A "PLM" IMPLEMENTATION IN A DESIGN PROJECT COURSE OF PRODUCT DESIGN ENGINEERING PROGRAM

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1. BACKGROUND

1.1. Introduction

This report presents the results of an investigative case study; the first ever implementation of a methodology called Product Lifecycle Management (PLM) for educative purposes in EAFIT University. The scenario chosen for this pilot implementation is the course "Project-8" of the curriculum of Product Design Engineering program, on the first semester of 2010.

1.2. Project Background

Product Design Engineering in EAFIT University has a course every semester, during the first eight semesters, called "Project". The objective of these courses is to apply the knowledge acquired by the students during their formation in the design and development of a product during the whole semester duration. Each Project course has a different theme and the intention is that students apply their knowledge in different fields and under different conditions. Project-8 is the last of these courses and it takes place in the eighth semester of the program's curriculum. Its theme is the design of mobility systems powered by electric motors. The project is done in groups of five or six students which must carry out all of the objectives in a collaborative manner during the five months that the course lasts. During semesters previous to the implementation of PLM (prior to the first semester of 2010) students were expected to plan and execute this group work by themselves with some aid given by the University's professors. Team work was evaluated but it was expected that students had already gained sufficient knowledge in previous courses to carry it out in the best manner.

EAFIT University fosters the idea of project-based learning. In a project, students learn by applying and articulating the knowledge they've gained during their academic formation. They acquire autonomy and self-discipline while also developing abilities for working in teams; abilities such as decision making, proper communication, problem solving and conflict resolution. For students to achieve these goals there must be a

preparation, implementation and subsequent realization of educational activities that are committed to the learning of assimilated concepts. Although all of the eight Project courses in Product Design Engineering are done in groups, in none of them there is a specific focus in teaching the necessary skills to carry out a collaborative effort. Students are expected to learn this by practice. Nevertheless, because of the lack of formal preparation and the involvement of many stakeholders in decision-making, numerous problems arise at every stage of this collaborative engineering design process.

One of the recurrent problems for the development of collaborative projects is sharing and managing information. One of the solutions to this problem has been Product Data Management (PDM), a communication system that allows all drawings and documents to be in a central database. PDM was later combined with Business Process Management (BPM) and a new concept called Product Lifecycle Management (PLM) was created. PLM is a methodology that helps to have control of a product's information during its whole lifecycle. Its use helps to manage a project in an organized manner and have access to all the information and resources necessary to execute it. This characteristic is essential in order to avoid re-worked units and the misuse of time and resources. Additionally, PLM helps having control over a work process and improves productivity, work efficiency and quality.

2. JUSTIFICATION

EAFIT University has the interest in implementing a PLM strategy, both in their undergraduate and graduate programs, as in the offer of services and technology transfer to the domestic industry with a global approach. Some of the steps that have already been taken towards this implementation are the creation of an elective course for developing PLM projects called “PLM Special Projects”, the purchase of a PLM commercial software license for EAFIT and the planning of a PLM lab on the new building to be inaugurated in 2010 in EAFIT for the engineering department. Additionally, the course Project-8 has been identified as ideal for the pilot implementation of a PLM system, due to its use of collaborative design with a high focus in product engineering. The mentioned implementation, for its pedagogical and educative value, will allow opening the way to further implementations of the PLM concept.

According to Flávia Maria Santoro [Santoro, et.al. 2005], of Purdue University, the challenge for designers of collaborative learning systems is to create the computational support that allows apprentices to follow the necessary paths for the development of the proposed project. If this is attained, it would provide a theoretical and practical perspective for relating educational objectives and technical innovations. This is a great challenge worthy of a thorough investigation.

EAFIT University has the interest in graduating autonomous, disciplined Product Design Engineers with the necessary abilities to work in groups. These students should become professionals able to generate final products being aware of the process performed by them in order to achieve their goal. PLM is a great tool to achieve these goals, but more than just support technologies are required; both attitude and team awareness from the participants are required also. A whole integral approach to the PLM philosophy, including education and rethinking of its methods and procedures, will take EAFIT to the forefront of collaborative product design engineering education.

3. OBJECTIVES

3.1. General Objective

Implement the Product Lifecycle Management (PLM) strategy in the Project 8 course of the academic program of Product Design Engineering at EAFIT University, through the use of PLM software based on the work methodology of the course.

3.2. Specific Objectives

- Formulate a procedure and program to teach PLM properly to the students who enter the course.
- Restructure the Project 8 guide according to the use of a PLM strategy.
- Program a PLM computational platform, focused on the use of the students and professors of Project 8, for the management of the project.
- Develop a comparative analysis of the development and outcome of the conceptual and detailed design phases of Project 8 before and after the implementation of the PLM strategy.

3.3. Scope

The Project has an academic application on two pilot groups from Project-8 course of Product Design Engineering Program of EAFIT University starting on the first academic semester of 2010.

3.3.1. Population Sample

The two groups account for a total of 12 students, from a total population of 60 students matriculated in Project-8 2010-1. This represents a sample fraction of 20%. According to the following equation for standard error [Wonnacott and Wonnacott, 1990]:

$$p = 0.2\,; n = 12$$

$$Standard\ Error = \sqrt{\frac{p(1-p)}{n}} = 0.115 = 11.5\%$$

In this case because the sampling fraction exceeds 5%, the margin of error must be adjusted using "finite population correction" [Wonnacott and Wonnacott, 1990]:

$$N = 60\ ; n = 12$$

$$Finite\ Population\ Correction = \sqrt{\frac{N-n}{N-1}} = 0.9$$

The standard error is then:

$$0.115 \times 0.9\ = 0.1 = 10\%$$

This gives the sample an accuracy of 90%.

4. METHODOLOGY

This project was performed under a four phase methodology to accomplish all the objectives of this investigation. The four mentioned phases are identified in Figure 1:

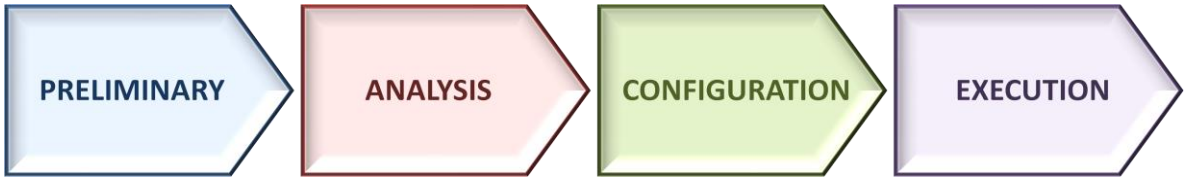


Figure 1: Four Phases of Methodology.
Source: Own Elaboration.

4.1. Preliminary Phase (Literature Review)

This phase gathers all the information necessary to prepare and plan the project. This includes 4 basic activities:

- **Work with Project 8 group prior to PLM Implementation:** The objective of this activity is to have a full understanding of the Project-8 course prior to the PLM implementation. This requires monitoring the activities and project development of one of the course's work teams. Additionally students in all Project courses will be surveyed with regards to teamwork in their Project teams. This work will set the basis for the objective of developing a comparative analysis of the development and outcome of the conceptual and detailed design phases of Project 8 before and after the implementation of the PLM strategy.
- **Literature Review:** This activity will provide the basic knowledge available in literature about Collaborative Design, Product Lifecycle Management, and the previous work done with PLM in education. This is necessary to give the investigation depth, direction and sustentation.
- **Planning Activities:** Consists of understanding the process, didactic material available to students (guide booklet) and methodology involved in Project-8 previous to the PLM implementation. It goes hand-in-hand with the first activity of

this phase, and it's a prerequisite to the creation of a new strategy and process model for the course.

- **Work with "Special Projects-PLM" Course:** This course was dedicated to the implementation of the PLM strategy on a more general level in EAFIT. Some of the activities done in this course directly affect the development of this project, like generating a General Design Methodology for EAFIT and the study of the software ARAS Innovator. This General Design Methodology will set the basis for creating a process model for Project-8 to implement the PLM strategy. Aras Innovator is the software that will be used to implement PLM in Project-8.

Note: Only the results of the activity "Literature Review" are presented as a chapter of the thesis report (View Chapter 5). The remaining activities have results that are analyzed and/or implemented in subsequent phases.

4.2. Analysis Phase

This phase is about analyzing the information obtained in the previous phase with the objective of fully understanding the situation before preparing the PLM implementation. It consists of two basic activities:

- **Data Compilation:** Consists of generating a compiled report of all the information generated during the preliminary phase. This includes generating an analysis and description of working methods of Project's students, and comparing the design process of the course with other methodologies available in literature.
- **Data Analysis:** Consists of further developing the analysis of the process and methods in Project-8. To accomplish this, the general Design Methodology created in "Special Projects" course must be confronted with the process done in Project-8. All the interactions between tasks, tools, deliverables and group members in the course must be analyzed. This is a necessary step towards creating a new process model, an essential part of the PLM Strategy.

4.3. Configuration Phase

This phase intends to generate the necessary planning and materials to set up the PLM implementation. After this phase is finished everything must be planned and ready to execute the implementation. The phase consists of three major activities:

- **Proposal Generation:** Consists of generating a new process model for Project-8 and validating it with Project-8 professors. This model will be an essential part of the PLM strategy, because it clarifies the process with means of programming and controlling it.
- **Software Configuration:** Addresses the objective of configuring a PLM computational platform, focused on the use of the students and professors of Project 8, for the management of the project. This configuration must be tested and validated by professors before it can be approved.
- **Preparation:** Addresses the objective of formulating a procedure and program to teach PLM and the computational platform properly to students who enter the course. This plan can be subject to recommended modifications after analyzing the results of the implementation. Another part of this activity is addressing the objective of restructuring the Project-8 guide according to the use of the PLM strategy.

