attributes from Windchill^{TM} ProjectLink are too restrictive to represent performance indicators or justifications. In workflows these concepts of "decision", "justifications" or "indicators" are not directly applicable for the management of product data. Nevertheless, variables can be created in workflows to store information and can be used to manage these concepts in workflows. The management of product data with variables requires a large amount of work by defining workflows with IT code.

The concepts of "objectives" and "constraints" are not used in the management of projects or in the management of product data in Windchill^{TM}, but these concepts can be included in the instructions of any activity defined in a workflow. These instructions are free text fields where objectives and constraints can be explained.

Figures 57 and 58 are drawn to clarify the relation between the concepts from the coordination model and from the PLM systems. These two tables are implemented after the generic analysis and specification phases; and these tables will be different for other PLM

systems than Windchill[TM] or if a major new version of Windchill[TM] is created. A detailed description of these concepts is given in section 6.4.

Considering this mapping between models and PLM concepts and these limitations a prototype to manage standard SME projects has been implemented. Thus, a project was created in Windchill[TM] ProjectLink in order to define all the required organisational structure information. In this prototype the data structure, the workflows to manage documents and the plan project were defined. Moreover, the specified roles, corresponding rights and users involved in the project were implemented in the project.

6.2.2.2 Prototype presentation

Windchill[TM] ProjectLink allows the definition of "document types" and also standard "document models" to manage standard workflow and life-cycles. The necessary predefined documents are stored in a folder structure for future users access (Figure 59): "department" folders contain internal documents linked to the developed product and general folders describe the product data to be shared (documents, CAD files and product configurations). The whole configuration (folders and document types and models) is stored as a "product development model" in order to become a generic configuration. By using this configuration, document types such as the design report document or any document can be instantiated when required by actors.

Figure 59: Data structure within Windchill[TM]

The prototype is implemented in order to manage the product data, the associated documents of design projects, and their access control and versioning.

Life-cycles and workflows are implemented for each "document type" from the detailed process modelling defined in the final step of the prerequisites of the methodology presented previously - in section 6.2.1. As an example, the following Figure 60 represents the workflow used to validate the "design report" document which is a synthesis of all technical studies of the product. First the author writes the report and submits the review. Then the validation process of the "Technical Department" manager is started. This is followed by three validation tasks for the Quality manager, the project manager and the manufacturing manager. Iterations are defined if validations are rejected. If all validation tests are passed then notifications are sent to marketing department for the customer (in the activity "Contact customer") and to the "Technical Department" manager. Adequate change state tasks are introduced when required. This formalism is the specific formalism of Windchill[TM] ProjectLink where for example "submit review" is an activity, "under review state" is an automaton which changes the life-cycle state, "technical dept notification" is another automaton which sends a notification by mail and "ground" is the end of a sub-section of a workflow without terminating the main workflow.
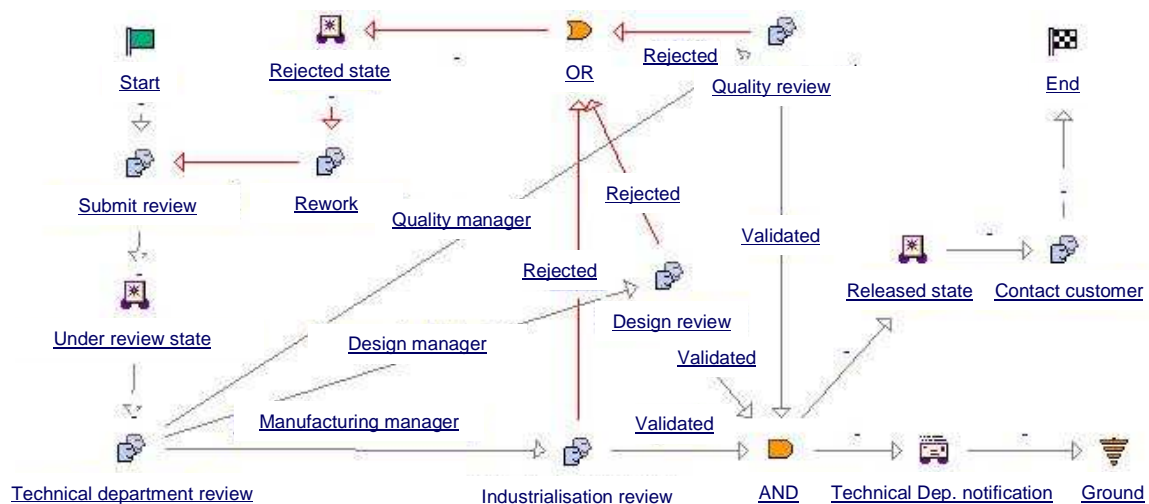
Figure 60: Workflow for "design report" validation

First the team was defined by selecting corresponding roles and actors involved in the product development from all relevant departments. The project plan (Figure 61) is implemented to represent the product development process as introduced in Figure 53 (Chapter 6.1.3): phases / "summary activities", tasks / "activities" and milestones. The decomposition of a task into several sub-tasks can be defined within Windchill[TM] ProjectLink, but it is not possible to represent the direct synchronisation of several tasks followed by one task. For example it is not possible to carry out the sub-activity "customer needs" in the same time than "feasibility study" and to synchronise the beginning of

"commercial offer" when these two sub-activities are completed. Only sequential order is allowed to define activities in the project plan.

Deliverables are associated with each necessary activity or milestone. This allows the project manager to control specific document-oriented workflows by defining deadlines for the corresponding deliverable. Indeed the complete fulfilment of a document workflow is controlled by this deadline. In order to control the way that actors work (before the deadline), he must define basic tasks with a detailed description of objectives, expected actions and document production or modifications as is shown in the example of the Figure 60. In this way the project implementation (Figure 61) is correlated to previous product data view (Figure 59) by the association of the main documents as deliverables of the project activities.

Plan		Status	Done	Start	Dur.	Finish
Project Start		●◡●		21 oct. 2004	0	21 oct. 2004
Feasability		●◡●	91%	21 oct. 2004	264	25 oct. 2005
Customer Needs		✓	100%	21 oct. 2004	3	25 oct. 2004
CN Review		✓	100%	25 oct. 2005	1	25 oct. 2005
Feasability study		●◡●	90%	26 oct. 2004	30	6 déc. 2004
Commercial offer		✓	100%	7 déc. 2004	4	10 déc. 2004
Design study		✓	100%	6 déc. 2004	20	7 janv. 2005
Prototype		✓	100%	7 janv. 2005	8	19 janv. 2005
Production		●◯●	50%	20 janv. 2005	15	9 févr. 2005

Figure 61: Project plan within Windchill^{TM}

With this plan project, some parameters may be used by the project manager to control the project task by task (see Figure 61): the "end date", "task status" and its "level of achievement" (done). Then, if he observes problems he will modify the project plan.
Other optional functionalities of this PLM system are used in the prototype in order to facilitate actors' collaboration: for example a document viewer (CAD and office documents) was used to allow mark-up and document subscriptions. So, the project manager can use these optional functionalities to control specific events, or technical forums to record exchanges between actors.

6.2.2.3 Discussion

First of all this prototype brings three important results to the company. Firstly, people can view and handle the new structure of the product development process in order to understand what the benefit of such an organisation is and what the role of the project manager is. Secondly, people can evaluate the level of benefit of a PLM system to improve their information flows especially in the control of their design projects. At a global level

the prototype seems to answer the needs of the company, especially for product data structuring and management. It implements shared concepts such as roles or formalised processes through a single environment useable by everyone. Thirdly, this implementation allows the validation of several elements from the previously formalised model of coordination such as the definition of the organisational structure, the roles of actors, the project plan or the product data by the main company stakeholders. The experiments carried out in Ederena on product data creation, corresponding life-cycle operations and project tasks management led to an understanding of the benefits of a PLM system implementation in SMEs.

Nevertheless the PLM project implementation reveals several obvious limitations. Actors and skills management do not exist. Indeed, the project manager has to manage the workload and the actors' skills (skills already known by actors as well as the learning of skill) separately because he cannot manage that within Windchill^{TM} system. Moreover; triggering events cannot be defined, indeed it is not possible to launch activities with predefined conditions (as for example if the document A is in the state "Validated" AND if the document B is in the state "Study" then the Activity N°5 must be launched). The memory of the design process is not possible because the same information is used for a scheduled task and its corresponding completed task and because the history of design process modifications is not stored. The implementation of the task concept is too limited: defining input and output information is not possible, except through the use of deliverables in the case of output information. Moreover the decisions taken during an activity or a milestone cannot be formalised and stored. The proposed attributes in the model of coordination of a process element, task or milestone, do not exist and the proposed status and level of achievement attributes from Windchill^{TM} ProjectLink are too restrictive to be capable of representing performance indicators. At the whole project level, the project structure is too sequential. Convergent links between tasks are not possible; indeed it is not possible to have, in the project plan, an activity A and B carried out in parallel and an activity C which begins when A and B are completed. Moreover alternative tasks sequences do not exist in the project plan while these are possible in a workflow.

This last point highlights the difficulty of implementing the necessary flexible design process of an SME, especially in this case study where innovation is a constant concern. In an SME the formalisation of the organisation is a critical point for the optimal management of resources. If the process is predefined at a global level, actors from all departments work daily in a context of "mutual fit" and this organisational aspect is rather incompatible with PLM functionalities. When establishing specifications for an information system in an SME, it is an important issue to: identify what must be really controlled and so predefined through a workflow; and what must be encouraged and not detailed. For example collaboration between actors cannot really be defined through existing project plan or workflow concepts. The collaboration processes are quite unstructured and the interaction between the various project teams' points of view leads to informal and unofficial information exchanges [Blessing 1994]. The management of product development

processes in PLM systems requires greater flexibility in the activities [Roozenburg and Eeckels 1995]. This flexibility notion is essential in order not to rigidify the design processes and to allow the possibility for the project manger to adapt these processes in accordance with the progress of the project. Moreover, the project-oriented approach in these systems must be improved in order to make a stronger link with document-oriented flexibilities and for a complete implementation of the proposed model for project coordination. So, flexible workflows linked together must be studied in order to structure the whole design process. Moreover, existing Windchill^{TM} concepts can be extended (as presented in Figure 57 and Figure 58) in order to directly implement the proposed model of coordination.

A second significant issue concerns the process modelling using activity diagrams and sequence diagrams. Such diagrams can be used to describe both the global process of the project and detailed document-oriented workflows. Consequently, in Ederena, the processes of the project and the management of documents are defined precisely and this leads to better project coordination.

6.2.3 Synthesis

IT systems like PLM systems support the management of documents and partially support the management of projects. Nevertheless, prerequisite tasks are indispensable in order to carry out the implementation of such a tool successfully. In fact, this work highlights the fact that the implementation of a PLM tool requires a prior step of rationalisation of the company's work. However, this rationalisation process often leads to a generic representation of the organisation that is too limited in some aspects (as was shown in the implementation of the PLM prototype):

- This representation tends to simplify the complexity of the socio-technical operations. For example, most of the time human factors are not adequately represented in the proposed generic model.
- This representation is mainly rigid as the proposed architectures are often very stable and predefined.

The proposed methodology of prerequisite tasks is based on the specific context of SMEs. Although the main steps are general and can be applied in both the context of SMEs and of large companies, the details of this methodology are specific to the context of the case study. Moreover it is specific to the document formalisation of the company; it is an internal representation of its organisational structure and results from several iterations of testing in order to match the prerequisites methodology to the reality of the company. The next step for the company will be to translate its internal representation into a classical representation such as IDEFØ or UML in order for it to become understandable by

everybody (inside and outside of the company), and to match these representations with administrative standards.

The methodology of prerequisite tasks formalises many organisational aspects but in order not to stifle the emergence of innovation the flexibility factor must be kept in mind. The introduction of flexibility could be made during the definition of the design and during the implementation of the tool. During the definition of the global process, short cuts can be defined by project managers according to the design situation of the whole project (product, customer, problems) in order to have various "ad-hoc" sub-processes which increase the level of flexibility of the global process. In Ederena, the possibility of defining these "ad-hoc" sub-processes in the milestones has been introduced. In other companies, during the implementation of the PLM tool, integrators can carry out, for example, the introduction of flexibility in the processes of document validation in a similar way. A specific tool could also be implemented: this means the implementation of a tool oriented toward the needs of the company for managing documents and design projects. Nevertheless this solution is onerous in terms of time, money and IT implementation process.

Moreover, for example, in Ederena the relationship between the Marketing Department and the Technical Department is complex. The Marketing Department gives customer information to Technical Department which then has to estimate the cost to manufacture the product. This activity is formalised and planned with tasks and milestones, but the actors may use various forms of collaboration to complete these tasks. For example, several scenarios were observed which represent different forms of collaboration in carrying out this collaborative activity: actors can collaborate in a synchronous or asynchronous way, in the same place or not, with or without guidelines to carry out their work and so on, with scheduled tasks, non-scheduled guidelines or only objectives, being autonomous … These alternatives depend on the situation and the collaborative practices used in the company. It was observed in Ederena that in innovative projects and non-routine activities the project managers prefer to maintain flexibility by using "encouraged collaboration" in order to let actors be reactive. This example shows that the same activity can be carried out through several forms of collaboration. Thus scheduling is not enough for the project manager to describe the conditions for achievement of a design situation. He can choose, define, or encourage several forms of collaboration in order to define the inter-actor exchanges.

The collaborative aspect must be studied to help project managers to define not only a schedule but also prescribed interactions, methods and tools between actors, depending on each design situation. In this way some flexible and detailed sub-processes can be defined.

Thus, project managers may have difficulties in choosing the form of collaboration in accordance with the specific context of the design situation in order to keep enough flexibility in the processes and to have the adequate situation in order to not stifle the emergence of innovation.

Thus the main problem for project managers is to choose the appropriate form of collaboration for each design activity. A solution is based on the analysis of existing practices in order to understand which form of collaboration is relevant to a design situation. This analysis is the more convenient way to solve this problem because every design situation is different and no existing model or experiences can help project managers to choose the appropriate form of collaboration. Thus the analysis of the collaboration will allow the anticipation of future design situations and helps the project manager to choose the appropriate form of collaboration.

After the re-organisation of the Ederena structure and the prototype implementation it was observed that the coordination of projects by project managers must take in account the collaboration aspect. Thus the next objective is now the study of collaboration and project management in order to introduce flexibility in a formalised process and the evaluation of the collective performance in a project. Consequently, experiments on new projects are carried out in order to improve project management by fostering the collaboration between actors, and by integrating flexibility into the design processes. Concretely, projects are followed in order to track and record the events occurring during projects. The tool CoCa is used in this study to record information on the collaborative events occurring during projects. Thus, the CoCa tool has been tested in an industrial context and will be upgraded. The main goal of these experiments is to demonstrate that the stored information on events is the basis for analysing the collaborative practices used in these events. This analysis helps project managers to take decisions, and coordinate the project.

In the next section, the analysis and evaluation of collaboration with the CoCa tool is presented with the intention of helping managers to identify "good practice" and to define flexible design steps in the product design process and the appropriate type of collaboration between actors.

6.3 Analysis of Collaboration to improve project coordination

This section deals with the analysis of the collaboration and its impacts on guidelines and improvements in design coordination. Each design activity has inputs like customer's needs, requirements, constraints… and outputs such as: production description, drawings, product, instructions… Actors collaborate during their design tasks to reach the objectives (decision-making) set by project managers when coordinating. The CoCa tool is used to collect data on the collaboration in design activities. This data is used to analyse design collaboration which leads to the evaluation of the collaboration and coordination in order to define guidelines to improve the future coordination (Figure 62).
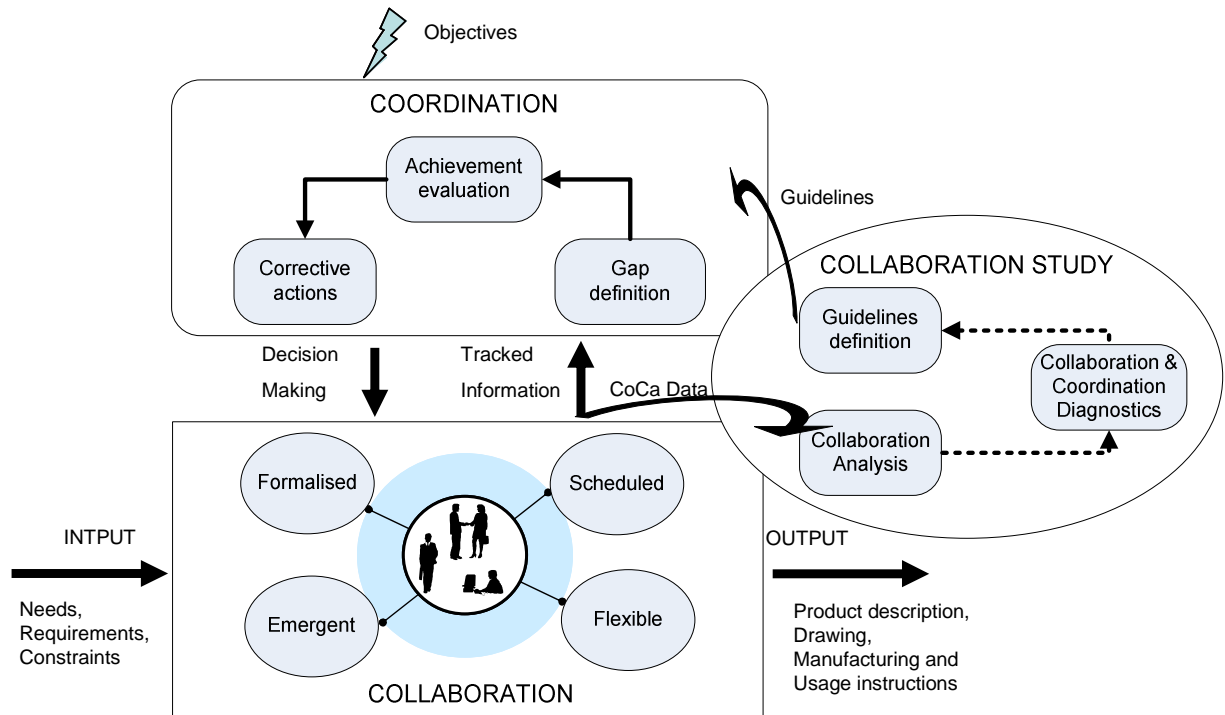
Figure 62: Collaboration study of design activities

The next sub-section describes how the Coca tool was used to track the information on the form of collaboration in the industrial case study. Then several examples illustrate the information that can be stored and what analyses can be achieved. The last sub-section will summarise the approach used in making the analyses.

6.3.1 Collecting data

In the industrial case study, the CoCa tool was used to follow several different projects:

   - AGV7: The customer is Company A[4] (a global leader in power and rail infrastructure) who demands a quotation to manufacture bonnets, for the train engine. First the project is about a prototype named "pegase" for the end of 2006 and leading to the manufacture of the series named "AGV7" in 2007.

   - TGV Duplex: The customer is Company A again which asks for quotations from their suppliers each year with regard to the internal partition panels and floors for trains.

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[4] The names of the companies are hidden for confidentiality reasons.

- Irish rail table: The customer is company B who manufactures all kinds of trains such as high-speed trains, light rail vehicles, locomotives, passenger coaches, freight wagons and etc. The demand concerns the manufacturing of tables for the Irish underground railway.

- Tong: The company C manufactures chip making machines in Taiwan. This project deals with the manufacture of the centre table of a chip making machine. This project is not finished yet.

- Lift: The company D manufactures lifts and demands a quotation to manufacture the floor of a lift.

All these projects concern the manufacture of products by bonded sandwich structure in composite materials glued together.

6.3.2 Example 1: Task analysis

- Analysis and evaluation

This example takes place in the project "Irish rail table". It concerns the RHPT (Weekly Review of the Technical Department) event (Figure 63). RHPT is the first general meeting of the technical department, i.e. the first collaborative event of the project. In this event the project manager allocates tasks and deadlines to each actor involved in the project
In this example the local evaluation and analysis are explicit enough to understand the problem. During this event, some technical traps have been identified by the actors.
The possible design traps concern the specific norms on "fire / smoke" for the materials used to manufacture the product. Moreover the designers worry about the resistance of the future product to fatigue.

- Diagnosis

The gap between the real analysed situation and the objectives must be evaluated. In this example, the materials used to manufacture the product are a new pairing (aluminium with stainless steel); no tests have been already done to test such glued assembly and its fatigue resistance. These tests take a long time (real situation) and the lead time is very short (objectives). Tasks corresponding to these tests do not exist in the existing design process formalisation.

Figure 63: Evaluation in the event RHPT of the Irish rail table project

- Guidelines for coordination

From the analysis and the diagnostic of this example, the project manager decides to modify existing design methods in order to integrate new steps to avoid such traps, and to make specific tests for "fire/smoke" norms validation and for product fatigue resistance.
Thus, the new design steps are defined to test the assembly and the fatigue resistance early in the design process and record the results for a future use of these materials. These guidelines for coordination deal with the improvements of the product development and project management processes. In this example, the analysis of this event helps the project manager to make the processes evolve during projects and to avoid making the same mistake again in future projects. Moreover in the definition of the design processes, the project manager can select the desired form of collaboration for each design activity. Thus, the analysis of the collaboration helps the project manager to choose a form of collaboration adequate for the future activities.

In this section the evaluation of one event alone has led to the characterisation of guidelines. In the two next sections, other examples show how a global analysis is

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performed through the study of several events from the design process and their mutual analyses.

6.3.3 Example 2: Local process

This example takes place in the project "AGV7" and concerns the event "Need definition". During this event the objective is to define and validate the detailed needs of the customer in order to draw up the specifications of the product (Figure 64).

Figure 64: Analysis of the event "Need definition" of the project AGV7

The beginning of collaboration analyses is often focused on the local analysis and evaluation of an event. In this example the local analysis shows that in this event "need definition", the parameters characterising collaboration are contradictory: three of them namely "consensus collaboration", "high motivation" and "constructive communication" have a good level but "productive collaboration" has a bad evaluation. The comments

explain that actors are fully involved but they do no have enough free time to take new tasks in charge (Figure 64). Thus there is no real participation of the actors: despite appearances to the contrary actors do not propose tasks that would be added to their existing and time consuming tasks.

The links identified with other events lead to a more detailed description of the problem. The tasks are time consuming if comparing this product with a previous one: identify the references for each car, identify the standards and some of possible combinations and draw a schedule… as mentioned in Figure 65. For all these tasks the lead time is very short: only three days to complete them!

The main problem incoming in this event is a lack of time for the actors to carry out the tasks.

Figure 65: Links of the event "need definition" in the AGV7 project

- Diagnosis

In terms of diagnostics, there are problems of management of project teams that lead to this kind of behaviour. The project manager has to manage the workload of each actor in order to know exactly at any time who has enough time to do the work. Moreover the project manager has also to manage the "skill pool" of the team, indeed to accurately know what the skills of each actor are in order to associate the right task with the right actor. Consequently this problem is a problem of project management: the project manager must be able to evaluate the design tasks to do in order to assign the right actor to the right task in order to get the best performance in achieving this task.

- Guidelines for coordination

A possible solution 'a posteriori' can be to negotiate a larger period of time with the customer; this is how the company generally manages delays. However, that can be difficult and another kind of preventive solution is to manage the skills and the experience of the designers differently by, for example, choosing the more skilled designers when the delay must be short. A third preventive solution could be to improve the way the project manager and the team manage designers' time and priorities between different projects in a multi-project environment. Both of the latter solutions are new to the company and its inexperienced project manager.
Consequently, the possible guidelines can be made at several levels. First in the short term, project managers can manage the actors' workload better, and use a scheduling tool to manage the multi-project environment. Second in the long term a strategy for skills management can be defined then applied. These guidelines will allow the assignment of the right person to do the tasks and to anticipate possible problems of overbooking tasks. Finally, project managers can improve their own technical skills in order to achieve a better control of task definition.

These guidelines are defined through the analysis of a local sequence of events. These guidelines must be added to the global guidelines which emerge from the global process analysis.

6.3.4 Example 3: Global process

- Analysis and evaluation

This example takes place in the same project "AGV7". It is based on the global context of the project in order to go deeper in the analysis of the collaboration. This global context

gives a global view of the events of the project, and therefore the links between events. This context ensures the capture of the global view of the project in order to facilitate the interpretation of the various collaborative practices occurring. Information about actors, the customer, and any other data like the impact of the project in the strategy of the company, or any text field to refine the description of the context of the project are included (Figure 66).

Figure 66: Context project of the AGV7 project

This context shows the list of the events occurring in a project together with the links between them. After having stored the context of the project, CoCa ensures the capture of detailed information about the context of collaborative events included in the project. Events are so contextualised for a specific project context. For example Figure 65 shows

the consequences of the problems from the event "PAT" toward another one named "need definition".

All these links (Figure 66) show the design process and allow the rebuilding of the sequence of the events of the project from the original event to the event where a problem is identified.

In this design process the collaborative criteria gives complementary information on the events occurring. In Figure 67, the event "tools design" is characterised as an emergent, free and non-formalised event.

Figure 67: Collaborative criteria of the project AGV7

-   Diagnosis

Both project manager and technical team did not define some technical tasks such as "tools design", and thus the design process must be improved.

The combination of information allows the identification of different kinds of results:

- Establishing links between several events.

- Establishing correlation between several parameters of different types between several events.

In this example, we can see that the event "tool design" is completely emergent. Indeed this event was not included in the schedule, it has not been planned.

- Guidelines for coordination

The identification of such a situation shows that some important events are not planned in the initial design process. The possible guidelines can be based on the introduction of "nodes" of flexibility in the design process. Indeed this leads to the definition of possible alternative sub-processes in the main design process that will be implemented during the project because such events cannot be planned and defined at the beginning. So, these sub-processes will add new sequences into the design process according to the evolution of the project. Moreover, these kinds of sub-processes can be managed automatically in the design process by a PLM tool for example.

As for the example 1, the guidelines of this example 3 deal with the definition of the design processes. Moreover, with this global analysis, the guidelines of the example 3 are more global and oriented towards the introduction of flexibility in the design process than the example 1.

6.3.5 Approach to analyse the collaboration with CoCa results

As can be seen in the previous examples, in the case study; a systematic and global method can be used to analyse the CoCa data. Firstly, the entry point is the analysis and the evaluation made "on the spot" during the data recording and the "problem" links which help the analyst to begin the analysis. These evaluations and analyses give a first overview of the situation and orientate the analysis toward other parameters or events in order to make correlations between them. Secondly, the analysis of events is achieved with the local context and the collaborative criteria in order to have detailed information that will allow understanding of the whole situation and its origin to finalise the analysis. Afterwards the same approach may be repeated for each event linked with another one. And finally the global context of the project may be studied to correlate all the information found from the beginning of the analysis with the global context of the project. At the end of the analysis the analyst has identified situations where technical problems or problems of collaboration appear, or where the collaboration is useful and "good practices" can be identified. This identification is based on the analysis of the CoCa results. Based on this identification and

on the complete analysis the analyst can then propose "guidelines" to improve the design coordination.

6.3.6 Synthesis

Section 6.3 shows the consequences of the analysis of the collaboration in defining guidelines for coordination. The data collected by the tool CoCa is used to analyse the form of collaboration, to make diagnosis on the collaboration and finally, to propose guidelines in order to improve the coordination.

The test of CoCa tool in the industrial case study confirms that the analyst can make an analysis of the collaboration in order to improve the coordination (the amount of data collected is: 6 projects, about 100 events and 12 versions of projects).

The data collected with the tool allows the analysis of collaboration to be made by also:
- Comparing the form of collaboration used in different projects.
- Comparing the theoretical process planned by the Quality Department and the real design process completed by the designers.

The analysis using the CoCa tool allows the definition of extra steps or processes in the global theoretical process based on these defined guidelines. These guidelines lead most of the time to the introduction of flexibility in the design process.

Thus, these guidelines defined thanks to the analysis of the collaboration impact directly the way of coordinating projects. The next section shows the consequences of these guidelines in the industrial case study. The consequences are about the introduction of flexibility in the design process, thus we are going to see how flexibility can be introduced within a PLM tool, and the improvements to the coordination.

6.4 Coordination improvements and flexibility introduction in the design process

The analysis of collaboration aspects leads to the understanding of the forms of collaboration occurring. This collaboration analysis allows the definition of guidelines for improving coordination aspects such as for:
- The definition of the organisational structure including internal structure, external structure and definition of the project phases. The project manager manages and adapts the project team based on the skills and roles required in the project,
- The definition of the future global and detailed design processes by describing the product development process and the project management process separately. This

definition is based on the identification and scheduling of the right design process. The analysis of collaboration aspects helps the project manager to define (or adapt for projects in progress) these processes in a flexible and detailed way,

- The selection of the form of collaboration for each design activity with the co-ordination rules (direct supervision, mutual agreement or normalisation), with the desired kind of communication between designers (diffusion, collection, circulation, exchange, meeting, knowledge sharing), and with the definition of a preferred type of collaboration (free or forced, synchronous or asynchronous, in the same or different places).

6.4.1 Consequences for the project manager

The analysis of collaboration leads to the definition of guidelines in order to improve coordination aspects and the implementation of detailed design processes. Guidelines are indications, advice given by the analyst to the project manager in order to help him improving the coordination of design, i.e. the organisational structure, the design process definition, the methods and tools to be used by actors, or the way that actors may collaborate. As we have seen in the previous section 6.3; analyses and diagnostics of the collaboration are described through three examples and some guidelines are proposed to illustrate how coordination can be improved. Some guidelines lead to the formalisation of more detailed processes and towards the introduction of flexibility in the design processes. This flexibility is a primary concern for SMEs in order to remain reactive in view of the unpredictable nature of design.

In Ederena, the global and defined design process was predefined and rigid. Now, with the guidelines, the design process is still predefined but also more detailed and flexible to take into account several possible design situations. The management of the design process is based on the scheduling, monitoring and control of the design activities.

The guidelines allow the:

- Formalisation of the design processes and activities to a greater level of detail,
- Definition, the control and the monitoring of tasks for quality control and project management,
- Establishment of flexible nodes in the design processes. These nodes are formalised by milestones in the process where project manager must take decisions about the design process to be scheduled using adequate criteria. The criteria are based, for example, on performance indicators, design objectives, completed process analysis, diagnosis of the progress of the project, technical results…

6.4.2 PLM specifications to support coordination and collaboration

The implementation of a PLM tool based on the coordination model has been presented previously in section 6.2. In this section the impact of the analysis of the collaboration and resulting guidelines on PLM tool implementation is studied. The specific implementation of a more detailed and flexible design process is presented through:
- The workflows to model the design processes,
- The lifecycles to manage the various states of the documents,
- The project team management in order to assign an actor to a role,
- The management of the document access according to design actor.

The study is based on a specific sub-process from the industrial case study: the CND (Customer's Need Definition) process. This example has already been introduced in Chapter 6.1.5 and is used in this section to show how the analysis of the collaboration with Coca can lead to the proposition of possible guidelines and how these guidelines can be introduced into a PLM system.

Context:
Initially, the CND document was managed entirely by the marketing person who builds it and validates it in collaboration with the customer. Indeed, this design phase defines the specifications of the product from the need expressed by the customer. First the marketing person defines the CND document with the customer, and then he validates the document and sends a notification to inform the technical department that the document is complete and asks them to make a quotation. In the PLM system this process is introduced through a workflow that manages the lifecycle of the CND document as is shown in Figure 68.

Figure 68: Initial CND process

Analysis of the collaboration:
From the analysis of this initial situation various problems were identified:
- The description of the CND process is too global and does not incorporate any details and flexibility.
- Only the marketing person is involved in the validation of the document.
- However, the marketing person does not necessarily have the adequate technical skills to deal with every customer.
- He may not have enough time to carry out all of the CND process.

-   Problems of data management appear between the Technical and the Marketing Department.

With the analysis of collaboration with the CoCa tool, the project manager can define guidelines and more detailed processes depending on the situations encountered. As a result, the CND process is updated and is described by the following points (see Figure 69):

-   The marketing person evaluates the needs of the customer, he may then select one of the four following tasks:
    · Validate the CND document.
    · Reject the project directly if the customer needs are not appropriate for the company.
    · Meet the customer alone in order to make a deeper evaluation of the needs. Afterwards the project then the CND document can be rejected or validated.
    · Meet the customer with a designer if technical skills are necessary ("customer visit 2"). In this case the CND document arrives at the state "study" without validation.
    If the CND document is validated, it moves to the state "study" in which the CND document is under control of the designer.

-   In the state "Study", the Technical Department make a design evaluation of the CND document and the designer may choose between four alternatives:
    · The CND document is validated if the necessary information defining the specifications is correct and complete.
    · The CND document is rejected with information to the Marketing Department and a notification to the customer, if the needs of the customer do not fit with the company know-how.
    · Nevertheless, an extra visit to the customer can be planned by the designer alone in order to finish the CND document definition.
    · An extra visit can be also made by the designer with the marketing person in case of a strategic project.
    For last two alternatives, the meeting is followed by a combined validation (between the Marketing and the Technical Department). Then the CND document is validated, rejected, or extra work is necessary: for example if the needs do not fit exactly company capabilities, but a quotation can be made by involving external partners.
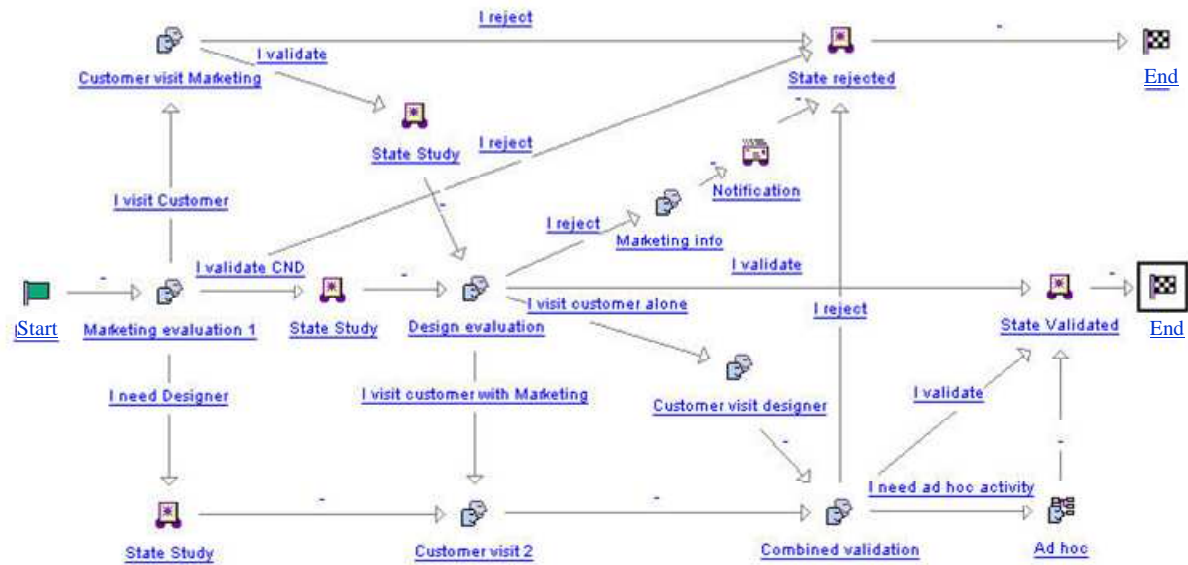
Figure 69: Final CND process

In this last case, this extra work is converted into an "ad hoc activity" introduced into the process just after the "combined validation" and before validating the CND document. This "ad hoc activity" allows the creation of non-predefined activities dynamically. For example, it is typically a solution for the problem of Irish rail table project presented in the example of the section 6.3.2. In that example the presented RHPT meeting corresponds to the combined validation meeting where the technical and marketing departments evaluate the document. During this meeting, the project team notices that the materials must be tested, in particular on the fire/smoke reaction before the validation of the customer's needs. These tests are indispensable to validate the feasibility of the product with these materials. This emergent activity (not planned previously in the design process) needs to be managed and must be included in the design process. Thus, the "ad hoc activity" can be used to implement the fire/smoke test on the new assembly materials for specific actors, therefore giving the right information that determines whether or not the CND document is validated.