4.4. Execution Phase

This phase consists on executing the PLM strategy that has already been configured in the previous phase. It consists of three main activities:

- **Execution:** Consists of performing an induction to PLM for students, running the software that has been configured and teaching students to use it. This tasks are critical for students to adopt well the new strategy and use the software properly.
- **Monitoring:** Consists of observing, following and assisting students throughout their project development until the end of the Detailed Design phase. This will help students adopt the strategy and use the software better and will also provide

feedback for comparing results with those of Project-8 previous to the PLM implementation.

- **Report:** Consists of registering the final results of the PLM implementation and drawing conclusions as well as recommendations for a further development of this investigation project. Additionally all the investigation must be reported in a final document.

A map of the four phases and their respective activities and tasks is visible in Figure 2.

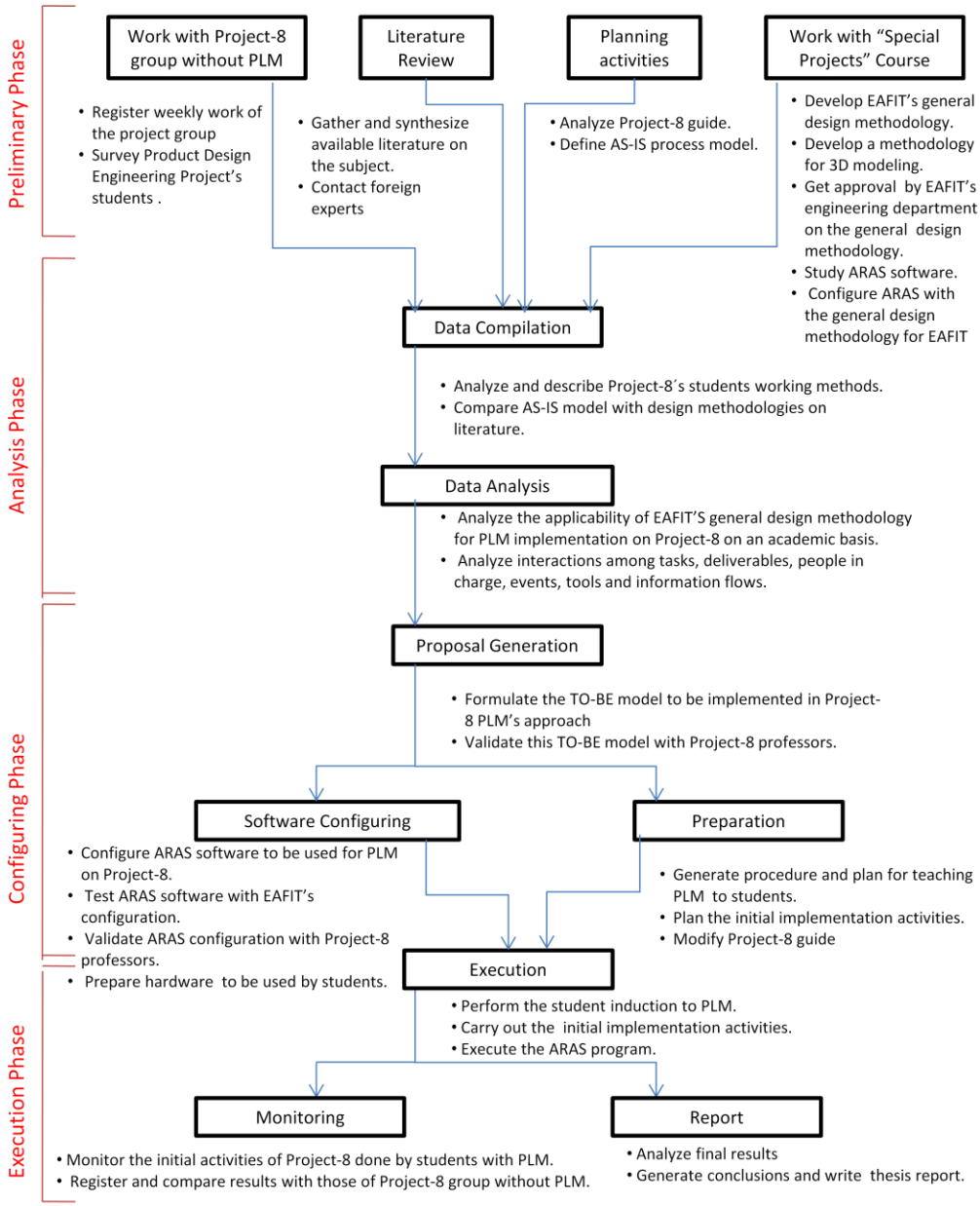


Figure 2: Map of Project Methodology
Source: Own Elaboration

5. LITERATURE REVIEW

5.1. Collaborative Design and Concurrent Engineering

With the competition between companies being fiercer and customers being more demanding, the efficiency of design decision-making must be improved to shorten the product design cycle. Intelligent collaborative product design is needed in the product design process [Yuliang Li, et.al 2003].

Team effort from all project participants (working in harmony with the project goals, timetable, and budget) is critical for product design. Collaboration, however, is not as natural and automatic as one might think. A collaborative attitude is a cultural matter. It needs to become part of participants' way of thinking in order to produce a collaborative environment [Santoro, et.al. 2005]. The lack of formal preparation and the involvement of many stakeholders in decision-making arise numerous problems at every stage of the collaborative engineering design process. Ability, aptitude, and order are three skills that must be demonstrated by students in order to succeed in a collaborative environment. Ability is achieved with knowledge, instruction, preparation, assistance and encouragement [Torres and Tomovic 2007].

The key aspect behind effective collaboration is the process. Process planning demands collaborative work, information sharing, and the exchange of ideas among multiple parties in different locations. Planning the interactions and the process in a collaborative project is a way to stimulate people to collaborate, while promoting interdependency and commitment to their work [Santoro, et.al. 2005]. One of the main issues in team work is the need for timely, reliable communication. The flow of information between each member of the project is a crucial ingredient to successful collaboration. Participants need to be aware of each other's activities and how these activities affect their own and the project in general. When activities are made explicit to all participants, and there is a well thought out planning of the process, participants become aware of their interdependencies and the need for collaboration.

Project-based learning is one of the most common ways of teaching collaborative design. In a project, students learn by applying and articulating the knowledge they've gained during their academic formation. They acquire autonomy and self-discipline while also developing abilities for working in teams; abilities such as decision making, proper communication, problem solving and conflict resolution.

A project can be described as a process that is divided into stages that are related to each other, forming a flow of work. Each stage is completed by executing one or more activities. These activities should stimulate information sharing and knowledge building. During the flow of work, the following goals can be achieved: (i) maintenance for the collaborative posture, awareness of each other's responsibility for work in the group; (ii) an understanding of each stage's goals in the global context; (iii) motivation for the maximum interaction among the participants [Santoro, et.al. 2005]. For students to achieve these goals there must be a preparation, implementation and subsequent realization of educational activities that are committed to the learning of assimilated concepts.

Collaborators often have pressures that undermine coordination. Team members deal with competing priorities from work, school, and personal demands. Meeting spaces need to be cleared at the end of a meeting, and team members leave a meeting with pieces of a puzzle that needs to be reconstructed at the beginning of the next meeting. Often critical pieces are missing, so the team is either unable to proceed or has to revisit decisions they have already made. Because not all team members can attend all meetings, some team members miss key information and activities. They may be unaware that certain decisions have been made or that critical information has been presented and discussed. In addition, students do not usually have dedicated project space. Team meetings take place in classrooms, personal offices, and open spaces. At the end of a meeting, the various artifacts—including notes, action lists, timelines, digital files, paper sketches, and prototypes—that have been produced must be distributed among the members; the white board gets erased, and no one person can reconstruct the meeting. Finally, individuals rely on the personal recall of these distributed items when formulating

new information. Without a central repository for both physical and electronic artifacts, the necessary co-construction of knowledge is lost during the project cycle. Team members lose the opportunity to build on each other's work and, more importantly, to learn from one another [Finger, et.al. 2006].

Four synchronous co-ordination methods that designers may take are shown in Fig. 3. Among these methods, Fig. 1c has no dependency analysis for designers to co-ordinate, while Fig. 1d shows that the right designer can automatically obtain the necessary design information based on the dependency analysis, and thus co ordination among designers becomes smoother [Yuliang Li, et.al. 2007].

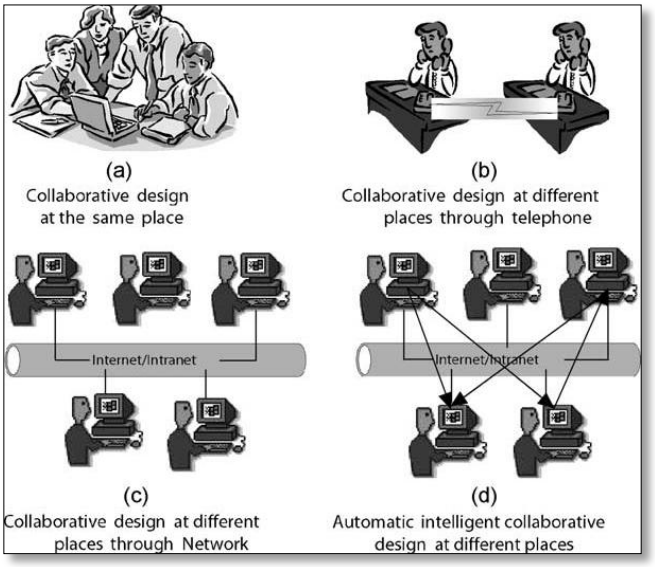


Figure 3: Synchronous collaborative design
Source: Yuliang Li, 2007

The most recurrent problem for the development of collaborative projects is sharing and managing information. During many years product designers and developers realized that they needed a way to manage and share all the product data they produced in an organized and controlled manner. This necessity became especially evident in the 3D modeling process of large assemblies like cars, airplanes, etc, where many people where involved at the same time and therefore accessing, sharing and keeping track of information was really difficult. An initial solution, called Product Data Management (PDM), was developed by The American Motors Company (AMC) around the year of 1985, according to François Castaing, Vice President for Product Engineering and Development

[Hill, 2008]. It consisted of a new communication system that allowed conflicts to be resolved faster, as well as reducing costly engineering changes because all drawings and documents were in a central database. “PDM introduced the idea that product data could safely and effectively be organized, maintained, and accessed in native digital form” [Grieves, 2006]. The product data management was so effective, that after AMC was acquired by Chrysler, the system was expanded throughout the enterprise connecting everyone involved in designing and building products. When this was combined with Business Process Management (BPM) a new concept called Product Lifecycle Management (PLM) was created.

5.2. Product Lifecycle Management

PLM is a strategy that helps to have control of a product’s information during its whole lifecycle. Its use helps to manage a project in an organized manner and have access to all the information and resources necessary to execute it. According to Sudarsan [Sudarsan, et.al. 2005], the PLM concept is a strategic business approach for the effective creation, management and use of corporate intellectual capital, from a product’s initial conception to its retirement. The implementation of a new Product Lifecycle Management (PLM) system results in cultural changes that affect how people involved in the system locate and manage their data [Cummings, 2006]. This characteristic is essential in order to avoid re-worked units and the misuse of time and resources. Typically, a considerable amount of time is wasted when engineers unknowingly create similar concepts on multiple occasions. Saaksvuori and Immonen [2004] identify the following advantages of a PLM system:

- Saves time
- Improves quality
- Reduces tied-up capital
- Measures the business benefits in daily operations
- Reduces inventory tied capital
- Improves the productivity of labor

The principal benefit offered by PLM is the complete control that management can have of the product in all of its stages. PLM has also been the link to several other disciplines and techniques such as Computer Aided Design, Product Data Management, and Computer Integrated Manufacturing. With PLM new products are reaching the market, more profits are gained due to larger lifecycles, and less waste is generated [Torres and Tomovic, 2007].

Micheal Grieves [Grieves, 2006] identifies the main points of PLM as the following:

- PLM is about product data, information, and knowledge.
- PLM concerns itself with the entire life of the product, from inception to end-of-life.
- PLM is an approach that is more than software and approaches.
- PLM crosses functional boundaries.
- PLM combines the elements of people in action, processes, and technology.
- PLM drives the next generation of lean thinking

Product Lifecycle Management (PLM) can drive the entire product lifecycle by integrating their information, knowledge, individuals, activities and tools. The whole life cycle of a product is usually very long. This causes a disagreement regarding the PLM definition, its stages and the tools it comprises. It also makes it too broad for a single tool to include all the capabilities it requires which in turn causes a lack of integration among several tools used throughout the PLM stages.

Figure 4 presents the taxonomy of PLM digital tools. It is divided into three major categories: tools for engineering, for knowledge management and for business activities. Each of them has subdivisions, which are presented. Representative examples are presented for most of those subclasses. These tools are implemented in every stage of the product lifecycle [Guerra-Zubiaga, et.al. 2007].

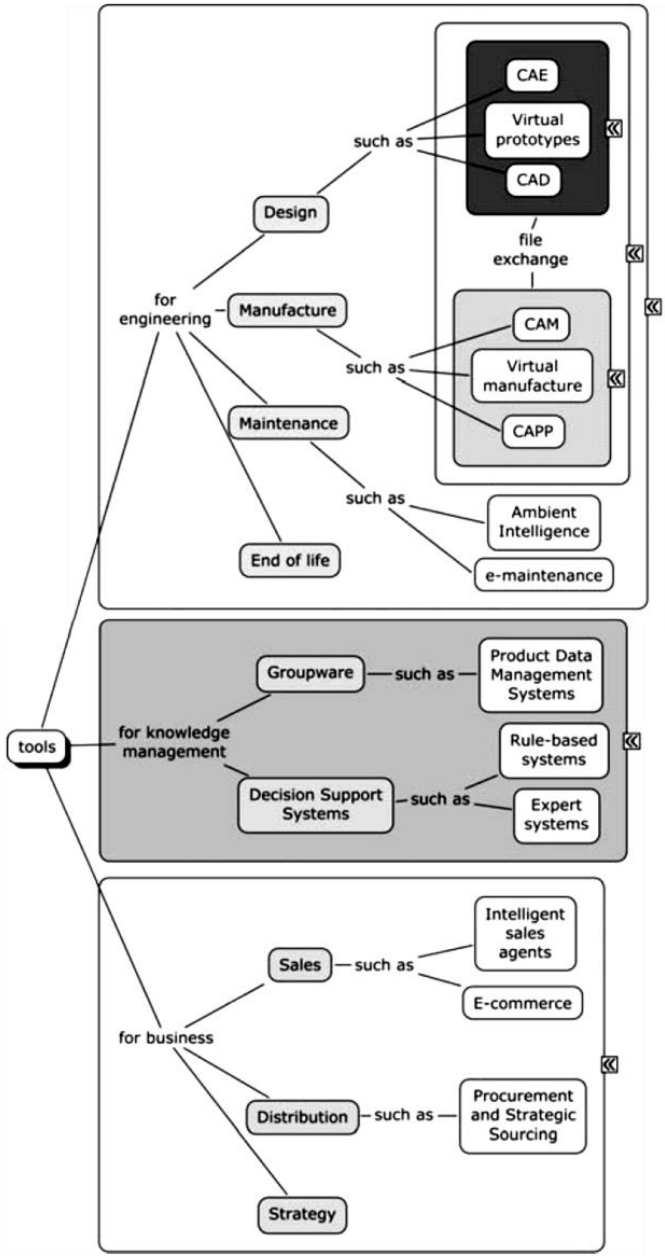


Figure 4: Taxonomy of the digital PLM tools
Source: Guerra-Zubiaga, et.al. 2007

5.3. Product Lifecycle Management in Education

5.3.1. Background

In order to keep up with today's industry, and develop the product realization programs, new requirements for the workforce need to be added to make them qualify for the changes in the industry brought by the new technology. With the recent developments in

Product Lifecycle Management (PLM), and in the related fields, it is necessary to readdress the education of college students as they need to meet industry requirements in global marketplace [Li, et.al. 2007].

Students are novices both in their domain knowledge and in their knowledge of the design process. Students work in unstructured teams of peers, even if roles such as team leader have been assigned. They often judge their success by the grade they earn or by the artifacts they produce. The client, whether it is a professor or a company, rarely plans to use the team's design directly. Rather, the goal is for the students to learn about the design process and to master new domain knowledge. For all these reasons, collaboration tools designed for teams in industry seldom work well for student teams. In response, design faculties on many campuses have begun to work on collaboration tools for student design teams [Finger, et.al. 2006].

Students and employees should be educated in PLM. They have a tremendous responsibility, while they hold the future of a company in their hands. Therefore, a course that will teach the most important aspects of PLM is crucial. Patricio Torres and Mileta Tomovic [Torres and Tomovic, 2007] from the PLM Center in Purdue University, Indiana, proposed in 2007 a possible curriculum plan for a PLM course, stressing the necessity of teaching PLM to students and employees. The following is a brief of the curriculum plan they proposed, taught in 4 modules:

Module 1: Introduction

- Definition of PLM
- Advantages of PLM
- Challenges in the implementation of PLM
- PLM elements
- Strategies in implementing PLM

Module 2: PLM Systems

- Product development
- Sales and marketing
- Process structures

Module 3: Combination of PLM with other techniques

- Database integration
- Computer Aided Design (CAD)
- Computer Integrated Manufacturing (CIM)
- Product Data Management (PDM)
- Enterprise Resource Planning (ERP)
- Supply Chain Management (SCM)
- Customer Relationship Planning (CRP)

Module 4: PLM Readiness Assessment

- Assessment of current systems
- Workforce assessment
- Process assessment

Stiffler and Romanow [2004] state that the key to a successful PLM implementation is not the fancy software function but the change of the mind-set. One major concern the authors picked up from early PLM adopters was that the new graduates right out of school often do not have proper training to consider a problem from different angles [Chang and Miller, 2005]. In order to develop an adequate PLM implementation in a product realization program, it is necessary to identify a basic set of competencies to be addressed in the curriculum. The competency, which is the capability to apply or use a set of related knowledge, skills, and abilities to successfully perform "critical work functions" or tasks in a defined work setting, will build upon existing ones and then complemented with the new requirements related specifically to developments in PLM and related field. Some members of the Department of Mechanical Engineering Technology at Purdue University, USA [Li, et.al. 2007] have identified the following set of competencies for the product realization under a PLM environment divided into these fields:

- **Product design:** Identification and planning, concept engineering and product engineering

- **Engineering fundamentals:** Mechanical, electrical, engineering basic knowledge of math, physics, etc, humanities, social sciences and communication.
- **Manufacturing engineering:** Process engineering, digital manufacturing, production/industrial engineering, product testing and quality, work analysis/ergonomics, material handling and facilities design.
- **Information technology:** Product data management, computing and networking, concurrent engineering infrastructure.
- **Support/ service:** Customer needs management, product service, maintenance, distribution and logistics, and disposal and recycling.
- **Business skills:** Collaboration/ teams, product portfolio management, financial analysis, operation management, international perspective/globalization, program/project management.
- **General education:** Interpersonal skills, leadership, problem solving, legal/ethics issues.