There are many benefits from this new CND process. Firstly the process becomes more detailed and flexible than the previous process. Then, the problem of technical skill is reduced thanks to the involvement of the technical department earlier in the process. Finally, the workload of the marketing person is improved because in the final process, the visit to the customer by the marketing person is not always necessary and depends on the characteristics of the project.

Nevertheless, in this new process the level of flexibility is limited, because it is introduced at the beginning during the creation of the process with the routing between the different activities. Thus, the process becomes more flexible but in the face of the unpredictable nature of the design, the process is not immediately reactive. Indeed the actors have to wait for a routing point (a node of flexibility) to be able to take advantage of this flexibility and to take a decision. The reaction cannot be made instantly after the emergence of design changes. Thus the ideal objective of the coordination is to manage projects in real time with a flexibility which is continuous and evolves dynamically. So, this solution with PLM systems, based on detailed processes with the introduction of some flexibility is only a partial solution. From the results of the case study, it has become clear that some further areas need to be addressed. For example: actors and skills management, triggering events, merging documents workflow and project process, and also the ability to re-use and build planned/completed/modified processes. The implementation of the task concept is not satisfactory: it is not clear how input and output information may be defined other than through deliverables and the elements to make decisions cannot easily be formalised.

6.5   Synthesis

We have seen in this Chapter 6 how the analysis of the collaboration with CoCa tool can be used to define guidelines for improving design coordination aspects.
The analysis of the collaboration form is drawn up by a combination of different information:

- The establishment of links between several events,
- The establishment of correlations between several parameters of different types between several events.

The study of the collaboration is composed of three main steps: analysis of the form of collaboration, diagnosis on the collaboration and coordination, and guidelines definition for improving coordination. These guidelines deal with the management of the organisational structure of the project (team and skills management), with the definition of detailed and flexible design processes and with the selection of the adequate form of collaboration for each design activity.

The analysis of the collaboration helps the project manager to adapt and manage the design team during projects. This management implies the choice of the right person for the right role in the project; and the training of an actor to specific situations in order to improve his know-how. The example 2 (section 6.3.3) illustrates this problem of team management in a real case.

The re-organisation and process re-engineering for design coordination demonstrates the importance to structure projects into processes and to manage the product data. In this situation the main issue is to retain enough flexibility in order to allow actors to keep the necessary amount of freedom to collaborate. During the industrial case study observation it was noticed with the analysis of the collaboration that schedule was not detailed enough and both project manager and technical team did not define some technical tasks. The examples 1 (section 6.3.2) and 3 (section 6.3.4) illustrate this problem of design process definition. So, the analysis of the collaboration leads to the improvement of the design processes through different approaches:

- by analysing and defining the specific parameters of situations encountered,
- by introducing tasks to make decisions (like milestones) before "risky" situations in the existing design process in order to introduce flexible sub-processes and to not stifle collaboration,
- and by introducing more detailed tasks sequences into the design process.

It was shown in the example of the CND (in the section 6.1.5) that a design activity can be carried out in various different ways by the actors. The analysis of the collaboration with CoCa helps the project manager to identify these different ways and to select the desired form of collaboration by defining: the co-ordination rules, the desired kind of communication between designers, and the type of collaboration.

Consequently, the tool CoCa allows:

- Establishment of a memory of design projects according to collaboration point of view,
- Fostering of the understanding of design collaborative activities,
- Improvement of managers' decisions.

We have seen also that a product data and process management tool is an information system that can support, with limitations, the design coordination. Thus, this information system needs improvements to manage projects properly. The solution based on the formalisation of detailed processes and their use into PLM systems is only a partial solution because this solution does not take into account the collaboration aspects. These collaboration aspects are very important to understand all the factors influencing the coordination.

As we saw in previous section 6.2.1, the prerequisite tasks are indispensable before implementing product data and process tool. So, during the implementation of the prerequisites, enough flexibility must be kept in processes to foster collaboration between designers in order to not stifle the emergence of innovation.

The product data and process management is a main concern of the companies. It is almost indispensable to implement a tool in order to help actors in data and process management. At this step the question appears of what sort of tool is more convenient for the company situation, a specific or generic one. A specific tool is burdensome in terms of resources: there must be sufficient IT skills in the company otherwise these skills must be brought into the IT Department, from the outside to manage these systems. Implementing such a tool is a long process requires people in charge of its maintenance is indispensable, both in order to solve problems which occur during its daily use and to customise the tool according to the specific situation of the company. However, such a specific tool would have the adequate functionalities for the specific context of the company.

Implementing a generic PLM tool is also burdensome, difficult, and expensive. In the case of SMEs the costs may be reduced, but generally the match between company needs and the configuration of the PLM tool is not complete, especially for implementing the complete design coordination principles. Moreover, a PLM tool cannot manage the global process of a project because it only manages documents and their validation processes. It is possible to add extra specific tools linked with generic functionalities supported by the PLM tool, for example, a specific tool can be used to manage the development product process from the project manager's view.

In the short term, the consequences of the collaboration analysis are focused on improvements for design coordination. These analyses of the collaboration lead to a better definition and formalisation of the design processes. Nevertheless, the project manager must take care to not rigidify the design processes by too many details. Thus, we are going to see in the next Chapter how the project manager can formalise detailed design processes whilst keeping enough flexibility to react dynamically in the face of the unpredictable nature of the design.

7 Discussion

In the previous Chapter "Results", the outcomes of this research work were presented. These results aim to support the coordination of projects. They are based on the definition of an organisational structure and design processes. On one hand, the possible tools like PLM tools are studied and tested to manage the coordination of projects. On the other hand, the analyses of the collaborative practices are explained. These two last results are the basis for the definition of possible improvements for design coordination. Consequently, this Chapter 7 "Discussion" sets out to evaluate the work carried out during this research in terms of synthesis, discussion and possible improvements. This approach is essential to stand back from these results and to propose new perspectives and further evolution. This discussion deals with the CoCa tool, the analysis of collaboration, coordination in design projects and the tools to support the coordination and collaboration in design such as PLM.

7.1 Implication for CoCa tool

The CoCa tool has been presented previously in terms of its design definition, implementation, and use in an industrial case study environment to analyse collaboration. Now a synthesis, a discussion and possible improvements to CoCa are given.

7.1.1 Synthesis on the CoCa tool

The use of CoCa helps project managers to take into account collaboration aspects in the coordination of projects. In this domain, project managers often have an approach to coordination based only on task scheduling and control. At present, the interactions between actors are not completely taken into account in project management. The introduction of collaboration in design coordination starts with the analysis of the collaboration in order to understand the forms of collaboration used and to propose adjustments for design coordination.

The CoCa tool groups three main functionalities: data recorder, structured database and visualisation of data. The data is recorded in real time during the evolution of a project. For each incoming event of a project, a lot of information concerning collaboration is stored. The event could be a formal event such as planned meeting or an informal event such as a coffee break.

All the information is stored in a database structured according to a model of collaboration oriented toward the characterisation of the collaboration. Finally, various GUI forms are used to visualise the recorded data. This visualisation aims to help the analysis of the collaboration by representing the links of chronology, problem and causality between events in order to have a view of the interaction between events and therefore make correlation easily. One of the most important results of the use of the CoCa tool is the establishment of a memory of design projects by taking into account collaboration aspects. CoCa records all the design events with their characterisation in terms of collaboration criteria and practices. Formal and informal events are captured with the tool as a "camera" focused on the project's progress. This characterisation of design events is essential to complete the collaboration analysis successfully. With the tool, the actual design process completed is recorded in order for it to be compared with the theoretical design process initially defined by, for example, the Quality Department. This comparison allows the quality references (documents, processes, recommendations…) to be adapted to the real references used during the design work by the actors.

7.1.2 Discussion on CoCa tool

The CoCa tool captures events, formal as well as informal ones; but it is very difficult for the analyst to be present at all the design events of a project in order to record all the necessary data about them. Moreover, sometimes various events occur simultaneously but not in the same place, thus the analyst cannot record all of these events. Most of the time, in reality, when the observer cannot be present at an event, he records the data about the event "a posteriori" through interviews with the actors concerned. Although the recording of data after the end of the event is possible, some of data could be forgotten or recorded with an incorrect interpretation. Thus, the choice of the right person is difficult. The analyst can be the project manager because he follows most of the events of the project, but most of the time he does not have enough time to record the data in his daily work. Other persons may be chosen to fulfil this role of observer or analyst such as, for example, a quality person, trainees or researchers. Moreover, this observer role needs to be as neutral as possible to limit the subjectivity of input in the recording of the data with CoCa. This point is developed in the next section 7.2.2 for the discussion on collaboration analysis.

The same GUI forms are used to record and visualise the data. Indeed, the GUI forms of the tool have been specifically implemented for the capture of information and not for its display or to support the analysis of the data. Nevertheless, it is possible to analyse the collaboration with the data recorded in the initial GUI forms; but the analyst has to look for the right data in them. Thus, at this stage the GUI forms to "search" or to visualise data in an optimised way are not completely finished yet and will be implemented in the next version of the tool.

The analysis of the collaboration on projects in Ederena has been validated as was described in Chapter 6 "Results". Nevertheless, more experimentation is needed with more design projects in order to compare these analyses between projects themselves. This sort of comparison allows multiple-analysis of the collaboration, to identify other "good practices" and to make correlations between events from various projects.

Some caution is needed in respect of the use of CoCa in SMEs. The main caution concerns the organisation of the company, since most of the time in SMEs the projects are not managed as in large companies. In SMEs, one person may be in charge of the whole project and may ask a second actor for help in order to achieve his objectives. This second actor may not be clearly identified as a member of the project team. Thus, the person in charge of the project may accumulate various roles in the project. Indeed, for example, the project manager can also draw up parts, contact the customer and manage the raw material. So, the exchanges between various design roles in large companies are reduced in SMEs if these roles are taken by the same actor. Consequently, the importance of collaboration grows with the number of actors.

Moreover, this thesis has shown that CoCa is an additional and useful tool to help project managers to analyse collaboration in projects. Nevertheless, the aim of this tool is not to replace the corpus[5] written during project on the way that actors' work. This traditional corpus used by the analyst is another way to make this kind of analysis and can be carried out in parallel of the use of CoCa.

7.1.3 Version 2 of CoCa tool

CoCa is a tool which helps the analysis of collaboration. Nevertheless, based on previous discussion and limitations identified, various improvements may be made in order to improve the analysis.

- Links: In this first version, the CoCa tool provides two sorts of links, the "problem link" and the "causal link" described in a previous Chapter 5.4. In terms of improvements, another type of link could be used such as a "Warning" link to show a potential danger, or to focus the attention on an event; or a "Question" link where one question (on the form of collaboration) is unanswered and may be answered later in the progress of the project.

- Data display: The display of data is limited to the GUI forms also used for data capture. Thus, various functionalities must be implemented in order to drive the analysis of the collaboration. Consequently, new GUI forms are currently under

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[5] Corpus is a group of documents written by analysts during their intervention in a company and these documents play the role of a reference for knowledge sharing in a specific domain.

implementation to improve the analysis process by semi-automated and statistical treatments. These statistical treatments will be able to show critical recurring situations by charts, curves and graphs. The first improvement on the visualisation functionality concerns the visualisation of the events with their links in order to display the project process and the problem, causal and chronological links (Figure 70).
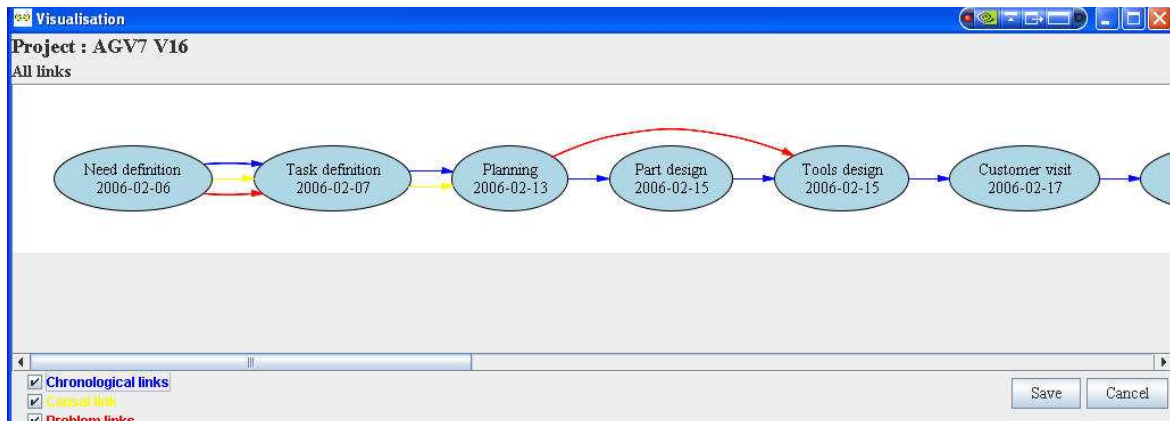
Figure 70: Visualisation of the event sequence with the three links

The analyst can choose criteria to display the event sequence of a project (Figure 71). He can choose the version of the project context, a period between a start date and an end date, and the kind of links to display (causal, problem and chronological).

Figure 71: Visualisation criteria

Moreover the analyst can ask for a display of only the "problem" or "causal" links in order to concentrate on the pairs of events linked by these types of link. Thus, the chronological links do not interfere with the visualisation (Figure 72).
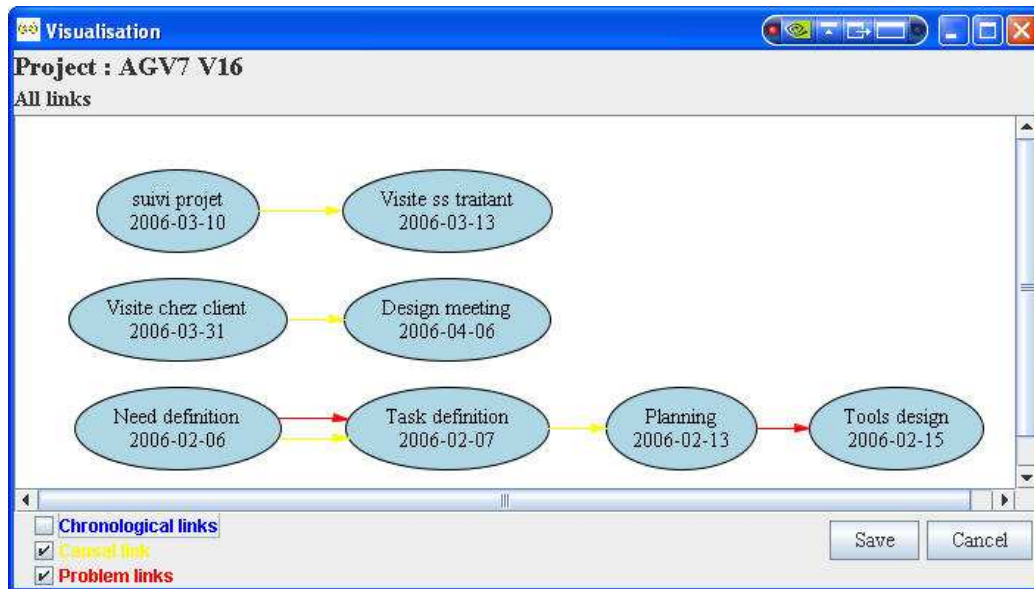
Figure 72: Visualisation of the event sequence with causal and problem links

The implementation of this improvement is now operational.

-   Multi recording: The observer encounters difficulties in the use of CoCa because he needs to be present at each event, and only one view-analysis is managed by the tool. Thus, the next version of the CoCa tool will be able to record data from several observers in order to make "multiple points of view-analyses". Thus, the problems of observer location and subjectivity will be limited and the interviews "a posteriori" will be used less and less. The use of the CoCa tool takes time, and observers would often like to reduce this. Therefore researchers interested in the collaboration or coordination in an industrial context could be introduced in the company to play the role of observer in addition to their role of researcher.

-   Sponsorship: It was noticed during the experiments that the analysis of collaboration is closely linked to the experience of the analyst. In terms of improvement it could be proposed that an experienced observer could be assigned to any new observer in order to train them to analyse collaboration.