PLM is indeed the next step in lean thinking. Today the challenge is to produce with efficiency and to eliminate any source of waste in order to achieve competitive advantage. The difference between success and failure is preparation. From that point of view, a course in PLM will offer great benefits for students, managers, and employees [Torres and Tomovic, 2007].

5.3.2. Previous Case Study: Purdue University PLM Education and "Industrial Applications for Simulation" Course [Chang and Miller, 2005]

The faculty at Purdue University has been working to reform existing PLM-related courses. One of the efforts is the offering of a Computer Graphics Technology (CGT) minor curriculum. Based on the original manufacturing graphics track in the Dept. of Computer Graphics Technology, this new curriculum provides an environment where participating engineering and technology majors can be exposed to different aspects of PLM. In addition to the freshman engineering graphics course, students in this minor track will take four more courses, including Solid Modeling, Surface Modeling, Manufacturing

Graphics Standards, and one of the following two courses: Industrial Applications for Simulation or Manufacturing Documentation Production and Management. The first three courses, offered in the sophomore and junior years, intend to build a student's basic PLM knowledge and skill sets. The last two senior level electives both provide a project-based learning environment to help the students synthesize what they have learned during the past academic years into a bigger picture. Built on the previous industry projects, different scenarios are designed for students to apply what they learn in lectures and labs to solve real-world PLM-related problems.

Of the two senior elective courses, the first one focuses on the applications of computer-based simulation in the four product life cycle stages, such as design, planning, manufacturing, and sustaining. The design of this course stresses how computer simulation can be used to support engineering decision-making processes. Comparatively, the second course centers on the handling of product documents throughout the life cycle period. In addition to topics on data generation and control in the product design and planning stages, the necessity of product data retrieval within the second half of a product life cycle (manufacturing and sustaining), is presented; the information of possible interactions between PLM/ PDM and ERP, SCM, or CRM is also elaborated.

The goal of the course “Industrial Applications for Simulation” is not only to provide students a first-hand PLM experience but also shape them to meet the skill competency that industry expects from new graduates. Using design principles of project-based and problem based learning, the students are presented first with what the end product will be (in this case, a simulation model), then for the rest of the semester they work toward this goal by learning more in order to answer problems that arise.

In the fall semester of 2004, the 21 students enrolling in this redesigned course came from five engineering and technology disciplines, including aeronautics and astronautics engineering, computer graphics technology, computer-integrated manufacturing technology, mechanical engineering, and mechanical engineering technology. While the multidisciplinary nature of the students' backgrounds more or less realistically simulated an industry work environment [Miller and Olds, 1994], it brought

difficulties as well in regard to topic selection. With the scope of the project that involved more than 20 people (including instructors, students, and industry contacts) and the given time constraint, the practice of project management popular in today's industry setting was introduced for better project execution. The students were first briefed on the key elements of project management, e.g., time, cost, and resources, and the foreseeable benefits of tactics. Next, a project handbook and a special presentation were used to give the students up-to-date information, such as project history, objectives, team composition, stakeholders, and the operation environment. Each student then had to conduct a task analysis for her or his own stations, set up personal goals and deliverables, and articulate the outcomes in an individual project proposal. An individual timetable was also designed by the students. Later during the project execution, personal work logs were kept to track individual and overall progress. Project meetings were held weekly, and project memos were delivered to the corresponding personnel if necessary. Instead of learning by following the demonstration in the lab, students learned different software modules by reading the user manual and familiarizing themselves with key functions through trial and error and specially designed assignments.

The setup and atmosphere of the course were very different from the usual engineering and technology classroom, and many students initially could not clearly understand the purpose of different exercises. Sometimes even the instructors, after hearing feedback from the students, wondered if all these problems were normal, or they were actually the by-products of this new approach. It was not until later when Purdue University held two conferences with its industry partners, where representatives from industry spelled out expectations and shortcomings in current engineering education systems, did the instructors realize that this class is exactly what industry is looking for. Such confirmation from industry directly was great encouragement to the instructors.

6. ANALYSIS

This chapter contains the analysis of the situation previous to the PLM implementation. It consisted of a broad study of Product Design Engineering students in regards to teamwork and collaboration, and a detailed analysis of Project-8's methods and students. This work would provide the necessary information to identify the necessities and design the correct strategy to implement PLM.

6.1. Teamwork survey analysis

To evaluate certain aspects of teamwork done in "Project" courses, a short survey was designed for approximately 700 students that were registered in one of the eight Project courses in the fall semester of 2009. The survey was done to 151 of these students during their project final exhibition dates, on the 11th and 13th of November 2009[1].

6.1.1. Survey Results

Results for the first question show that clearly a vast majority of students enjoy working in teams. Most of the people that answered option C said that this depended on the team, but nevertheless the overall idea of teamwork is generally well received (View Figure 5).

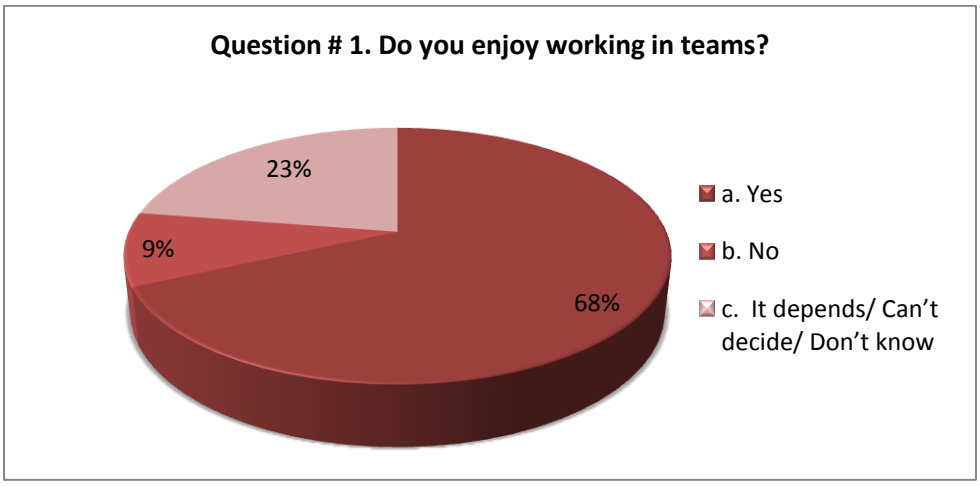


Figure 5: Percentage pie of answers to Question 1
Source: Own Elaboration

[1] View Appendix 1 to see the questions and the technical data of the survey

However, a trend did come up when evaluating this particular answer in respect to the course level each respondent was registered in. Freshmen and sophomore students (projects 1 to 4) generally gave more positive answers than junior and senior students (projects 5 to 8), as shown in Figure 6. Furthermore, the majority of Project 8 students answered option C, which shows that alongside the advance in the program, comes a greater understanding of the problems and difficulties involved with teamwork, thus making the answer more relative.

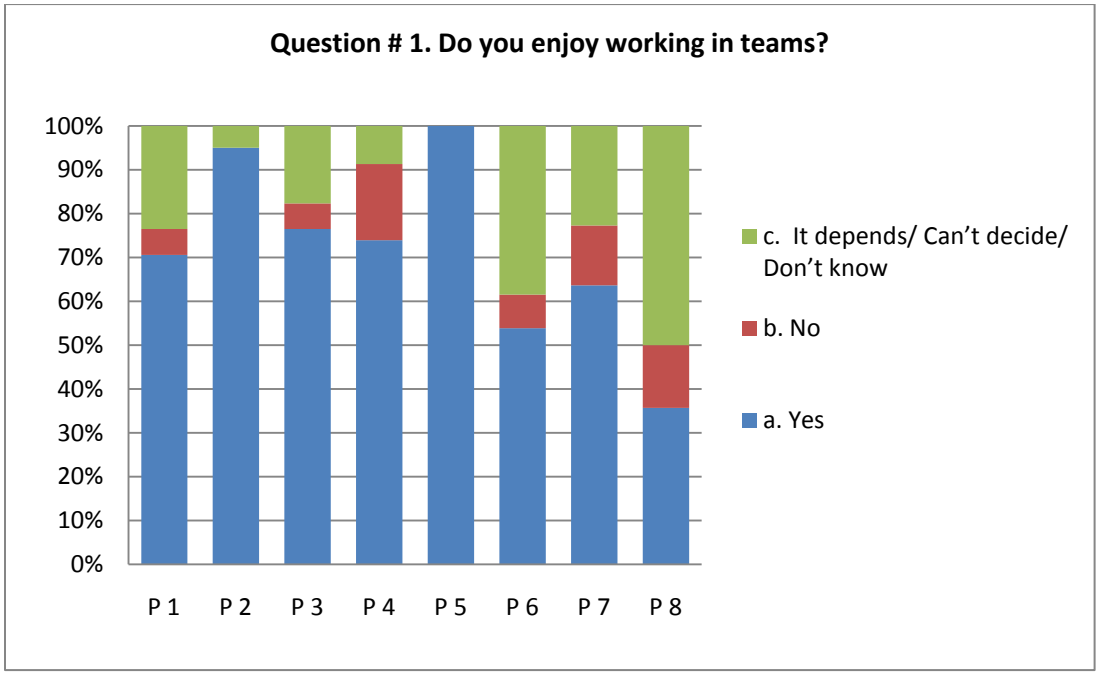


Figure 6: Bar percentage distribution of answers to Question 1 according to project course level.
Source: Own Elaboration

For question 2, the answers with the highest voting were B, F and H (View Figure 7). This clearly shows how students are aware of some of the greatest benefits of teamwork, as is learning from other team members and sharing costs. Additionally, there is a great awareness that teamwork will continue to show up in their professional life as Product Design Engineers and therefore there is interest given to learning the proper skills for doing so.

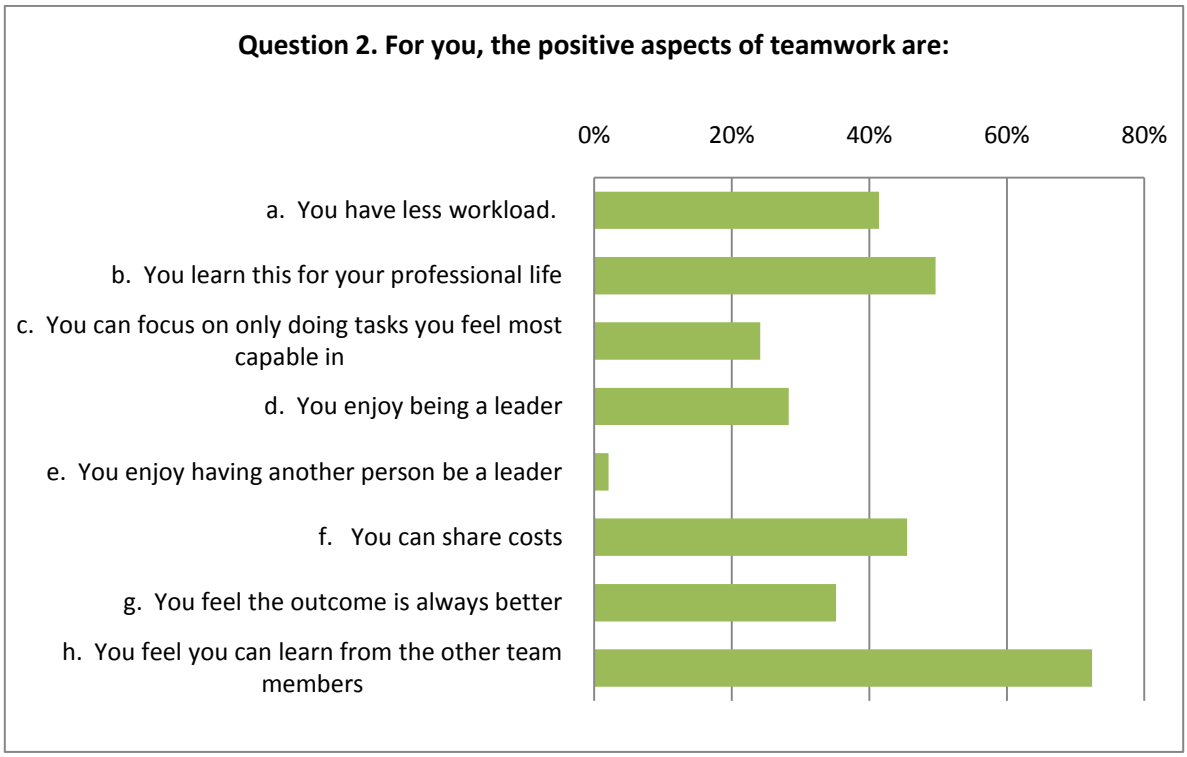


Figure 7: Bar distribution of answers to Question 2 shown in percentages.
Source: Own Elaboration

On question 3 the answers with the highest voting were C and D (View Figure 8). This shows that most students have had bad experiences with working in teams were workloads are not even and some team members don't do their share of work and let down their team. It's common knowledge that in most teams there are members that work harder than others and it's hard for these members to trust and depend on weaker members. The reasons for this are many, including personal attitudes, capabilities or time disposition.

Another common problem identified in teamwork is time. A large number of students answered that they found better managing their own time and/or found it hard to find time to meet with other team members. In most businesses employees share common work hours so this might not be as big of a problem as it is for students with different class schedules and daily activities.

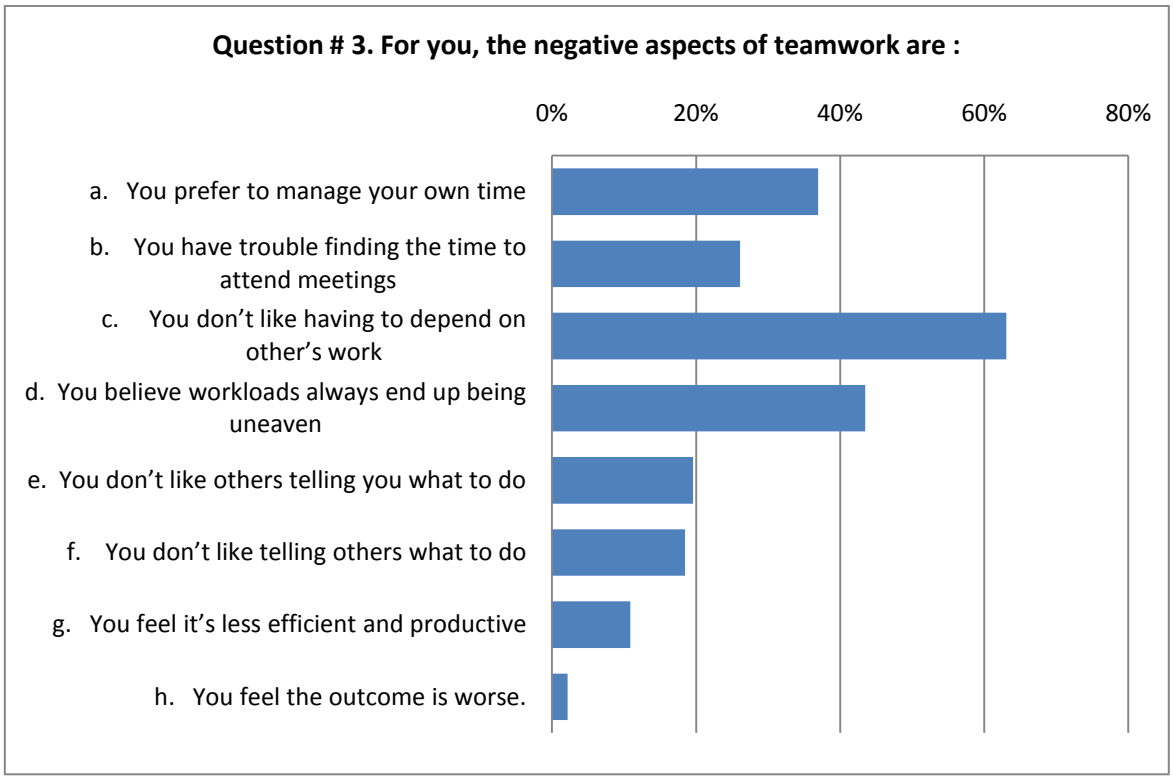


Figure 8: Bar distribution of answers to Question 3 shown in percentages
Source: Own Elaboration

On question 4 most students answered that they preferred to work in teams of 3, closely followed by those who prefer to work in teams of 4 or 5 (View Figure 9). Most project courses and activities are planned in groups with those sizes. The least popular of answers, chosen by only 1% of the population asked, is working in groups larger than 6 people. Although large groups can generally achieve greater projects, divide more the costs and share more knowledge among team members, they are hard to manage and deal with. Most if not all of the problems identified in Question 3 become even harder to overcome in large groups. The only experience students have with this situation is Project 5 course, done in groups of 10 to 13 students. Only one of the 11 persons interviewed from this course answered this choice, which shows that this was not an easy situation for most of them.

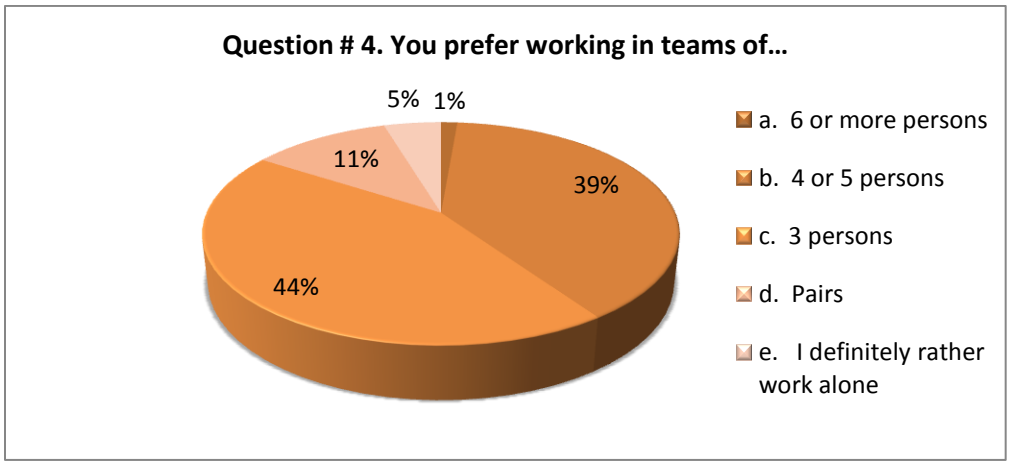


Figure 9: Percentage pie of answers to Question 4
Source: Own Elaboration

In Question 5 options B and C had a great popularity, each one being chosen by approximately 3 out of every 4 people interviewed, which represents around 110 people (View Figure 10). This answer is very congruent with the one given in Question 3; if time and workload distribution were identified as the greatest problems, the apparent solutions given by respondents were having a well planned chronogram of activities and dividing work in specific assignments.

Additionally, having an established leader was identified as positive for teamwork by 42% of the students surveyed. Nevertheless, 28% of the students answered in question 2 that they enjoyed being leaders and only 2% answered they enjoyed having others be leaders. Furthermore, 20% of students answered in question 3 that they didn't like being told what to do and 18% answered they didn't like telling others what to do. These answers pose a challenging situation for proper leadership in project courses and therefore innovative solutions like switching the role of leader and shared leadership must be explored.