- CoCa for light and portable systems: During the test of CoCa in Ederena, it was noticed that the observers often do not have enough time to use the tool in their daily work. Thus, the implementation of a version of CoCa specifically for light and portable devices such as a PDA (Personal Digital Assistant) will help the observer to use CoCa during his daily work without taking notes, using a laptop, or recording after the event. The use of a light system by the analyst will help him to record data "on the spot" and will take less time.

- Semi-automatic storage of scheduled events: if CoCa is associated to a scheduling tool, predefined tasks can be directly created in CoCa in order that the analyst has just to record the collaborative criteria.

All these improvements are necessary in order to perpetuate the interest in CoCa in research as well as in the industrial context. For the moment, only the improvements to the display of the event links have been achieved, nevertheless the others improvements proposed will be implemented after the thesis in a postgraduate study. After the discussion of the tool, the next section will deal with the analysis of collaboration with CoCa results.

7.2   Implication for collaboration analysis with CoCa results

7.2.1 Synthesis on collaboration analysis

In Ederena, six projects with around one hundred events have been recorded with CoCa. The analysis of this data leads to (see Chapter 6):
- Identification of collaboration and coordination problems,
- Finding improvements in the collaboration,
- Definition of guidelines for project coordination,
- Detailing the processes at a low level,
- Predefining future design situations.

Thus the analysis of collaboration with CoCa results helps to improve design coordination aspects.

An approach to analysing collaboration has been defined during the case study (see section 6.3.5).

This analysis approach is an upward one; indeed the analysis begins with the analysis and the evaluation of individual events on the spot, then, an 'a posteriori' analysis of the events is achieved, and finally the analyst makes correlations between these analyses of events in order to have a global analysis of the project. It is easier to identify problems during the project and it is better to identify solutions before the end of the project with a global view.

Moreover, the links between events and evaluations and analysis "on the spot" support the achievement of an upward approach. This upward approach was tested and validated in the Ederena case study.

The analysis work is based on the combination of several pieces of data from the events that have been stored. Then the observer establishes links between several events and correlations between various parameters from different events. These correlations help to understand the collaborative design activities and to identify problems or good practices. Finally he is able to identify improvements in the form of collaboration used between actors according to their motivation, skills, interest, and the design situation. For example, the analysis of each stored event will allow the comparison of the main characteristics of the achieved collaboration and the evaluation of its positive/negative impact. This better understanding of the collaboration will help the project manager to identify in future projects an adequate form of collaboration for each design activity in terms of coordination rules (direct supervision, mutual agreement or normalisation), of communication type between actors (diffusion, collection, circulation, exchange, meeting, knowledge sharing), and of collaboration form (free or forced, synchronous or asynchronous, in the same or different places). Then, during new projects, he will be able to define more precisely these different elements when scheduling activities to his design team. Moreover, the project manager can adapt and manage the project team in order to assign an experienced actor to a difficult task or an inexperienced one to improve the actor's skills.

7.2.2 Discussion on collaboration analysis

The case study showed that the validity and the completeness of the data recorded are strongly linked to the experience of the analyst. Indeed, the analysis of collaboration requires a minimum of know-how about the collaboration and coordination aspects of design in order to evaluate each criteria during the recording and also to understand its significance during the analysis. The experience of the analyst is essential both in carrying out the analysis and in proposing solutions for design project coordination. It is well established in this study that the tool only provides support for the analysis of collaboration: it cannot give to the analyst a detailed and automatic analysis of the collaboration already done. Thus, CoCa captures and displays the information in a synthesised way with criteria and comments. The analysis with CoCa results is more orientated toward statistical or systematic analysis while sociological analysis is more orientated toward analysis of corpus, or video capture which focuses on the actors without taking into account the design aspects.

The proposed upward approach of the collaboration analysis begins with the study of the evaluations and analysis carried out "on the spot" and the links between events. Another approach can be imagined: a downward approach. Indeed, a downward approach begins

with the identification of global problems at the end of the project, and continues with a deeper analysis of the concerned events to find the causes of these problems. Nevertheless, this downward approach is not dynamically applicable during the project; the analyst has to wait for the end of the project to analyse the identified global problems. However, this downward approach can be coupled with the upward one in order to identify new elements not already analysed during the project.

In fact the way to analyse collaboration by using CoCa is not unique, and may be adapted to any specific method of analysis in accordance with the situation, or the analysts themselves. Nevertheless any sort of approach must include the analysis of collaborative criteria, coupled with the global study of the contexts, the links and the evaluation and the analysis made "on the spot".

The collaboration analysis in Ederena can be influenced by the analyst's subjectivity. Indeed, two analysts carrying out the same event can input different collaborative evaluations, because they do not have the same personal view of the event, the same involvement, knowledge of the technical subject, experience, or background. Moreover the comparison of points of view between two analysts can lead to the identification of new problems or the acquisition of new experience in their job.

This subjectivity is introduced in the analysis process in two main places: during the recording of data and during the analysis itself. During the recording of data, the observer is influenced by his own point of view and does not really record what he sees but what he understands. This difference between how things are, how things are understood and how things are displayed could lead to different results. During the analysis phase, the subjectivity of the analyst is included in the analysis in accordance with his own interpretation of the data. The analyst could interpret the words used in the CoCa tool differently, because for one analyst, behind each word (a word is information) there is a concept (a concept is knowledge), but for another analyst behind the same word there could be a different concept. At this stage of the study, subjectivity cannot be eradicated completely from any analysis. Nevertheless some propositions can restrict its influence by making the analyst as "neutral" as possible. A "neutral" analyst could be:

- An experienced researcher, but with caution on the misunderstanding based on the specifics and technical languages,
- An external person such as a consultant.

The analysis of the collaboration also depends on the level of granularity at which the analysis is made (Figure 73). Indeed, differences are noticed between analyses made at a detailed level (event) and analyses made at a global level (project). In design, various levels are taken into account when describing a situation. The global context is the project and the local context is the event but between these two levels there may be various intermediate levels of granularity, namely: projects, sub-projects, processes, sub-processes, activities and

events. In this study, a difference is made between "task" and "activity". This difference needs to be explained because most of the time, in design these two notions are used interchangeably. The main difference lies in the scheduling and the achievement of the activity or task. A task is scheduled and a task becomes an activity when it has been completed.
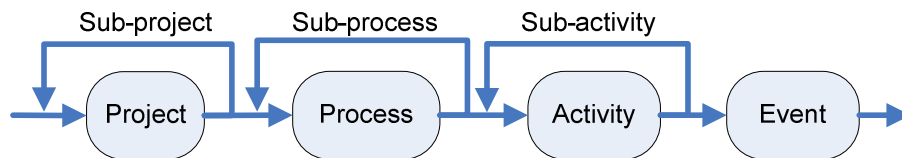
Figure 73: Levels of granularity in design

For example, a large project to design a plane is structured into various sub-projects like the "design of the wings of the plane" (see Figure 74). In this sub-project, various processes exist to complete the sub-project like "to validate the specifications of the front part of the wing". In this process, various sub-processes are defined to detail the main process like for example "to define the angle of attack". The sub-processes are composed of various activities. The actors carry out these activities to reach the objectives given for the sub-processes according to the coordination elements defined by the project manager: who, where, when and how these objectives have to be reached. For example the activities could be: "meeting with specialist", "propositions of angles", "tests in wind tunnel" and "validation". In each activity events occur, for example for the activity "tests in wind tunnel" events can be: "book the wind tunnel", "meeting before the tests", "implementation of tests", and "debriefing".
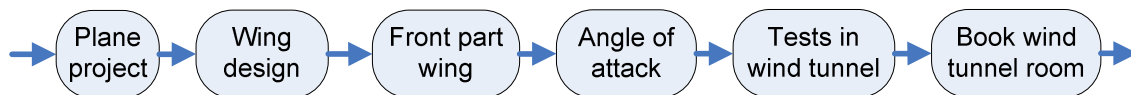
Figure 74: Example of granularity levels in a project in Ederena project

In this form of granular structure, information and comments have to be transmitted from the low level to the upper levels in order to maintain the information flow and to make decisions with all information known.
So, the objective of this example is to show what the granularity is and what the impacts on the analysis of the collaboration might be. Indeed, the analyst must decide at which level of granularity he wants to make the analysis: he can analyse the collaboration on one event (event level), or on various events (activity level), or on a group of activities (process level), or on the project (project level). The analyst has to make correlations between

analyses made at a same level of granularity in order to make more global or relevant conclusion on the upper level of granularity. This mechanism must be repeated several times to make an analysis at the project level. Thus analysis of the events will not have the same results and impacts as an analysis made on the whole project. The analysis of a whole project is labour intensive; such global analysis relies on several analyses at each level of granularity (event, activity, and process levels).

7.2.3 Improved collaboration model and approach of analysis

From the previous section 7.2.2 various propositions are possible to improve the analysis of collaboration.

The first main improvement concerns the automation of the analysis by statistical study. We have seen in the Chapter 6 that the method to analyse collaboration with CoCa material is carried out by correlations between criteria and information. These correlations are not easy to find. So, this automation will be based on the analysis approach presented in the Chapter "Results" section 6.3.5. This approach begins with the analysis and the evaluation made on the spot to orient the analysis. Then, correlations between criteria of these events are analysed and correlated. And this approach is repeated for each "critical" event in order to make a global analysis at the project level. Nevertheless, pre-requisites are needed before the analysis can be automated:

- To validate the way collaboration is characterised then analysed in various projects,
- To record enough data to make the statistics relevant,
- To define adequate statistical tools to manage the data.

Thus, the future work to make semi-automatic analysis lies in the implementation and introduction of statistical tools into CoCa. Semi-automatic analysis will be a requirement in the future because the amount of data will become too large to be managed without such tools. Two steps are necessary to introduce a statistical tool into CoCa. Firstly, the collaborative criteria have to be validated by for example correlation in a Principal Components Analysis (PCA), in order to sort the linked criteria and the independent ones. Indeed, in Ederena it was noticed during the analysis of collaborative events (section 6.3) that some criteria are correlated together. For example, as was presented in section (section 6.3.4) most of the time when the event is emergent then, this event is not formalised. Thus, a study of these criteria is needed on order to sort the criteria into dependent and independent ones with the correlation between them. This study is necessary to make a Principal Components Analysis. Secondly, the statistical tool itself must be implemented to exploit these criteria.

The second improvement concerns the approach to analysing collaboration. For the moment the approach begins with the study of the analysis and evaluations made "on the spot", but the improved method must be based also on a detailed statistical analysis of the criteria. This statistical analysis would provide a "check list" of critical information recorded with CoCa in order to drive the progress of the analysis. In the short term, an extra module is under implementation in order to support this method. This module will be used to show by graphs and queries the sequence of events depending on the type of links between them, and to notify to the analyst if the event has an evaluation or analysis created "on the spot". So, more studies are needed to have more data in order to improve the approach of collaboration analysis toward a scientific methodology. This second improvement demonstrates that the analyst spends a lot of time to find correlations between criteria. Thus, it will be interesting to automate a list of criteria with their correlations in order to support the analysis.

In the discussion section 7.2.2, the importance of managing the level of granularity in the analysis has been explained. In terms of improvement; the CoCa tool must be able to manage this notion of granularity. At present, the tool manages the higher level: the project, and the lower level: the event. In the next version, the tool must take into account the notion of processes and activities in order to have other levels of granularity and to record more detail on design situations. These improvements would have consequences for the initial model of collaboration (see Figure 34).

The consequences are mostly on the addition of classes to manage the level of granularity. For example, a class *Activity* must be created in order to manage an activity which is a sum of events like meetings, calls, mails... As for the *Event* class, *Activity* class as is linked with *Analysis*, *Evaluation*, *CollaborativeCriteria* classes in order to have more information on the activities and events than previously with only the *Event* class. So the *EventActivity* class has been added to make an inheritance to the class *Activity* and *Event (see Figure 75)*

These notions of granularity can be included in the improved model of collaboration by the links between the class *Process*, *Activity*, and *Event*. These links reinforce the notion of granularity in the model by recording each level of the project structure.
This improved model of collaboration becomes the new support for a future integration of collaboration into the coordination of design management. The improvements of the model would then lead to the improvement of CoCa in order to include this notion of granularity in the tool.
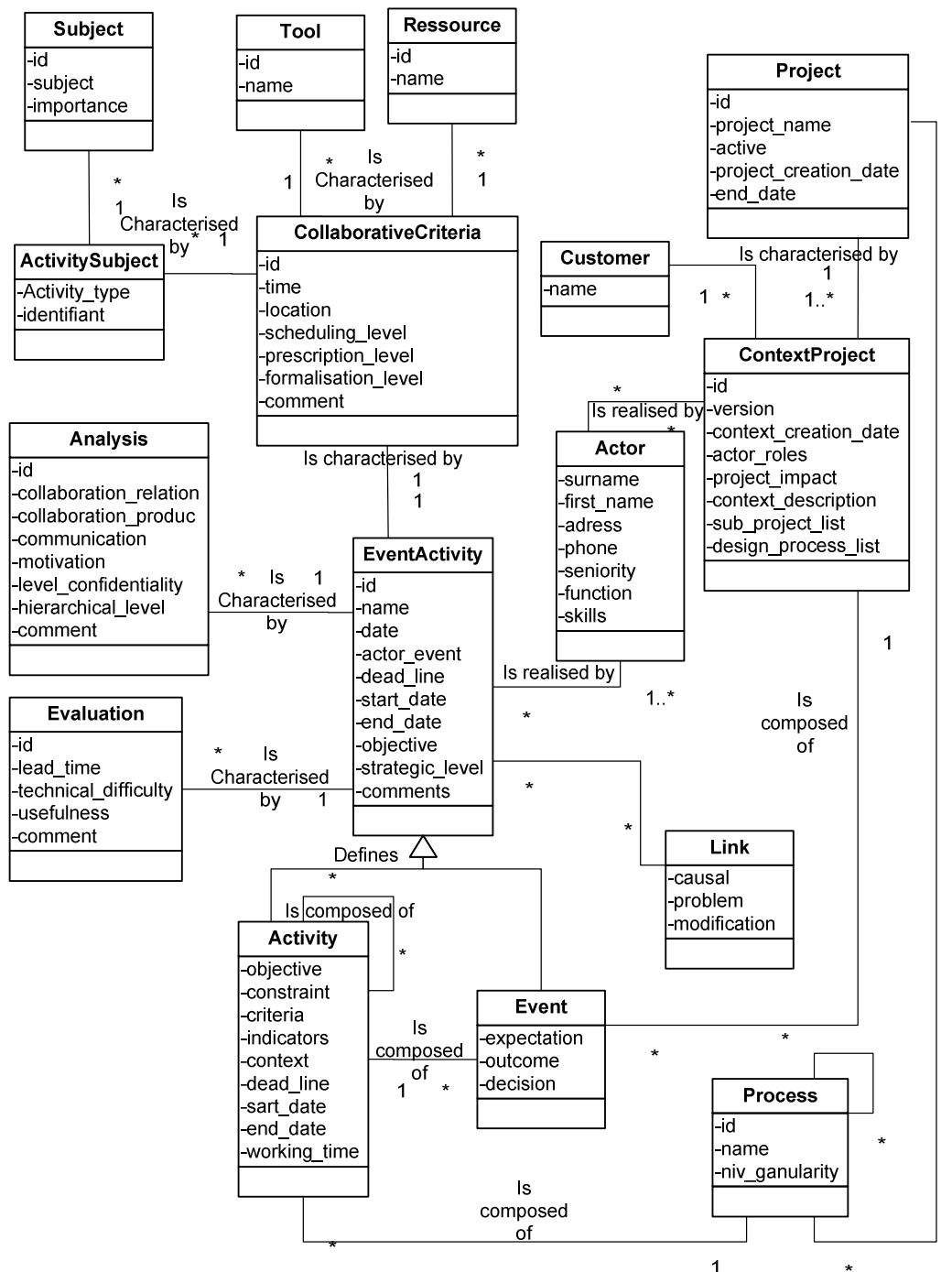
Figure 75: Improved collaboration model

7.3   Implication for design coordination

7.3.1 Synthesis on design coordination

The approach traces collaborative events - formal as well as informal ones - in order to analyse collaboration. This analysis of collaboration leads to the incorporation of additional information into decision making in order to improve the coordination of projects. Moreover, the analysis of the collaborative practices during events helps project managers to understand design and coordination errors because they have additional inputs concerning informal and collaborative aspects. This analysis leads to the definition of guidelines for improving coordination aspects such as:

- The project manager can better handle the roles and the skills of the project team. Indeed, with the analysis of the design events he knows what roles and skills were used in previous events in order to adapt the project team for the future events. Moreover he can also have a policy of skills learning by assigning actors to new roles for them, if the situation makes it possible, in order to improve the pool of skills for each actor.
- The project manager can define more detailed and flexible design processes by the introduction of flexibility nodes (milestones, routing activities, activities which are defined on the spot and not previously), and by introducing new sequences into the design processes during the project. Thus, the projects become more flexible and collaboration aspects are taken into account.
- The project manager can identify the recurrent forms of collaboration which give good results in terms of performance, i.e. of reaching the objectives at least in time and with the required generated information, in order to introduce them in the design processes and in the same situations. These forms of collaboration are defined by the coordination rules, the kind of communication between designers, and by the type of collaboration (free or forced, synchronous or asynchronous, in the same or different places…).

7.3.2 Discussion on design coordination

The study carried out in this thesis proposes a methodology to analyse design collaboration in a context of SMEs. This methodology is based on theoretical models (of coordination and collaboration), and a tool CoCa to capture collaborative events. This methodology of collaboration analysis is aimed at the proposal of guidelines on coordination aspects.

These guidelines lead to improvements in design coordination by including collaboration inputs and by identifying "good practices" in human management, processes, and form of collaboration (Figure 76).

The methodology begins with the capture of data about collaborative practices, then, this data is used to analyse how actors collaborate and to identify "good practices" or problems. The identification of "good practices" means the identification of the collaborative practices in design situations where the objectives are reached and the indicators of performances are completed. This identification is based on the recording with CoCa of all the characteristics of these design situations in terms of coordination and collaboration criteria.
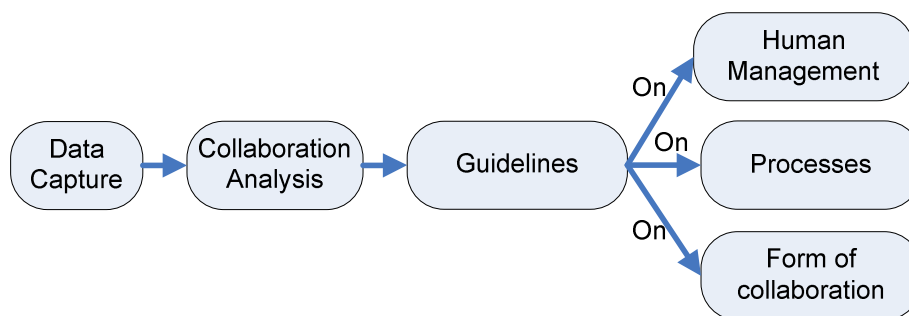
Figure 76: Guidelines improving coordination aspects

Guidelines identified from the solving of problems or from the characterisation of good practices can be described through several categories such as the following ones:

- Human management category, i.e. how the management of the human aspects, can improve the design process according to the design situation, as for example the management of the actors' skills. Each actor has his or her own skills; of course it is very important for the project manager to know how to use them in order to assign the right task to the right actor. Moreover, it is interesting for the project manager to know the desires of the actors in terms of skill improvement. If an actor is motivated to learn new skills, the project manager can select projects in this sense in order to have a real management of human skills and knowledge and allow the actors to evolve in the company.

Example from the industrial case study:

As we have seen in the example 2 in section 6.3.3 where the conclusions were that the project manager needs to manage the skills of actors in order to assign the right actor to the right activity according to the project constraints (workload, lead-time, skills improvement…). Thus, the project manager in

Ederena wants to better manage the skills which deal with the human management domain.

-   Processes category: design processes are a succession of activities used to coordinate projects. The identification of successful processes allows the improvement of the quality of the control and the re-use of these processes in future similar design situations. The main issue lies in the creation of a pool of processes available for re-use and linked with guidelines in order to indicate in which situation the process could be used. It will then be possible to select the right pre-defined process from the pool of processes and to apply it in the right incoming design situations. The selection of the appropriate process is led by the guidelines which is associated to the individual characteristics of the design situation. Thus, it is possible to imagine integrated tools of project management that are based on this idea. Based on a model of collaboration a tool like CoCa can be re-used to not only for recording but also for scheduling the "appropriate" stored processes in correlation with the new situation. And finally, the project management tool can give guidelines and propose processes to the project manager (see Figure 77).
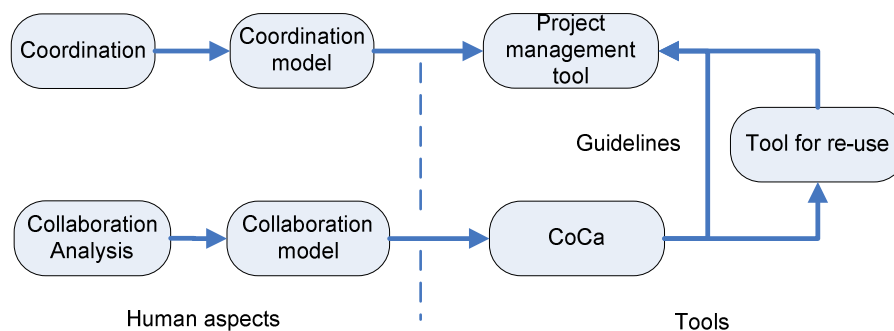
Figure 77: Interaction between tools and guidelines for re-use

The flexibility nodes introduced into the design process after a detailed analysis of collaboration lead to the adaptation of the design process to the design situation. Indeed, at each node of flexibility the project manager will have to take a decision: as several optional sequences of activities exist after the node of flexibility, he must decide which sequence the process must follow. Nevertheless, this introduction of flexibility is limited and mainly centred on the nodes of flexibility. Indeed, the project manager can take a decision only at this node of flexibility; if a design change happens, he has to wait for a node of flexibility in order to re-orient the process. Thus, these flexibility nodes are only a first step toward a dynamic management of the design process. This notion of dynamic management is a future issue of the

coordination in design. The final objective is to manage the project in real time, without waiting for a flexibility node.

> Example from the industrial case study:
>
> As we have seen in the example 3 in section 6.3.4 where the conclusions were that often in Ederena (and more generally in SMEs) some design tasks are not planned in advance in the design process. Thus, the design process needs to become adaptive and change dynamically during its evolution. The analysis with CoCa tool helps the project manager to define the design processes with sub processes, nodes of flexibility and with ad-hoc activities defined "on the spot".

- Form of collaboration category: the model of collaboration and the CoCa tool support the analysis of the collaboration in projects. This analysis helps the project manager to identify various forms of collaboration defined by collaborative criteria. Thus, he can have and give detailed information on how actors worked, work or must work. The project manager can manage the design activity and processes at a very detailed level. Moreover, he can understand a larger proportion of design problems where the causes deal with collaboration aspects. Now, the project manager can understand, act and solve these design problems which come from collaboration aspects. The main difficulty lies in the management of the possible contradictions between the collaboration and coordination constraints as the analysis of the collaboration may lead towards a guideline which is not applicable because of coordination constraints. For example, for a better collaboration the actor A must be included in an activity and at the same time for a problem of coordination such as high workload, the actor A cannot work in this activity. Nevertheless, with this collaboration analysis, the project manager is now informed of these collaboration guidelines or constraints.

> Example from the industrial case study:
>
> Based on the example presented in 6.1.5 and expanded in 6.4.2 with PLM workflows, we saw that various design processes are defined, but for each process a particular form of collaboration is associated. For example, the Marketing person can write the CND and transmit the document directly to the technical department for "similar product". For a "re-design" product, the marketing person writes the CND but another visit to the customer could be required. And for "innovative" product a global meeting with the customer, marketing and design persons is necessary at the beginning of the

> design process. Thus the form of collaboration is associated with the design
> process which it is itself associated with the type of product.

From the industrial case study, some results obtained with the analysis of the CoCa tool can be trivial for an experienced project manager, but for an inexperienced project manager these results are very important. The introduction of collaboration aspects in the assessment of the project management may be sometimes misunderstood by older project managers who do not have an open mind on the subject, and who consider these collaboration aspects useless and not linked to design coordination. Nevertheless, in the author's opinion this approach to analysing collaboration with a tool like CoCa is beneficial to any project manager (experienced or inexperienced) who wishes to understand and improve the way he manages projects by taking into account collaboration aspects.

The CoCa tool is useful in helping the analysis of collaboration by recording essential data on collaboration; but this tool does not replace an industrial study in the company with corpus, or project management training. Nevertheless, in the case study, the CoCa tool helps the project manager to look at the design situations in projects and then take better decisions to manage them.

7.3.3 Improved coordination model

The problem of granularity has been identified in previous sections; this leads to improvements in the model of coordination at a detailed level. This detailed description will include the notion of projects, sub-projects, processes, sub-processes, activities and events. The sub-project will be managed by design processes. Indeed, as we saw in section 6.1.5 the example from Ederena (and three scenarios) demonstrates that the management of the granularity level in project is very important and needs to become more detailed in order to manage projects efficiently. Thus, in the improved coordination model, the management of the granularity level in projects is represented by the loops on the classes *Project* and *DesignProcess* to represent the sub projects and sub processes and their links (Figure 78).

This deeper description includes a representation of how each resource is used during events. For the moment the tool records only the name of the resource used, no more. In fact, it is interesting to know how the actors use the given resources. Indeed, for each resource, a description will be recorded to know who has used the resource, how long the actors used the resource, together with comments on their use. Moreover, as we saw in the entire Chapter 6 and more precisely in sections 6.1.1 and 6.1.2; the notion of "role" is very important in SMEs, because most of the time one designer can accumulate various different roles in a project. So, the improved coordination model must take into account this notion of role directly at the level of the project and not at the level of the processes. Thus, the

roles of each actor are stored in the class *Project* with the attribute <u>Roles</u>. In this improved model of coordination the rules of coordination and the form of collaboration are managed with the attributes in the class *Process element*. Now, based on the results from Chapter 6 on the analysis of the collaboration new classes and attributes are added in order to take into account some collaboration aspects in the coordination of project. The <u>form of collaboration</u> indicates if the collaboration is free, encouraged or forced, synchronous or asynchronous, present or distant, and formal or informal. And the <u>coordination rules</u> record if the project is coordinated by direct supervision, mutual agreement or normalisation. These two last points are described to detail how these attributes are applied and help to characterise the problems (presented in section 4.3.1) which remain in the coordination of project with the previous model of coordination.
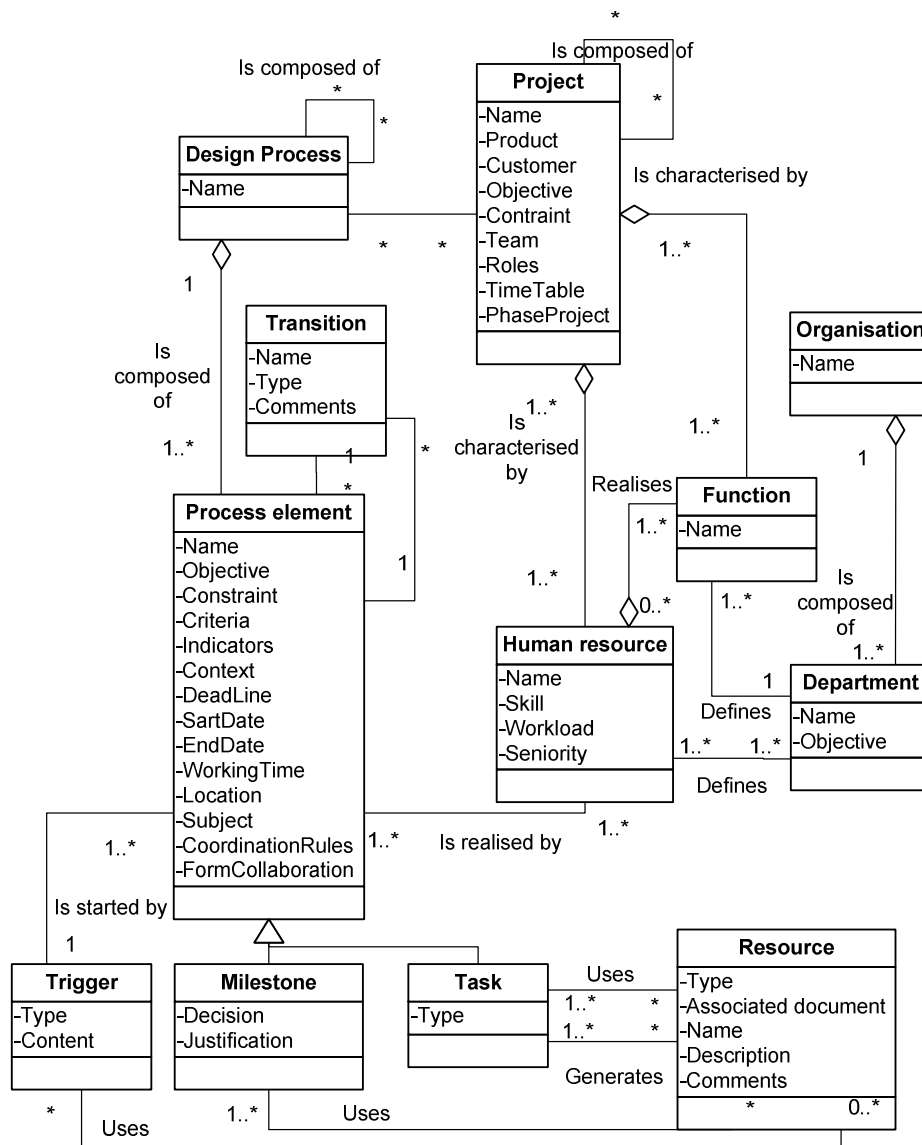
Figure 78: Improved coordination model

The new version of the coordination model also takes into account the notion of flexibility in the design process. Indeed, links between process elements will be used to represent the various ways that the design process is followed. As we saw in section 6.3.4 with example 3, the links between events (chronology, problem, causal links) help the project manager to "re-build" the design process followed. Based on this idea of link, more types of links are defined (as "and", "or", "if", "else") in order to add information on the relation between events in the design process. Thus, in the improved coordination model, these links are managed by the new class *Transition* in order to manage these new types of links: "and", "or", "if", "else" … These types of link will more faithfully represent the various relations

between design events. Therefore the project manager can better manage the design processes by excluding or creating new sequences of the design process according to the design situation (customer, product, actors, suppliers…). Moreover, these models of collaboration (Figure 75) and coordination (Figure 78) can be mutually enriched to implement complex tools where the coordination and the collaboration are coupled. Thus, the sequences of design activities recorded in CoCa can become predefined processes in a design management tool based on the model of coordination. The processes and tasks defined during the scheduling can be used to identify the events which will be followed with CoCa with an adequate level of granularity.

7.4   Implication for PLM systems with coordination and collaboration aspects

7.4.1 Synthesis on PLM tools

PLM tools are implemented in more and more companies to rationalise their processes and document management. Such a PLM tool was tested in Ederena, it was noticed that these tools are more oriented to implementation in a large companies than in SMEs. Thus, for SMEs, these tools have deficiencies in terms of functionalities to manage projects and analysis of collaboration. Indeed, as it was presented in the Figures 57 and 58 many useful concepts to manage projects and collaboration analysis are not implemented in the PLM tools. These tools decrease the level of flexibility by increasing the constraints in the processes. This statement can be a positive point for large companies but not for SMEs, where the flexibility in the design processes is one of the main concerns.

Moreover, SMEs cannot invest as much money as large companies for the implementation of these tools. Thus, the implementation is often made quickly with a lack of analysis in advance. In this study, it was well established that a deeper and rigorous analysis of the initial situation in the company is necessary to avoid the introduction of rigidity in the design processes during the implementation of the PLM tool and during its configuration.

For the implementation a methodology is drawn to support the adaptation of such tool to the individual characteristics of the company. For the configuration of the tool a detailed analysis of the collaboration is possible and supported by CoCa in order to introduce flexibility nodes in the design processes.

PLM tools are not focused on project management; nevertheless it could be possible to integrate a project management aspect into these tools in order to add specific functions for project managers. Concretely, PLM tools must be improved at various levels: management of actors and skills, triggering events but also recording the planned/completed/modified process for later reuse. Where some project functionalities are available, task concept implementation is too limited: defining input and output information is often impossible,

except using deliverables; the element of decisions cannot be formalized [Pol, et al. 2005c]. At the project level, the project plan concept is too sequential. Convergent links between tasks are not possible. Moreover alternative sequences of tasks are not supported; this is, however, possible in a workflow.

In a PLM tool, when a project manager plans an activity, he may link it with a support document (deliverable). When controlling the planned activities, he may need to modify the initial schedule. But he cannot modify the schedule of the activities from the workflow of the linked document. In fact these document workflows are not under the control of the project manager and this may lead to incompatible constraints on the completion of the design process activities. An improved PLM tool integrating project and workflow aspects may allow project managers to manage workflows as sub-processes of the project process and so to control the related tasks: e.g. by modifying the end date, or the users allocated to it, or even by replacing it by different tasks. To conclude, it is important to preserve a high level of flexibility in the product development processes. The project management approach must be improved by the definition of processes and sub-processes to manage projects and documents with the integration of flexibility in these processes. This flexibility must not be restricted to the nodes of flexibility (reviews, milestones, main phases of the projects) but must be introduced in the whole project management approach by the synchronisation of processes, sub-processes and activities (an example is given in the next section 7.4.3 and Figure 80).

7.4.2 Discussion on PLM tools

Previous sections highlighted the necessary flexibility of a design process in an SME, especially in this case study where innovation is a constant concern. In an SME the formalisation of the organisation is a critical point for the optimal management of resources. If the process is predefined at a global level, actors from all departments work daily in a context of "mutual agreement" but this organisational aspect is rather incompatible with PLM functionalities. The main issues during the definition of the PLM specifications for an SME are to identify:
- what information must be controlled,
- through which predefined workflow,
- what must be encouraged and not formalised.

For example, the collaboration between actors cannot really be defined through existing project plan or workflow concepts. The cooperation processes are quite unstructured and the comparison of the various project teams' points of view leads to informal and unofficial information exchanges [Baumberger, et al. 2003].

7.4.3 Identification of future work on PLM systems

Previous discussion has dealt with the introduction of flexibility nodes in strategic points of the design process in order to control and adapt the design project quickly. Nevertheless this improvement is a first step toward a dynamic management of the project, but the limitation is that the project manager has to wait for a flexibility node in the design process (most of the time a milestone) to take a decision. The real issue for him is to manage the project dynamically without waiting for a flexibility node and react in real time. Thus, project managers need detailed design processes which pilot sub-processes for document management.