Periodic meetings and evaluations of the whole team were also identified as benefic by a large amount of people, yet finding time to carry them out was identified as a problem in question 3. Therefore it's necessary to find new solutions to fulfill these requirements but limit the time they take up.

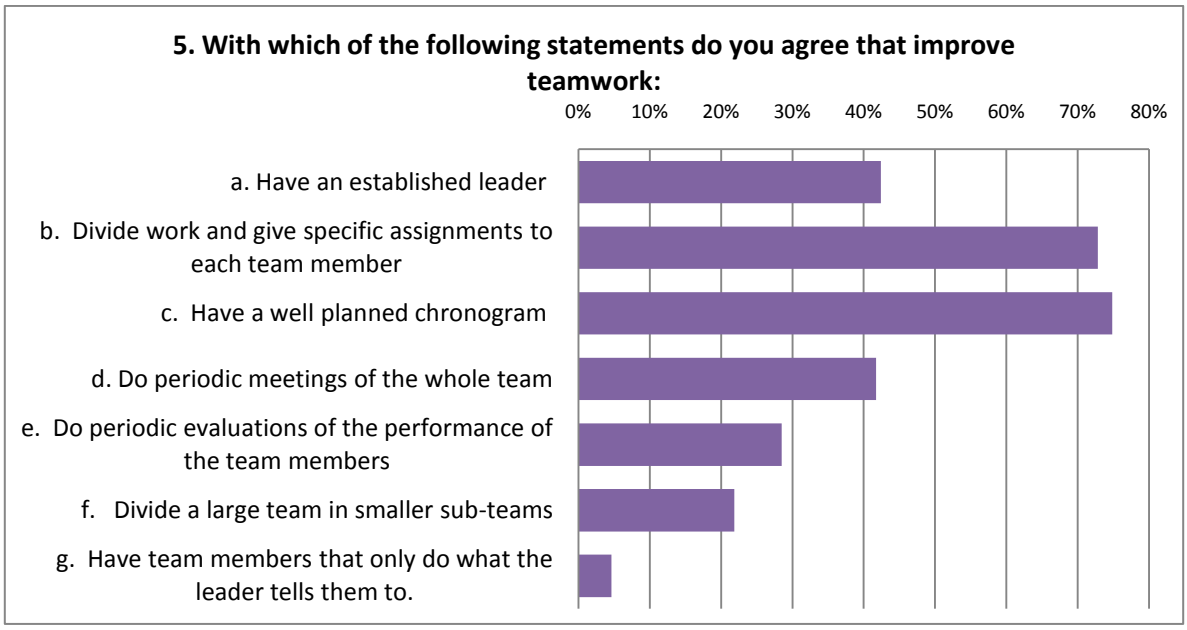


Figure 10: Bar distribution of answers to Question 5 shown in percentages.
Source: Own Elaboration

6.1.2. Analysis in regards to PLM implementation Project

- Most students have a positive attitude toward teamwork and identify it as important for their learning and professional development.
- It's important that students in teams continue to share time and information because they identified teamwork as an opportunity to learn from each other.
- Students in "Project 8" course have sufficient experience to know firsthand and evaluate the benefits and difficulties of teamwork.
- It's necessary to balance workloads in projects and have a proper distribution of activities as well as fair evaluations of each student's performance and involvement.
- For many students, time is hard to manage and dedicate, so they need solutions to reduce time they spend and do so in a more efficient manner. Time schedules and chronograms are identified as possible solutions, as are also the opportunity to manage their time individually and reduce the amount of meetings required.

- Team sizes of approximately 5 or 6 people that have been established for “Project 8” course provide a good opportunity to generate many of the challenges involved with teamwork and students show good reception to these group sizes.
- Leaders are identified by most as beneficial for teamwork but implementing them in Project courses poses challenges, as many students are not willing to or don’t enjoy following leadership and/or imparting it.
- More students voted on assigning tasks individually rather than in sub-groups.

6.2. Analysis of work done in “Project-8” group previous to PLM implementation

6.2.1. Introduction

One of the first decisions taken to start this project was to follow the activities of a Project-8 group during the Conceptualization and Detail Design phases of the fall semester of 2009. This was considered necessary to have a general idea of how a group works under circumstances up to that moment; previous to the PLM implementation. This general idea would be further complemented by the contact and discussions with Project-8 professors, students and by general observation of the activities and results of the course.

A pilot group enrolled in this course was selected considering their good performance and positive disposition towards the project up to that moment. The reason for this is to hopefully have the best possible results. While it’s possible that other students with a weaker performance could have more trouble and possibly a less positive outcome, the idea is to create a high standard for the comparative after the PLM implementation. The chosen group was composed of 6 students, as most groups in Project-8.

The work done with this pilot group was under the role of a supervisor, as well as an advisor in terms of organization and proper work distribution. Nevertheless, careful take was given not to influence the group too much, as this would create an impact on the final results and analysis.

6.2.2. Results

6.2.2.1. Results prior to involvement in group

When the group was selected they had already been working together for six weeks. During this period the first set of deliverables had been done and had been handed in, on which good results had been obtained. They had developed a product concept that consisted of a kit to be adapted to a standard wheelchair in order to power it with electric motors. The concept's advantage was that it could be adapted by the user to any commercial wheelchair available, thus being a very affordable solution towards electric wheelchair mobility for handicapped people.

The group acknowledged that their results for the first stage had been good and their project was promising but they identified certain problems they had. One of the group members had been acting as a team leader, although this hadn't been established formally. This member said (and some of the team members agreed) that the workloads in that first stage hadn't been equal. Although the end results had been good some members had been working harder than others. Much of the work had been left for the days previous to the due date, resulting in working until late hours those days to make up for lost time. Many of the meetings that the group had programmed had resulted unsuccessful because two or more of the members arrived late or never showed up. According to them it had been difficult to have all members show the same compromise and positive attitude with the project. The group had distributed their work but in an unorganized manner, never setting up specific responsibilities or keeping a track of their individual work and outcome.

The initial recommendations given towards solving these problems consisted on creating a common document that kept track of the work distribution in activities assigned to each team member and their individual performance and accomplishment of these activities. Every two weeks there would take place a group meeting to update this document with a revision of how the group was performing and assignment of activities for the upcoming weeks. The team took in this recommendation and a Microsoft Excel file

was created for this purpose[2]. In order to share information, such as this file, the group had created a common Email account at the beginning of semester. All team members had the username and password to this account and therefore they could all check the emails they would self address and send with all the new information. This solution was implemented by their own initiative (professors had no control or involvement in this) as an alternative to sharing data through individual emails or memory sticks, CDs, etc. With a common Email account, they could keep track of the documents they have shared up to date through the inbox tray and they could all access them through any internet connection in any computer and at any moment. Despite these advantages, no care was given towards standardizing the way to upload/send documents to this account; the email formats were always different, no folders or users were created and many emails with no relevant information or only addressed to one of the team members were also sent and they made browsing and finding specific emails harder.

6.2.2.2. Overall results during the Detailed Design Phase:

After the team had defined their design concept the next phase they had to do was the detailed design of the product. This phase includes activities such as:

- 3D modeling of the design concept.
- Finite Element Analysis of the structural loads and deformations on the design.
- Material and part selection and procurement for the model.
- Model production process planning.

The group divided itself in three pairs, each one having specific activities assigned. These pairs were formed according to affinity between the group member's strengths and also according to personal affinity or friendship. The activities assigned followed a certain thematic congruence which led each pair to be identified with a certain role. Though this was not made explicit, these were the basic roles that could be identified:

[2] The document "Results of Project-8 2009-2" can be found as Appendix 2.

- Pair 1. *Design.* This pair was responsible for the main activity in this phase, the 3D modeling of the product in CAD software. This included making a lot of design decisions, as to dimensions, form, and general appearance.
- Pair 2. *Engineering.* This pair was responsible for doing all the necessary calculations that backed-up the design and CAD model. Their initial responsibility was to calculate the power output that the motor(s) needed to give for the wheelchair to climb a certain inclination with a certain weight. Once the 3D model was done they had to do a Finite Element Analysis of the structural loads and deformations on it in order to optimize the design.
- Pair 3. *Production.* The responsibilities of this pair were to do all the necessary market investigations towards production of the product and the model. They had to find available materials, production processes, standard parts, etc. Within these responsibilities they should've also had to look for available motors in the market and buy the ones needed for the model, but due to the fact that these components were so critical, the group leader, which was not part of this pair, took on the job to find them himself.

The team had two main problems during this phase: Having to repeat work due to changes and having to wait for other team member's work to be done to start their own. They found out very soon going into the detailed design that the concept they had done in the previous phase was no good. They had initially planned the wheelchair to move with one motor that powered both wheels in the wheelchair. As soon as they tried to find an electric motor in the market that had all the technical requirements to fulfill this task they found out that it was too expensive and they had to import it from abroad which could set them back up to 2 months in time. Therefore they had to change their whole design to have 2 independent motors, one for each wheel, which were of smaller size and power each and could be found in the local market easier and cheaper. This modification changed almost everything in the design, from the positioning of the components, to the size and dimensions, to the general appearance. It set them back in time defining all those things again. If they would've done this research since the design requirements phase

prior to designing they wouldn't have had to do so many changes and could've gone straight to 3D modeling the concept.