Therefore, the study of the main improvements on PLM tools concerns the management of projects. This study is focused on processes and activities (see Figure 79) because projects and events are already managed by Windchill^{TM}. Thus, the possible improvements are concerned with the processes and the activities.
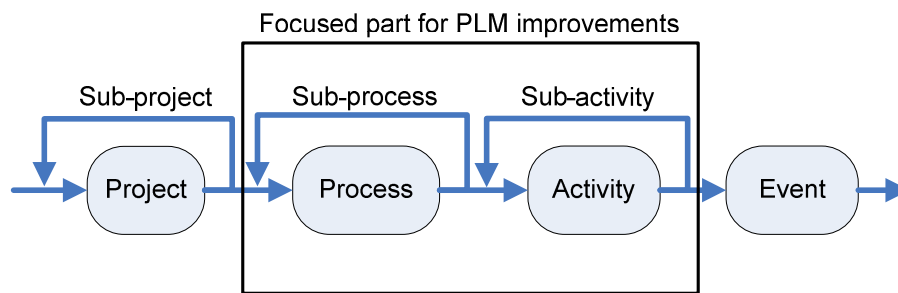
Figure 79: Coordination approach and focused part for PLM improvements

In the PLM tool Windchill^{TM}, virtual documents are used by the system to manage project processes. These virtual documents are hidden, and invisible to the user. They are managed with a main workflow (a group of activities which admit sub-workflows) and with life-cycles (group of the states that the document can take in its "life"). The workflows are composed of activities but also of automatic tasks (mails, change life-cycle state, synchronisations, IT code…). Using these automatic tasks, it is possible to link the workflows and sub-workflows. The synchronisation between workflows is made by a change in the life-cycle state of the linked workflow (Figure 80). Nevertheless, it is well established that a workflow is predefined before the launch of a project and this does not allow for modifications during its progress after its instantiation.

The "change design process" illustrates this approach. When a problem is reported a "change request" workflow is launched. This main workflow ("change request") pilots the other workflows "change notice" and "change activities" with synchronisations. The "change notice" workflow informs the actors of the change, defines the "change activities",

launches these "change activities" and validates it. The "change activities" manage only the implementation of these activities. All these workflows are displayed in Appendix E
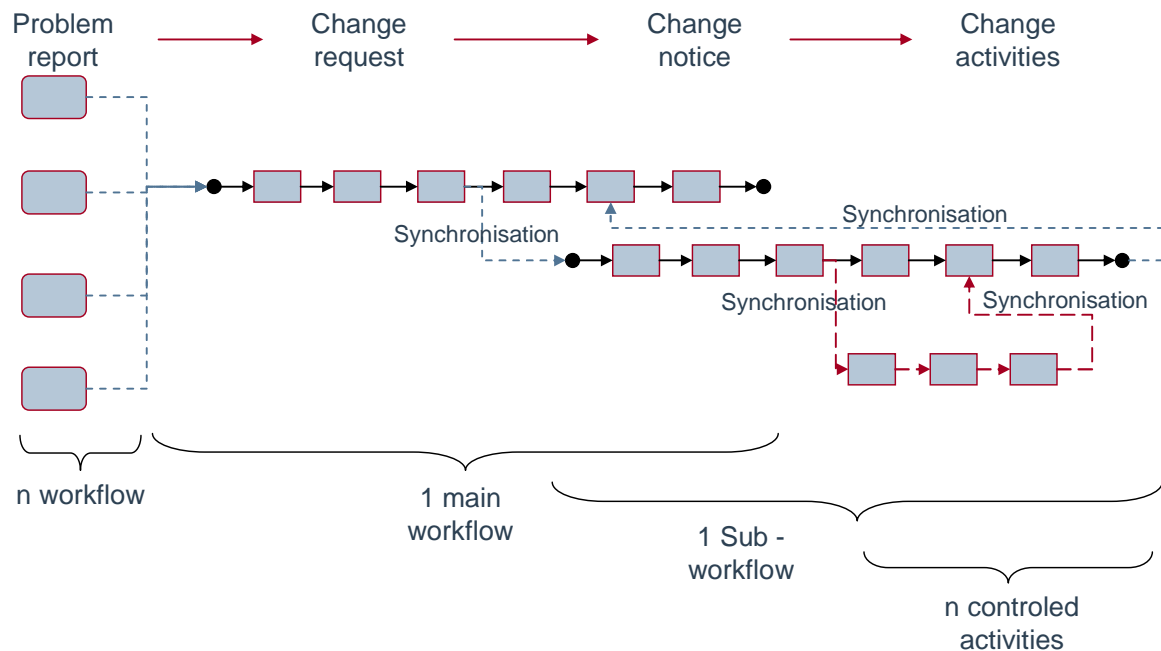
Figure 80: Example of the change process

In their project management approach, project managers have to be aware of the completion of design tasks in order to pass through the milestones. Thus, the visualisation of the workflows and sub-workflows allows the project manager to have the information on the tasks completed during the project and take the right decision. The decision could be:
- To validate the completed tasks and the project goes on,
- To suspend the workflow and put the project in stand by for modifications,
- To terminate the workflows in order to begin again with new workflows.

In PLM tools the project can be managed with virtual documents, synchronisation and with flexibility through the creation of dynamic activities called "ad hoc" activities. Nevertheless, this definition of workflows is very onerous in terms of IT implementation and of time, because each workflow corresponds to the specific way to manage projects in the company and must evolve with the progress of the project. For example in large companies this customisation is made by a whole department or external integration companies focused on the workflow management, life-cycles and documents in the PLM tool. Thus, for the moment SMEs cannot afford such an implementation. The detailed definition and the integration of flexibility and collaboration aspects in the project

management with PLM tool is very complex in terms of IT knowledge and PLM architecture. This topic would be the basis for a new PhD study.

7.5   Synthesis

This Chapter "Discussion" sets out the main comments on the main results addressed in this research work. These evaluations identify limitations, positive as well as negative points and lead to new possible improvements.

One of the main results of this thesis is the implementation of the tool CoCa which records and displays information about informal and collaborative events of projects in order to help the analysis of collaboration. At this stage, a first version of this tool has been implemented. This version manages the characterisation of the collaborative events with their links. Nevertheless, more work is needed to implement new functionalities, notably on the statistical analysis with charts. Other industrial case studies will bring extra data to propose, test and validate new improvements.

CoCa aims to help the analysis of the collaboration. After tests in Ederena, some limitations are identified:
-   The know-how of the analyst is very important in locating useful situations and information to make correlations with his experience,
-   A statistical analysis of the data collected is almost indispensable to drive the analysis of the collaboration at a high level,
-   The subjectivity orients the analysis made and precautions must be taken to limit this interference.

Therefore, various improvements are proposed:
-   The collaboration analysis can be supported by statistics in order to make a driven or semi-automatic analysis,
-   The analysis method can be improved in terms of steps, main information to check, or charts,
-   The analyst can be chosen to be as neutral as possible in order to limit the impact of the subjectivity into the analysis of the collaboration,
-   Several analysts can collaborate to make multiple and mixed analysis of the collaboration,
-   And finally, an improved collaboration model is proposed in order to take into account the level of granularity.

This collaboration analysis is not an end in itself; the objective is to improve various design project coordination aspects such as human management, processes definition, and identification of forms of collaboration. The analysis of informal and collaborative events

allows the identification of recurrent situations which can be re-used in future situations. Moreover this analysis can lead to the improvement of the collaboration and the introduction of flexibility in the design processes in order to manage projects in a more flexible and reactive way. It was observed in the industrial cases study that various levels of granularity must be taken into account. For that purpose, an improved model of coordination was defined to represent coordination aspects in design management with the following levels of granularity: projects, processes, task, and the links between processes element such as "and", "or", "if", "else" links. These links are extra links implemented in the next version of CoCa in addition to the existing links "causal", "problem" and "chronology".

A PLM tool is often implemented in companies to manage documents. It can be the basis on which the coordination approach is structured. Thus, flexibility in the project processes can be introduced in the tool without waiting for flexibility nodes. A solution for this introduction of flexibility will be to use virtual documents, synchronisation and ad-hoc dynamic workflows. Nevertheless the problem of IT implementation must be taking into account, because this approach is very demanding of time, money and adequate skills. This approach can be the basis for a new PhD subject in order to find a detailed solution to project coordination with PLM tools whilst taking into account collaboration aspects.

8 Conclusions, contributions and implications for further work

This Chapter presents the synthesis of the work carried out and its achievements are outlined in detail showing the conclusions from the research. The contribution to knowledge made by the research is described and topics for future research are identified.

8.1 Conclusions

Nowadays the management of product development projects is mainly oriented towards the coordination of design activities. Nevertheless in a context of concurrent engineering, managers have difficulty in taking into account the collaboration dimension during design projects. Thus this thesis has focused upon the introduction of collaboration aspects to improve design coordination. For the purpose of the research work, the introduction of ways of controlling and encouraging collaboration in flexible design processes is based on the analysis of collaboration between designers in order to define guidelines for future flexible coordination. These notions of collaboration and flexibility included as elements in the coordination of design projects are becoming significant issues for companies.

Thus, before introducing collaboration aspects in design coordination, a better understanding of coordination and collaboration with their relationships is required. Indeed, a project manager has to coordinate various elements in order to reach the objectives of a design project. He defines an action plan to coordinate the design processes and actors' activities. The actions of project managers concern design coordination and process control. Then, actors collaborate during their design activities to reach their specific objectives and follow the defined action plan. The CoCa tool is used to collect data on the collaboration occurring during these design activities. This data is then used to analyse design collaboration and then to make diagnostics on the 'efficiency' of the collaboration and on the achievement of design objectives in order to define guidelines for improving future coordination. The results of the collaboration analysis support project managers in controlling the design process.
Thus, first a coordination model that characterises the main notions used in project coordination is proposed. This model is specifically proposed and aimed at helping project managers in SMEs in their work. It allows the storage of the information needed by the project managers to structure design projects and to control accomplished design activities

and compare them to scheduled tasks. Nevertheless in the industrial case study, it was noticed that coordination and collaboration aspects are complementary and the low input of collaboration aspects in the model of coordination is demonstrated. As project managers have difficulties in introducing collaboration aspects, it is then necessary to help them to understand the detailed collaborative practices of their team.

Consequently, from this model, a second model describing collaboration is defined in order to allow the characterisation of collaborative mechanisms in design activities. Several parameters for describing collaboration are introduced. This characterisation is made by the recording of context and objectives of the project, then of collaborative events; and of criteria to categorise the collaborative situation in design projects. The model of collaboration allows also the storage of a short analysis of the collaboration form used between actors in order to evaluate each collaborative situation.

These models of coordination and collaboration are validated through the partnership established with an SME called Ederena which designs and manufactures structure products based on an innovative technology. It was noticed that both coordination and collaboration models are not sufficient by themselves to be useful for project managers in design. As a consequence, an IT tool called CoCa has been implemented to support the analysis of the collaboration occurring in design projects in SMEs. A great deal of effort was made to connect the implementation of a tool to the theoretical work (the models) in order to test the hypothesis that the analysis of collaboration really helps project managers to coordinate design projects. The approach to developing CoCa is set out in the three main steps: Analysis, Design and IT implementation. The description of this approach is defined with various diagrams based on the UML formalism which is suitable for the implementation of such a tool. These diagrams are used to define the architecture, GUI forms, database and the IT implementation for the tool. Thus, CoCa allows the collection of large amounts of data and its visualisation in order to support the analysis of the collaboration.

The aim of the CoCa tool is to assist analysts in the recording of the information of the collaboration model in order to help them in their future analyses and definition of guidelines for design coordination. The main user of the CoCa tool is an analyst that follows all the steps of a design project, recording information about the activities that occur. This recording is carried out by collecting data such as: projects, events, and collaborative criteria (time, location, tools, methods, level of formalisation…). These records provide detailed data for the analyst, in order to analyse the collaboration and thus to help the management of projects. This analysis enables the identification of deficiencies or good practices in collaboration and allows the proposal of the project manager's coordination tasks and also of improvements of the design process.

All this theoretical work is supported by an industrial case study in order to test and improve it. The work carried out in Ederena demonstrates three main points. First, the analysis of the collaboration is possible with CoCa in an industrial context. Secondly, the resulting diagnosis has an impact on the coordination of projects (on the project managers' way of working as well as on the definition of design activities by the project manager). Thirdly, PLM systems are a type of information system which can support the management of data and management of projects but within limits. They can be used to implement some of the guidelines that can be made by using CoCa tool. PLM systems require additional functionalities to manage projects with detailed and flexible processes.

The analysis of the collaboration is possible with CoCa in an industrial context:

CoCa was tested in Ederena to record information on the collaborative events occurring during projects. Concretely, projects were followed (the amount of data collected are: 6 projects, about 100 events and 12 versions of projects) in order to track and record the events occurring. The approach used in Ederena begins with the recording of data during projects. Then, the data collected by the CoCa tool is used to analyse the form of collaboration event by event, to make a diagnosis on the collaboration by comparing the different events and finally, to propose guidelines in order to improve the coordination in design projects.

The combination of different types of information allows the identification of different kind of results by:
- Establishing links between several events,
- Establishing correlations between several parameters of different types between several events.

In Ederena it was noticed that the analyst recorded and identified enough data via CoCa to analyse the collaborative practices used in various design projects. Although CoCa does not analyse collaboration itself, it provides the data recorded during the project with various GUI forms to support the analysis. CoCa thus fosters the understanding of collaborative activities in design. Nevertheless the use of the CoCa tool and the associated method is based on a six months study with one SME. Other projects with other companies are needed to validate the approach as a generic one.

The resulting diagnosis has an impact on the coordination of projects:

The analysis of collaboration leads to the definition of guidelines to improve design coordination by the introduction of flexibility in detailed design processes, by helping project managers to anticipate future design situations, by defining and choosing the form of collaboration in design events and by identifying "good practices". The identification of "good practices" means the identification of the collaborative practices in the situation where the objectives are reached and the indicators of performance are achieved with the

expected values. This identification is based on the recording of all the characteristics of this design situation in terms of coordination and collaboration criteria usefully achieved with CoCa. These "good practices" deal with the design processes, the human management and the collaborative tools used. When a problem of collaboration between actors appears in a design event, the project manager is interested in analysing this event in order to understand what was wrong and what could be improved. This will orient the decision to take, improve or reject a collaborative practice that has occurred in projects. Of course the work of the analyst is not easy: well-defined events such as meetings are much easier to track than emerging events during a coffee break. But this challenge brings the richest results.

The resulting analyses have a great impact on the project manager coordination tasks, various examples have been presented through this study. Here is the main one:
- Guidelines can be defined to help project managers when selecting designers to use an approach based on skills management, defining required tasks, scheduling tasks, etc…
- Role of the project manager or of the company managers can be reinforced or decreased depending on the context of the project to define the appropriate form of collaboration. Thus the form of collaboration can be defined more or less prescribed, formal, scheduled, confidential, etc…,
- Formalisation of design process can be improved and made more detailed by adding extra steps, for example through the quality and standard documents of the company,
- Flexibility can be added in the design process by introducing decision nodes for choosing the best sequences of tasks.

Thus this analysis helps the project manager to choose the appropriate form of collaboration and to take decisions on design coordination.

This collaboration analysis helps the project manager to coordinate future design activities by anticipating the future activities and problems in order to manage them earlier in the design process. Moreover, this analysis allows the assessment of the collaboration in terms of performance in order to propose new forms of collaboration or to define the form of collaboration in the future design processes. These predictions of design activities, the re-use of forms of collaboration and the definition of future collaborative practices are an important part of the know-how of the project manager.
CoCa allows the establishment of a memory of design projects according to the collaboration point of view. So, the analyst can compare the theoretical process planned by the Quality Department with the real design process carried out by the designers. Thus, extra steps or processes can be defined to introduce flexibility in the global theoretical process. Nevertheless, the flexibility is limited, because the project processes are still

predefined with more detailed routing between the different sequences of activities. Thus the actors still have to wait for intermediate milestones to take a decision. The future goal will be to authorise the modifications of predefined processes at any time and to be able to react dynamically according to incoming changes in the project.

The main limitation of a tool such as Coca is the subjectivity of the observer. However, the actual architecture of the tool does not allow us to have a multiple points of view on the same event. Indeed two persons cannot collect information on the same event in the same database. However, the capture of different interpretations and analyses will be interesting for a future version of the CoCa tool.

This collaboration analysis is not an end in itself: the main objective is to improve design project coordination. The analysis of informal and collaborative events allows the identification of recurrent situations which can be re-used in future situations. Moreover this analysis leads to the improvement of the collaboration and the introduction of flexibility in the design processes in order to manage projects in a more flexible and reactive way. The level of granularity of the events was also a methodological problem. It was decided to track events at their more detailed level, i.e. basic events. But when analysing, it can be more difficult to navigate between events and to have a global view of the different phases. The possibility of indicating the level of granularity and to group sequences of events in a higher level event will help the analyst. Thus, the analysis will be able to make comparisons properly between elements at the same level of detail. As a result, improved models of collaboration and of coordination have been proposed to manage granularity of collaborative events and to improve events visualisation.

PLM systems can support the management of data and projects but with limitations:

In the worldwide competition among companies, the development of new products has become a challenge where innovation and coordination of design process are two main keys for success. In SMEs design activity is not completely structured and controlled due to the high level of flexibility of processes required. At the same time PLM systems help to rationalise basic design processes and are the main information systems managing the product life cycles in companies.