The other problem they had was due mostly to bad planning when they assigned activities and to unawareness of the process workflow. When they assigned the 3D model only to two of the group members they made a mistake because many of the decisions that were taken by this pair affected the other pair's work and therefore they were dependant on them. Additionally, this pair took an excessive amount of time to do this step and therefore a lot of time was lost just waiting for them to finish this in order to continue. Other team members didn't hustle them enough or help them to do it quicker, in part because one of them was precisely the team leader. He didn't realize how much their delay was affecting others and the overall advance of the project. The group went in a real halt during these weeks and professors started to worry because they saw no progress on the weekly revisions. Pair number 3 was slow in their research and the reason for this given was that they still weren't clear on the product's design in order to look for materials, standard components and production facilities in the market. The same happened with pair number 1, which couldn't do a Finite Element Analysis until they had the finished CAD files from pair number 2. A week before the deadline this situation continued and it came to the point where they had to do a lot of last minute work and late hour reunions to get the work done in the end. They practically didn't sleep the night before the deadline. Even so, the work they delivered had a lot of flaws and was very incomplete. Professors were disappointed on the team's work and how much they had lowered their work quality.

Setting up reunions with this group was quite hard. Members had different agendas and it was difficult to find a common time to get together. Additionally, there wasn't much commitment from some of them to attend. 4 reunions were done on September 7, 14 and 28 and on October 12. On the first two of them only 3 of the members attended. On the third one, five of them attended but it started quite late and the last one had to be done in two separate sessions because they couldn't attend all at the same time. The reunions and the file created to distribute their work weren't effective

solutions as expected in the sense that workloads continued to be unbalanced and work was still left to be done at the end, although it was supposedly distributed evenly in the weekly chronogram. Since this file and their individual performance remained to be anonymous and had no real effect on their individual grade, students continued to do their work according to their usual habits and didn't comply with the compromises they had made during planning. More effective methods of control are needed to change poor work habits that students have from past semesters.

Although involvement with this group was initially planned to cover only until the Detailed Design phase, according to this implementation project's scope and objectives; there was also some involvement in the continuing phases of Model Construction and Launching and Testing. After their bad results in the detailed design phase the group had to do a lot of corrections and fill in some gaps they had left on their work during the construction of the model. Many things that should've been done already by then had to be thought out and done at this stage, such as the design of some handles for the user to operate the motors that powered the wheelchair, and the cylinders that transmitted the power directly to the wheels. Nevertheless, with an extra effort done during the last month previous to the project's deadline and presentation, the objectives were managed to be achieved and the final result was good (View Figure 11). The group obtained a good grade on the course and many of the people that attended the presentation of the final model were very impressed and gave excellent opinions on it. Additionally, this group went on to win the Product Design Engineering Awards for best Project-8 2009-2.

Figure 11: Rendering of final CAD Model presented by pilot group for Project-8 2009-2
Source: Own Elaboration

6.2.3. Analysis

- Good final results don't necessarily mean a good development of activities, and vice versa. Many flaws in the process might not show up in the end, like individual member's performance and involvement, time planning, organization, etc.
- Some students can be fully informed of their individual responsibilities and still don't accomplish them due to lack of commitment, responsibility or any other reason. Proper methods to have control over this and consequences must be implemented with the PLM tools.
- Roles are helpful for distribution of work activities, but the interactions between them must be planned carefully.
- 3D modeling is such a critical activity and has so many implications on this particular project that it should be given special planning and focus.
- Physical team reunions are hard to plan and carry out on most cases, and many times they are not productive and are inefficient.
- Dividing a group in smaller groups like pairs worked in some cases but in others, like in pair number 3, didn't help because one of the two did the work for both. Individual responsibilities must also be assigned.
- Many students are completely unaware of the sequential nature of some design processes. They don't realize that delays or faults in certain tasks have repercussions in subsequent tasks, and rather look at them as independent entities. PLM should help them learn this.
- Planning activities with enough anticipation is rarely practiced by students. Scheduling dates to start and finish tasks and assigning and controlling individual responsibilities is something these particular students had never done before or seen any of their classmates do. Improvising and planning on the run is usually the approach given to student projects.

6.3. Project-8 process analysis

During the Literature Revision it was established that the key aspect behind effective collaboration is "*the process*". Participants need to be aware of each other's activities and how these activities affect their own and the project in general. When activities are made explicit to all participants, and there is a well thought out planning of the process, participants become aware of their interdependencies and the need for collaboration.

Project-8 is a course where students are expected to have already learned the basic steps of a design process, but are nevertheless guided along this process by professors. As in previous Project courses, students are handed at the beginning of the course a guide booklet created by professors and faculty members with the basic guidelines of the course; expectations, grading methods, formats and a basic working plan with deliverables and their respective due dates. This working plan and the description of the deliverables is not very detailed, mostly because students are left the freedom to reach the results and objectives expected through their own methods and procedures. Nevertheless, faculty members have identified a general lack of process planning in the students, and the results often evidence that they're reached without having followed a previous well planned out procedure. One of the reasons identified for this problem is the lack of an official Product Design Methodology taught at EAFIT's Product Design Engineering. Students are taught throughout different courses a variety of design methodologies and are left in the end with the task to choose themselves which of them to apply. This sounds theoretically like a good approach towards product design, however in practice it's rarely applied and students are often uncertain of what their professors consider a good design process is.

An elective course called "PLM Special Projects" was opened the second semester of 2009 and one of the course objectives was to tackle this problem and create an initial draft of what will eventually become the afore mentioned EAFIT Official Design Methodology. After this course ended a successful draft of this methodology was achieved and initially approved by most faculty members. The objective behind this methodology is not to eliminate other methodologies taught to students, but to create EAFIT's own

contribution to this field of knowledge, as well as to have it available to be used by EAFIT employees and students on projects the University is involved in with outside companies.

In the particular case of Project-8 it was also identified as necessary to re-structure the Project's guide towards the PLM implementation and create a Design Process to be proposed (not mandatory) to students for the development of this course on the second semester of 2010. EAFIT's General Design Methodology would set the basis for creating it, but first it was necessary to evaluate the particular case of this course and the design process as it was formulated up to the second semester of 2009. This process will further on be referred to as the AS-IS model and the design process generated will be referred to as the TO-BE model.

6.3.1. Project-8 AS-IS Design Process Model

As mentioned earlier all the design process in Project-8 is documented in a guide booklet created by professors and faculty members and handed out to students on the first week of classes. Project-8 is evaluated in 4 sets of deliverables, distributed throughout the semester. These sets of deliverables roughly represent the basic phases of a design project. The following is a table that shows the deliverables and the respective phases of the product design they evaluate, along with the week they are to be handed in:

Delivery-Phase	**Week**
Delivery No.1- Design Requirements and Conceptualization Phases 1. Design Brief 2. Product Design Specifications (PDS) 3. Design Concept	4
Delivery No.2- Detailed Design Phase 1. 3D CAD Model 2. Product Manufacturing Drawings 3. Engineering Report	11

4. Product / prototype Cost Chart	
Delivery No.3- Construction Phase 1. Functional model of the product suitable for testing	15
Delivery No.4- Product Launch Phase 1. Prototype- Functional Model 2. Exhibition Stand 3. Test results	18

Table 1: Deliveries, Project Phases, Deliverables and Due dates
Source: Own Elaboration

Descriptions of each of these deliverables, along with the content that they must include and that will be evaluated by professors in an evaluation format, are included in the Project-8 guide. Nevertheless, this model is very basic and superficial. It lacks an understanding of relationships between tasks, information used and generated, tools used and the human resources involved. Understanding these relationships is crucial for any PLM implementation and it sets the basis for effective and organized collaboration. Therefore, analyzing and documenting these relationships would be the first task towards configuring the TO-BE model.

7. CONFIGURATION

The project's configuration consists of all required work to set up the PLM strategy implementation. As PLM derived from Business Process Management (BPM) and Product Data Management (PDM), the analysis done up to this stage set the basis to create the business process model for Project-8, which is necessary for BPM. This process model is explained in this chapter in section 7.1. Additionally, PLM software is required to do both the functions of controlling this process and managing the product data and other information generated. The selection, installation and configuration of this software are also explained in sections 7.2 and 7.3.

7.1. Project-8 Business Process Modeling

Any business process can be described by modeling the relationships between the tasks, deliverables, information, tools and human resources involved in this process. Business Process Modeling is an activity usually performed by Business Analysts of an enterprise to identify opportunities to improve process efficiency. Laying out the relationships involved in a process helps to generate a better understanding of the process itself and eliminate unnecessary delays as well as redundancies and other aspects of inefficient work. One of the most common methods of BPM is generating a flowchart called an Event-driven Process Chain (EPC). This EPC represents the interactions between tasks, deliverables, information, tools and human resources.

Figure 12 depicts ARIS Notation for an EPC on "ARIS Express", a BPM tool created by IDS Scheer[3], a leading company in Business Process Management. The modeling language of an EPC is somewhat of a standard for BPM in the industry. It requires an understanding of every activity as part of a workflow, meaning that each activity has predecessors and successors; certain events are required to happen before the activity starts and other events are produced after the activity is finished. Just as well, activities require input information and produce output information. These activities are assigned to a person with a certain role of work (marketing, engineering, etc) and they might

[3] http://www.ids-scheer.com

require special tools or procedures to be performed. All of this must be recorded to assign time and resources efficiently.