When considering design coordination in Ederena, product data and process management was one of the main concerns. In parallel with the collaboration analysis experiments, the company evaluated the implementation of product data and process management tools which would be well-adapted to the company settings. It specifically evaluated PLM system use; then a prototype system with a PLM tool named "Windchill^{TM}" has been implemented. This prototype finalises the study carried out on the coordination of design projects in Ederena and is the basis for making experiments on possible solutions for automation and support of the work of project managers. The prototype is based on the use

of workflow technologies in order to elaborate the structure and the schedule of the project phases and tasks through different and synchronised levels of granularity.

Moreover the implementation of this prototype is based on the definition of a methodology focused on organisational change and the implementation of a system combining project management and PLM functionalities in an innovative SME. This methodology is focused on the prerequisites tasks which must be done before the implementation of an information system. Although the main steps of this methodology are generic and can be applied in both contexts of SMEs and of large companies, the details of these prerequisites are specific to the context of the case study

Within PLM systems the design process is managed through workflow implementation. As an example an implemented design situation can be achieved through several types of collaboration. Thus scheduling a standardised design process is not enough for the project manager to describe all the necessary guidelines for the achievement of a design situation. Several forms of collaboration can be defined in order to formalise the inter-actor exchanges. Thus, project managers have difficulties in choosing the form of collaboration in accordance with the specific context of the design situation. As the CoCa tool can track such collaborative forms, the definition of more detailed processes has been implemented through the studied PLM systems. Thus managers can keep in mind the matter of the flexibility in design processes in order to improve coordination and to not strangle the emergence of innovation.

This PLM solution based on detailed processes with the introduction of some flexibility is a part of the solution. From the results of the case study, it was found that some further areas need to be addressed, for example: actors and skills management, triggering events, and also the ability to re-use and build on the planned/realised/modified process. In PLM systems, the implementation of the task concept is not satisfactory: it is not clear how input and output information may be defined other than through deliverables and the elements to make decisions cannot easily be formalised. The proposed attributes of process elements, tasks or milestones do not exist given the inadequate status/level of the concept of implementation. Thus this prototype illustrates the need to incorporate new methods, functions and tools in PLM systems to manage design projects properly and include collaboration aspects.

Thus the next objective for the coordination will be to manage projects in real time with a flexibility which is continuous and evolves dynamically. This objective could be the basis for a new PhD subject in order to find a detailed solution to fully coordinate projects within PLM tools with the integration of collaboration and flexibility concerns. The possibility to integrate flexibility in the design coordination with PLM system is the next challenge for these tools. PLM systems are an adequate solution to manage product data and documents; nevertheless many other issues (project management, collaboration management) need to

be addressed in the future in order to answer to the actual needs of managing the whole product lifecycle in a context of collaborative design and of extended enterprise.

8.2   Contributions

The results obtained during this research study bring several kinds of contributions and perspectives:
-    first a contribution to what is coordination and what is collaboration in the context of design project management in SMEs, by formalising models of coordination and of collaboration,
-    second a contribution on support tools to help design project managers to analyse and understand what interactions exist between actors during design projects,
-    third a methodological contribution to propose an adequate approach to use such a support tool by capturing and analysing collaboration,
-    fourth a methodological contribution to support design coordination in SMEs by proposing an improved way of managing design projects and by characterising a better way to implement PLM systems.

Each kind of contribution has been evaluated through experimentation and several questions and issues appear to enrich existing avenues for research or to generate new ones.

In this research work models have been proposed to help the analysis of collaboration. Most results have been validated in the case of Ederena, which is an SME designing products based on an innovative technology. The proposed models of collaboration and coordination are based on this situation. Nevertheless, such models are easily applicable to other SMEs contexts because the innovative characteristic of Ederena does not influence the models but other aspects of the contributions. So other companies can apply these models as a basis to adapt them to their own context by adding extra criteria or classes. Moreover the UML formalism used to define these models is adequate to allow the evolution of the models in another context.

Collaboration between actors is important to federate actors and make coordination effective. Choosing an appropriate form of collaboration between actors is necessary and requires analysis of the collaborative practices inside the company. Thus, such an analysis tool, CoCa has been implemented.

The entire analysis of the collaboration is not done by the tool; it records the main information required to make the analysis of the possible collaboration. Therefore the analyst has to study the sequence of events, make correlations between various attributes and study the evaluations and analysis made "on the spot" in order to carry out the analysis.

This analysis leads to the re-use of collaborative processes in similar situations or to the solution of collaboration problems or conflicts in order to help project managers to coordinate projects with the extra point of view of collaboration.

Several improvements to the CoCa tool have been proposed: extra functions need to be implemented in a new version in order to include the following improvements. This new version of CoCa will provide other types of links, like "Warning" and "Question" links. Indeed, links between process elements will more faithfully represent the various possible transitions of the project. These links are managed by a new class 'transition' which can represent links types such as: "and", "or", "if", "else" … In this way the project manager can manage better the design processes by excluding sequences or creating new ones according to the design situation (customer, product, actors, suppliers). He will be able also to manage multiple analyses by the configuration of a server in order to centralise the data and to have various analysts sharing the same database. Consequently, the pool of data will be larger and the analysts will be able to compare each others' analyses. Moreover, the new version of CoCa will take into account the new notions described in the improved model of collaboration in order to include the notion of granularity. Thus, the analysis of collaboration will be made at various levels of detail (events, activities, processes, projects). Moreover, in terms of extra functionalities, CoCa needs additional GUI forms with graphical functions in order to analyse sequences of events and explore links. So, CoCa needs to provide a search by keywords and attributes to find main text data. A graphical visualisation of information will be implemented to represent and compare various forms of collaboration with common criteria. Other improvements also concern the method to analyse the collaboration. A statistical analysis will be able to provide a "check list" of critical information recorded with CoCa in order to drive the analysis progress. In the short term, an extra module focused on the support of this method is under implementation. This module will allow the representation by graphs and queries of the events in accordance with the type of links, and to notify to the analyst if the event has an associated evaluation or analysis "on the spot". Moreover, a deeper study needs to be carried out about the Likert type scale in order to have a better definition of the collaborative criteria, and to prepare a statistical analysis of the data. In addition, collaborative events exist outside the company and it is necessary to define solutions for traceability in a mobility context. The use of CoCa in every place where events occur is to be studied: a version of CoCa implemented on PDA system will be of great interest.

CoCa allows the capture of events of design projects from the point of view of collaboration and is used to identify best practices, analyse problems encountered and improve managers' decisions. Some tests were done in Ederena with the current version of CoCa. Ederena was quite satisfied with the results achieved during the industrial case study. From now the company will have a more detailed and flexible project coordination integrating collaboration concern. These tests validate that CoCa is useful to support the analysis of the collaboration and that this analysis has benefits to improve collaboration and

the coordination aspects. The examples presented show the complexity of the analysis tasks and the richness of the kind of results for improving design coordination. More experiments are planned to demonstrate the added-value of an analysis with CoCa tool in a more generic context.

Coordination in design is a great challenge in companies. Focusing on SMEs, coordination must take into account flexibility factors and consequently anticipate emerging phenomena and collaboration between actors.

8.3   Implications for further work

In terms of perspective, the models of coordination and coordination need to be improved. An interesting way would be to have a research study coupled with the social and psychological sciences in order to improve the way that human aspects are managed in these models. At this stage collaboration and informal aspects are introduced in these models, but to complete the definition of such models, a study may be carried out in association with human sciences. These improvements of the models could also lead to the improvement of the supported tools. The final objective will be to enrich the competences of projects leaders with more than collaboration aspects but also with human and psychological aspects.

Independent of this perspective, more tests are needed with CoCa to have more information, results and to test the more useful functionalities with a great potential in various other SMEs contexts. At present, the tests carried out in Ederena brought results and improvements for the specific context of this company. Thus, it would be interesting to carry out additional tests in other case studies in order to propose generic models, tools and improvements for the project managers. Moreover, these tests will propose a method or an approach to adapt the models and CoCa to other SMEs.

The approach to the analysis of collaboration needs improvements. In terms of further work, this approach to analyse the data is the first step towards the definition of a detailed and scientific method. At the end, this scientific method needs to be validated by various analysts in various case studies. At this stage the information recorded with CoCa is recorded manually with some devices to show information in a particular way (charts, links, and GUI forms). Nevertheless, the next step will be to have a semi-automatic recording and displaying of the information, with an extra module to drive the analysis of the collaboration. For example, this module should be able to propose to the analyst the pertinent information to see first, critical situations should be recognised and stored; the information should be displayed in a sensible way according to the method of analysis…

Indeed this module should drive the analysis of the collaboration to help the analyst in his work.

Another perspective on this research study is to have a comprehensive management of the knowledge. Indeed, the tool would be able to record the skills already known and learnt by the actors in order to have a detailed management of skills. It would also be able to record design information and knowledge with its context (project, process, and event). In this way the project manager will be able to re-use this knowledge in future projects.

With the definition of the improved theoretical models of coordination and collaboration, the levels of granularity (event, activity, process and project level) are now included and can be managed in the project coordination. In terms of further work, these two improved models can be aggregated to form an integrated model where the aspects of coordination and collaboration are associated and where prescription and scheduling is linked to the identification and storage of achieved events. Thus, coordination as well as collaboration aspects would be completely defined and linked together. Moreover, based on this integrated model a tool can be implemented to manage projects by taking into account collaboration aspects directly in it without having various disconnected tools. Thus, in a practical way, a specific tool to analyse collaboration like CoCa can be coupled with a specific coordination management system like IPPOP to help project managers to take collaboration aspects into account in design coordination.

Moreover, the analysis of collaboration is also useful in managing the implementation of PLM tools in companies. Thus, CoCa can be used by integrators to understand the way of working of the actors during project in order to adapt the tool to the company and vice-versa (adapt the company to the tool).

The final objective of the collaboration analysis is to improve the coordination of projects. The PLM mock-up presented in this study is based on the current functionalities of the PLM system, but it is not completely adequate to ensure the coordination of the whole design project. Thus, new modules need to be implemented. Firstly, there should be a module to manage the coordination of projects in a better way. Indeed, for each level of detail (project, process, sub-process, and task) the information system must manage the organisational structure, the objectives, the actors, the resources and the indicators of performance. These indicators must be automatically defined according to the lifecycle state of the documents or to the task progress. Secondly, there should be another module to help project managers to monitor and check the progress of the project. This module must also include the collaboration analysis to support and improve the coordination of projects. The main objective of this module for monitoring and checking should be to support the dynamic way of management of projects (with detailed and flexible design processes in order to make decisions without waiting a node of flexibility), to introduce flexibility into the processes, and to take into account the collaborative aspects.

All these avenues for research can be the basis of a proposition for a new PhD subject.

The theoretical models need to be coupled with studies from social and human sciences in order to enrich the competences of the project manager with human and social aspects. CoCa needs improvements to have a semi-automatic recording and displaying of the recorded information. Moreover, CoCa would be incorporated into an information system to help project managers to take collaboration aspects into account in design coordination tasks.

More tests are needed in various other industrial case studies to propose generic models and test the proposed improvements. The support of the coordination management with collaboration aspect would be introduced in PLM systems by implementing two modules. One module would be used to manage the organisational structure, the objectives, the actors, the resources and the indicators of performance for each level of detail. A second one would be used by project managers to monitor and check the progress of the project.

All these perspectives lead to the management of projects by project managers in a more human and humanist way where performance, reactivity and flexibility remain the main concerns.

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Appendices

Appendix A – IT implementation

The IT implementation allows the GUI forms to be linked to the database by storing the data in the right place and making the right query to display the right information in the GUI forms. The format of each data item is defined and correlated to the format of the data stored in the database.

The definitions of the IT code implementation are based on the definition of the database with an Entity / Relation diagram of the data model and by a detailed class diagram to represent the IT classes, database classes, and GUI classes in the same diagram.

A.1   Definition of the database

The database stores the necessary information defined previously in the theoretical model of collaboration. Thus, the data model is defined with tables, data stored, relations, foreign and primary key, and various extra tables are added to represent the relations existing between the classes (according to their cardinality: *.*, 1..*, 1..1) of the theoretical model. A diagram of the data model is provided in order to represent all this information (Figure 81). The definition of the data model aims to transfer the notions defined in the model of collaboration to the database to structure this information and make queries.
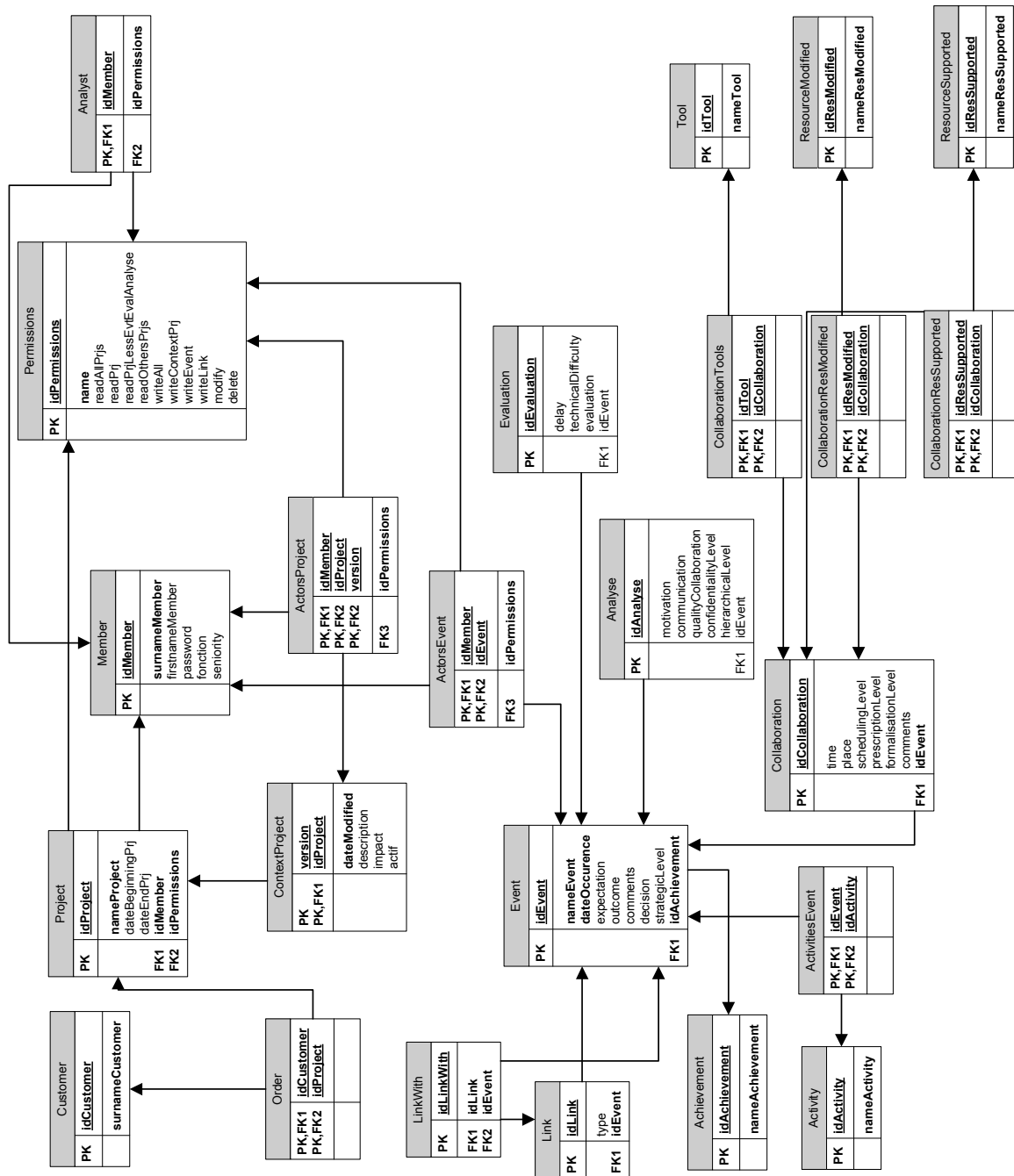
Figure 81: Entity / Relation diagram of data model

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A.2   Class diagram for IT implementation

This class diagram is very useful because all the classes from the GUI forms, IT implementation and database are grouped in the same diagram. Thus, the IT implementation must be based on a complete class diagram which takes into account the classes of the database, classes of the GUI forms, classes of the model of collaboration and additional classes indispensable for the storage of data temporarily (as for the results of requests). Moreover these classes are very detailed because there is a clear definition of the functions needed and the attributes with their format for each class. This complete class diagram for the IT implementation is shown in the following Figure 82.

Following the functional analysis, and in collective agreement with IT engineers, choices have to be made to implement the tool. These choices lead to constraints as the language to implement the tool, its architecture and the operating system under which the tool will run. Java language is chosen because it is an object oriented language, well known by the IT engineers, and in terms of evolutions, a future version of CoCa will use the Internet technology coupled with Java to be used everywhere without a location constraint.

Controler

-_lg:Flogin
-_databaseFB:FirebirdBD
-_us:User
-_welcome:Welcome
-_prj:newProject
-_contextPrj:
-_actor:NewActorProject
-_prjSelected:ContextProject

+enterLogin()
+save()
+quit()
+addProject()
+newProject()
+addActorProject()
+deleteActorProject()
+addActorEvent()
+deleteActorEvent()
+okAddActorProject()
+history()
+openSelectedHistory()
+openSelectedEvent()

DataBase

+loginVerify(lg:String,pwd:String):User, null si il faut()
+getAllProjects():Vector(Project,//derniere version)()
+getAllProjects(u:User):Vector(Project,derniere version)()
+deleteProject(p:Project):void()
+getAllMember():Vector of member()
+getAllClients():Vector of customer()
+getAllActors(p:project):Vector of actor //se sont les participants project dont le role à les permission arctor()
+addProject(p:project)()
+addActorProject(p:project, a:Actor,)//à la table participantsproject()
+addActorEvent(e:eventPrj, a:Actor)//a la table participantsEvent()
+getAllRoles(dont permission=actor):vector role ou string()
+getProjectLeader(p:project):member ou null()
+setProjectLeader(p:project, m:Member)()
+getAllContextProject(p:ContextProject//actuel):Vector of contextProject()
+getAllEventSelectedContextProject(p:ContextProject):Vector of EventPrj()
+()
+getSelectedActor():Actor()
+deleteActorProject(p:Project, a:Actor)()
+deleteActorEvent(e:EventProj, a:Actor)()
+nbEventsContextProject(p:ContextProject):int()
+addEvent(p:Con... ... ...)
+deleteEvent(e:Ev...

FHistory IHM

+FHistory(c:Vector of context project, p:contextProject courant)()
+getSelectedContextProject():ContextProject()

FWelcome IHM

+Welcome(c:Controler,proj:Vector,u:user)()
+getSelectedProject():ContextProject()
+removeSelectedProject():void()
+changeSelectedProject(p:ContextProject):void()

BouttonAction

+actionPerformed(ActionEvent):void()

Flogin

+Flogin()
+getPwd() : string
+clear()
+getLogin()
+Fshow()
+Fclose()

NewProject IHM

+NewProject(client:Vector, member:Vector)()
+NewProject(client:Vector, member:Vector,name:String;dateStart:String, dateEnd:String, client:String)()
+getClient():String()
+getProjectLeader():Member()
+getDateStart():String()
+getDateEnd():String()
+set pour tout les get()

FContextProject

+setRead(bool) tt grisé sauf history all event et history of events()
+setAnalyst(bool) mets bt modifyproject actif()
+FContextProject()
+FContextProject(p:ContextProject,a:Vectorof Actor, lp:Member, e:Vector of EventPrj()
+updateTableActors(a:Actor)()
+getSelectedActor():Actor()
+getSelectedEvent():EventProject()

ContextProject

-_id:int
-_name : string
-_Version : int
-_status : string
-_dateStarted
-_dateEnd
-_client
-_description:String
-_impact:int

+ContextProject()()
+setRead(bool)()
+get..()
+ContextProject(tout les parmetres)()
+setAnalyst(bool)()

-_id:int
-_name
-_p:ContextProject
-_sI:int
-_dateOccurence:Date
-_expectations:string
-_outcome:String
-_decision:String
-_comment:String
-
-
-
-

Permission

-readAllPjs : bool
-...

+set...(X:boolean)()
+get...():boolean()

Member

-_id:int
-_surname:String
-_firstname:String

+get....()

...wActorProject IHM

+NewActorProject(actor:Vector,role:Vector,nameprj:string,v:int))()
+getSelectedActor():String()
+getSelectedRole():Vector()
+clearSelection()

User

-_surname:String
-_analyse:boolean
-_idMember:int
-_seniority:String
-_function:String
-_firstname:String
-_permission:Permission

+User(surname:String, idMember:int ...()
+setRole(role:int)()
+getRole():int()
+getMemberId():int()
+getpermission(p:permission)()
+setPermission ():Permission()
+get..()

Actor

-_id:int
-_surname:String
-_firstname:String
-_fonction:String
-_role:String//participant project dont rroles a les permissions actor
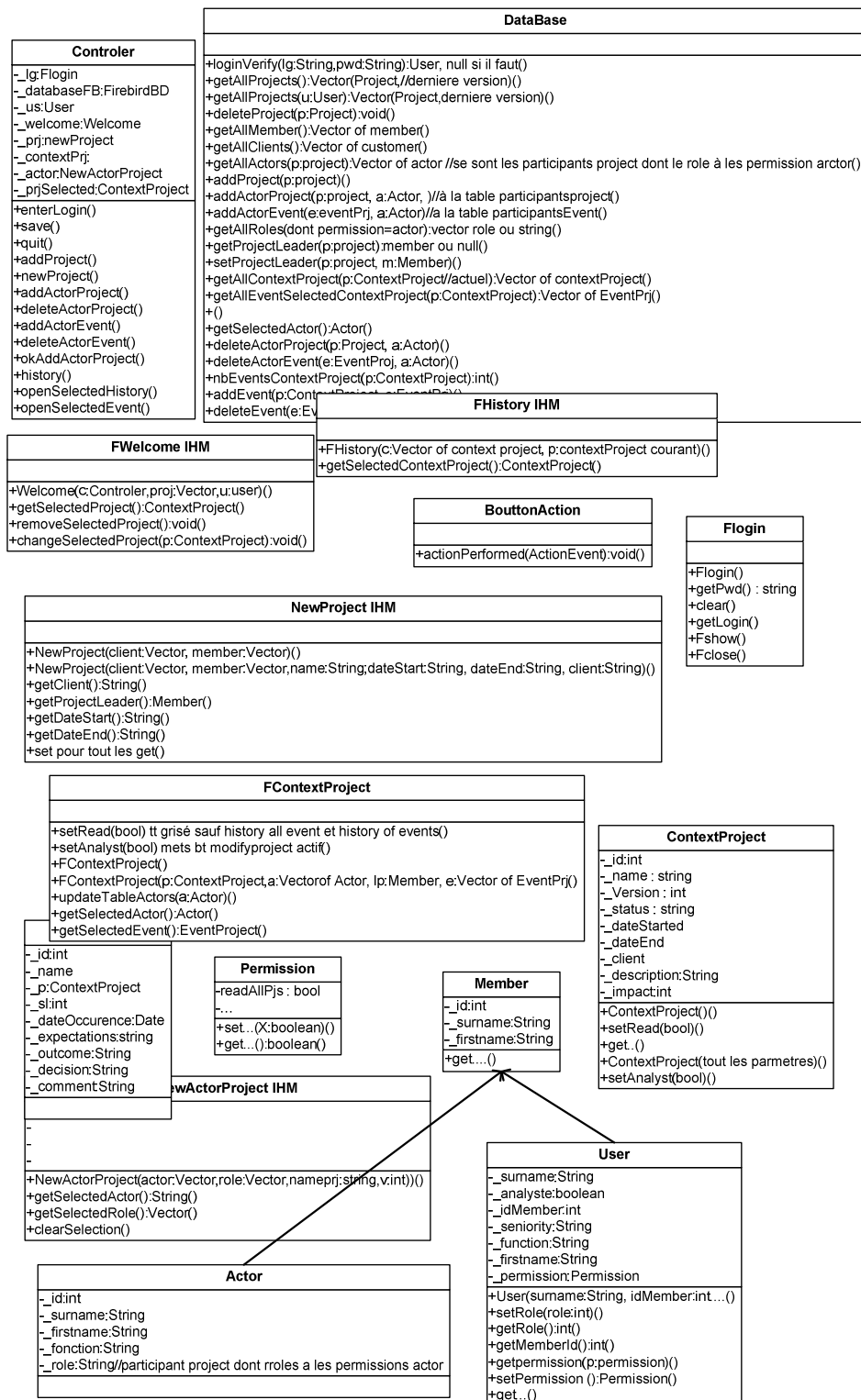
Figure 82: Class diagram for IT implementation

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Appendix B – Activity diagram for the CoCa

Figure 83: Detailed activity diagram

This detailed activity diagram of the tool completes the description of the tool in the section 5.3.1.

Appendix C – List of permissions with associated rights

Member / Permissions	analyst	leader project	actor
readAllPrjs	YES	NO	NO
readPrj	NULL	YES	NO
readPrjLessEvtEvalAnalyse	NULL	NULL	YES
readOthersPrjs	NULL	YES	NO
writeAllPrjs	YES	NO	NO
writePrj	NULL	YES	NO
writeEvent	NULL	NULL	YES
deleted	YES	NO	NO

List of priorities:

readAllPrjs	writeAllPrjs	deleted
readPrj	writePrj	
readOthersPrjs	writeEvent	
readPrjLessEvtEvalAnalyse		

Explications:

readAllPrjs	Read all in projects
readPrj	Read all in projects where he is project leader
readOthersPrjs	Read all except Eval and Analysis of other projects
readPrjLessEvtEvalAnalyse	Read all except Eval and Analysis in projects where he participates
writeAllPrjs	Write all in all projects
writePrj	Write all in projects where he is project leader
writeEvent	Write event where he participates
deleted	Supress all in all projects

Figure 84: Permissions for the use of CoCa

Appendix D – complete PAT

Ederena Concept	PAT

Code and Ind of the model

Customer		Project	
Aoc + Ind		Aoc End	
Order		Order End	
Project manager		Statut	

					AOC State	Order state	Responsible	Lead time expected	Lead time done	Delay
10	**Contract Definition**	101	**Clause by clause**	**Technical specifications of the Needs (TSN)**						
		102		**Amdec, Charter 4P, …**						
		103		**Contract**						
		104		**Logistical specifications**						
		105		**Quality specifications**						
		106	**List of contractual documents**							
		107	**Schedulling for the study**							
		108	**Schedulling of the**							
20	**Quality**	201	**Audit AMDEC**							
		202	**Quality plan**							
		203	**Control plan**							
		204	**Control form for entry**							
		205	**Control form for**							
		206	**First Article Inspection**	**Internal**						
		207		**Customer**						
		208	**Audit of processes by the**							
		209	**Approval of suppliers by**							
		210	**List of Articles and suppliers**							
		211	**providing of standards for**							
20	**Design and development**	301	**references of hte product in**							
		302	**Fonctional analysis**							
		303	**Technical Specification of the**							
		304	**Risks and consequences**							
		305	**Calculous note**							
		306	**Product**	**Conceptual plans**						
		307		**Global plans**						
		308		**Sub-global plans**						
		309		**Detailed plans**						
		310		**Manufacturing list (ERP)**						
		311	**Prototype for review**							
		312	**Mass balance**							
		313	**List of the mass of no-metalic**							
		314	**Review of intermediary design**							
		315	**Design validation**							
		316	**Quality requierement**							
		317	**Purchase specifications**							

20	Design and development	318	Tools	List						
		319		Conceptual plans						
		320		Global plans						
		321		Sub-global plans						
		322		Detailed plans						
		323		Manufacturing list (ERP)						
		324	Study on manufacturing							
		325	Technical instructions	Assembly						
		326		Adjustments						
		327		Handling						
		328	Packaging	Definition						
		329		Validation						
		330	Check-list of logistical							
		331	Review for manufacturing kick							
		332	Produit validation							
		333	Review of the first assembly							
		334	Chart of configuration							
40	Experimentations	401	Tests of type	Test of type program						
		402		Test of type procedure						
		403		Test of type report						
		404	Norms for fire, smoke and							
		405	Fire report							
		406	Mass report							
50	Process	501	Procedure description							
		502	Procedure qualification for							
		503	Procedure qualification for							
		504	Description of new procedure							
		505	Operator qualification							
		506	Security form for dangerous							
60	Modification	601	Configuration management							
		602	Consequence on teh product							
		603	State of the stoks							
		604	Upgrade							
		605	Application domain							
		606	Process of modification							
		607	Tracability of the modification							
		608	Customer validation							
70	Review	701	Review 1							
		702	Review 2							
		703	Review 3							
		704	Review 4							
		705	Review 5							
		706	Review 6							
		707	Review 7							
		708	Review 8							
		709	Review 9							
		710	Review 10							

Figure 85: Complete PAT

Appendix E – Workflows "Change request", "Change notice", "Change activities"

Figure 86: Change request workflow

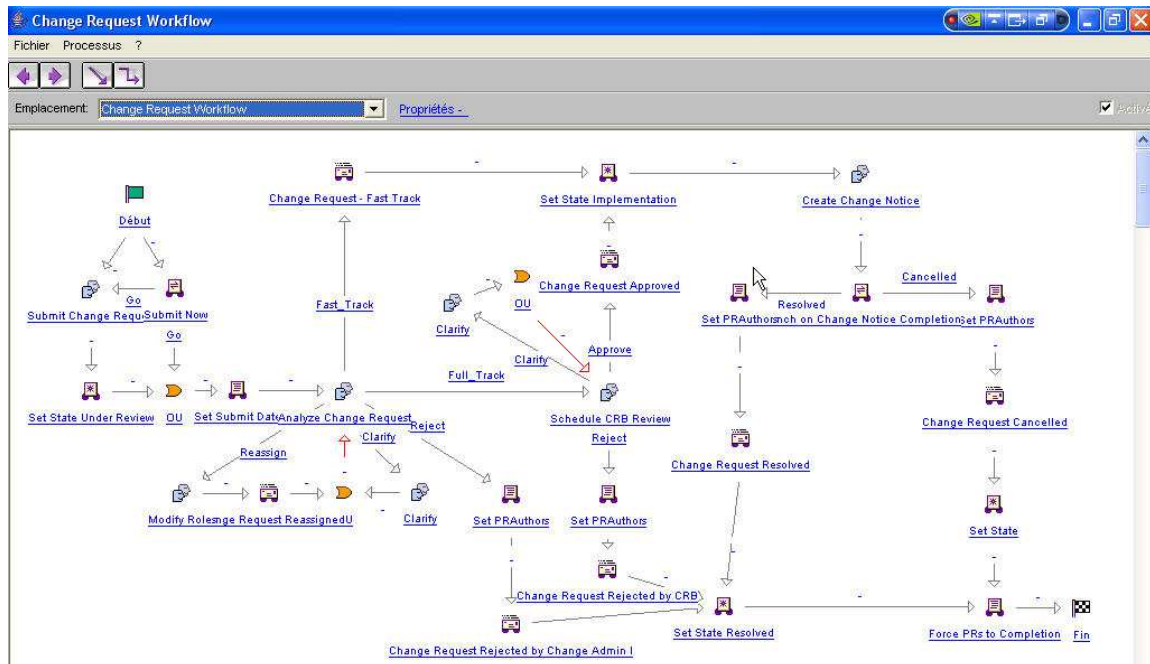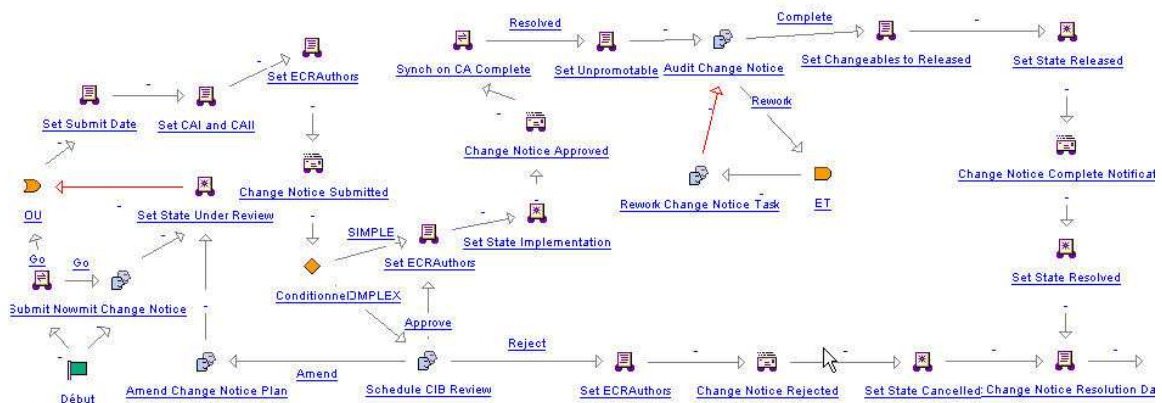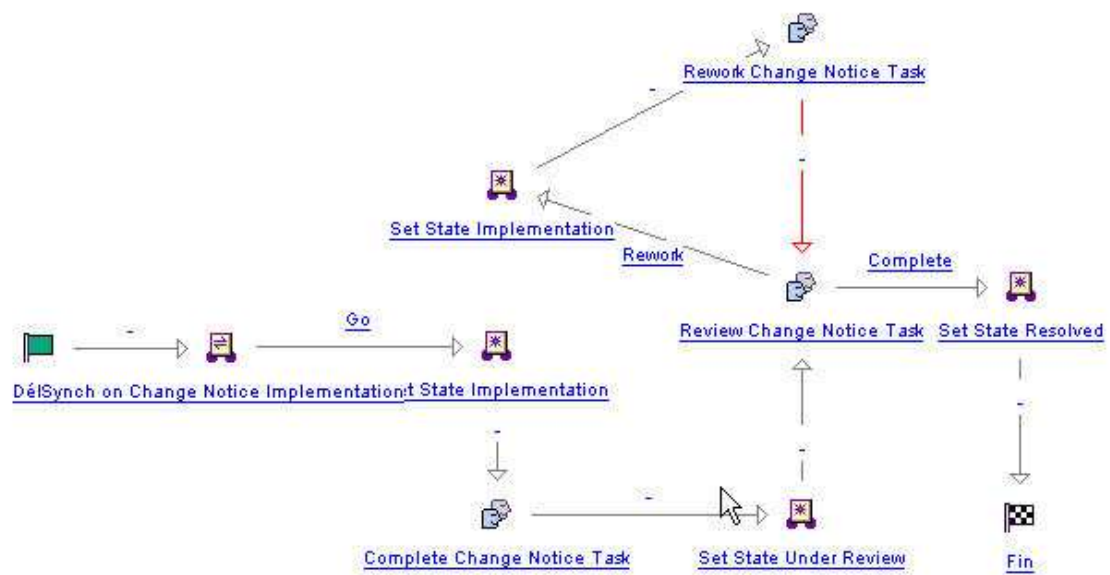**Figure 87: Change notice workflow**

Figure 88: Change activities workflow