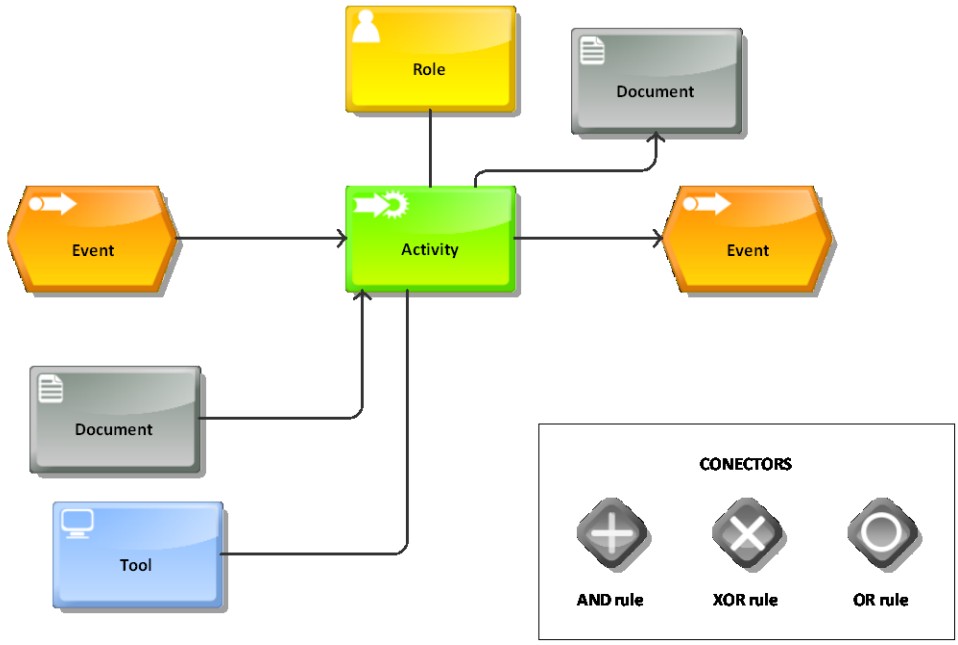


Figure 12: ARIS Notation for an Event-driven Process Chain (EPC)
Source: Own Elaboration

7.1.1. Project-8 TO-BE Design Process Planning

There are many different levels of detail in a project's plan. A project might for example be divided in phases. Within these phases there might be a number of activities, and within these activities there might be specific tasks to be done. How in depth the project is defined depends on the project manager. The more detailed the project plan is, the more control he has over it, but also the more restrictive it might become for the project executers. In the case of Project-8, these decisions were to be taken by the course's professors according to the educational purpose the course has. The professors clearly wanted to gain more control and supervision of the project's process and development but still leave enough freedom for students to program their project themselves and learn to plan ahead. Handing them a very detailed project plan at the beginning of the course could create the undesired effect of making them lazy planners with everything already mapped out for them. On the other hand, handing them a very vague project plan like the

AS-IS model had already proven to be unsuccessful. Schematic representations of the two options are shown in Figure 13.

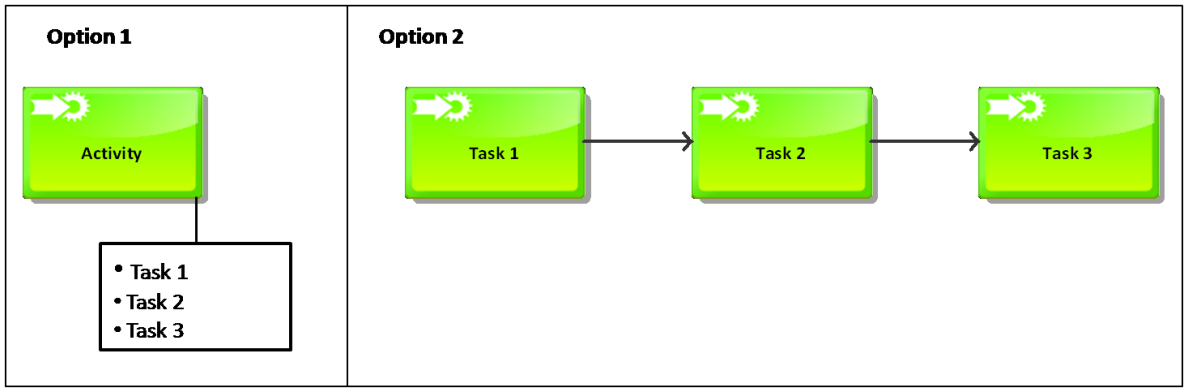


Figure 13: Schematic representation of two different options in Business Process Modeling
Source: Own Elaboration

The main difference between the two options is that the tasks that appear listed in the first option become activities in the second option, and therefore each of them can be assigned roles, tools, deliverables, tasks and due dates separately. Examples of a very lax plan (Figure 13, Option 1) and a more detailed one (Figure 13, Option 2) of a 3D modeling procedure are shown in Figures 14 and 15 respectively.

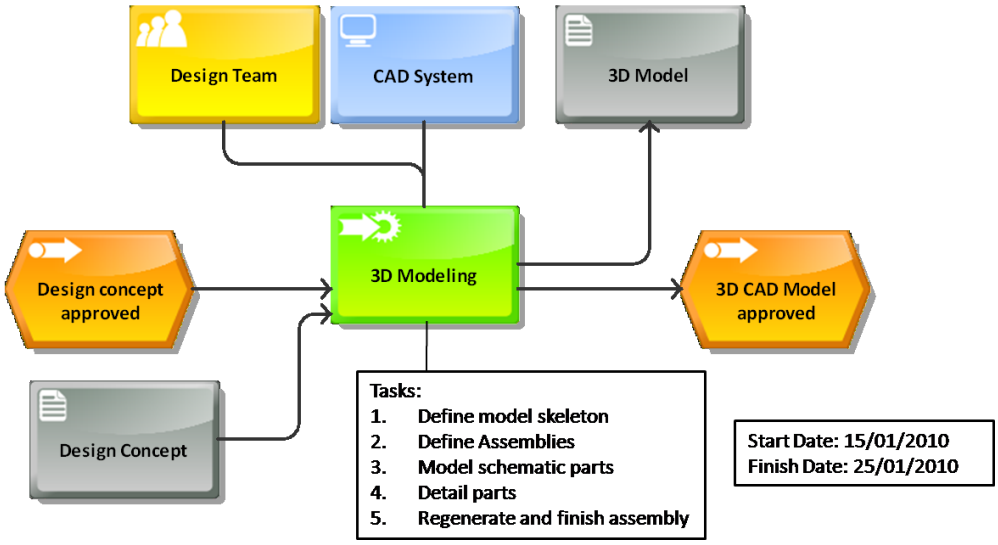


Figure 14: Example of a poorly detailed plan for 3D Modeling
Source: Own Elaboration

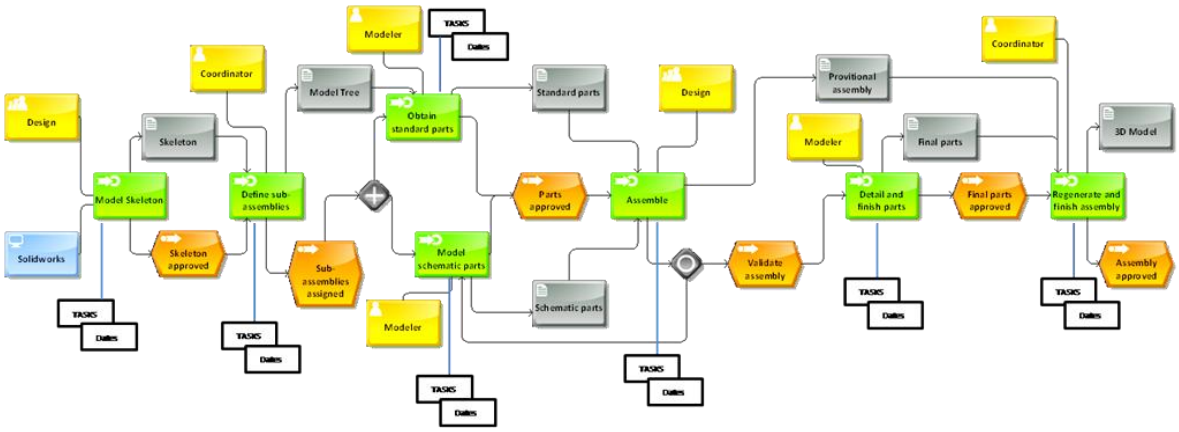


Figure 15: Example of a detailed plan for 3D Modeling
Source: Own Elaboration

The AS-IS model of Project-8 basically considers the four phases as functions (green boxes) and then defines tasks within those functions. The next level in detailing would therefore be considering those tasks as functions and then proceed with defining new tasks for each one of them. Professors of Project-8 defined that the best route to take would be defining all the basic activities of Project-8 as functions and propose some tasks to perform in each of them. Only some of these functions and tasks would be mandatory and the others could be modified or changed by students. This decision somewhat represented a compromise that would generate more control over the planning and development of the project but at the same time leave some room for planning by the students.

7.1.2. Project-8 TO-BE Design Process Model

EAFIT's design methodology is based on some of the world's most known design methodologies [Tomiyama, 2009]. These include Pahl and Beitz's Systematic Design [Pahl and Beitz, 2007], Pugh's Total Design [Pugh, 1991], Ullman's Mechanical Design Process [Ullman, 2002], among others. Project-8's TO-BE model is based on EAFIT's Design Methodology so therefore it also considers these methodologies. The working methods and procedure that students are taught, have been developed over more than 10 years the program exists at EAFIT University. It's nevertheless still a flexible methodology and open to changes.

Project-8 is done in groups of 6 students. These groups are formed in most cases by the students themselves. In most cases they're unstructured teams of peers, even if roles such as team leader have been assigned. The main roles identified in the previous Project-8 semester and throughout the professor's and student's experience are: Marketing, Engineering, Design and Production. This means that each group member usually identifies himself with certain strengths in one of these fields and thus dedicates more effort to the activities related with it. This is usually beneficial for a project because it helps divide labor. Although all Project-8 students are studying the same career, they usually have different profiles and it's not efficient having all of them working on everything. The organizational structure devised for Project-8 may be represented as shown in Figure 16.

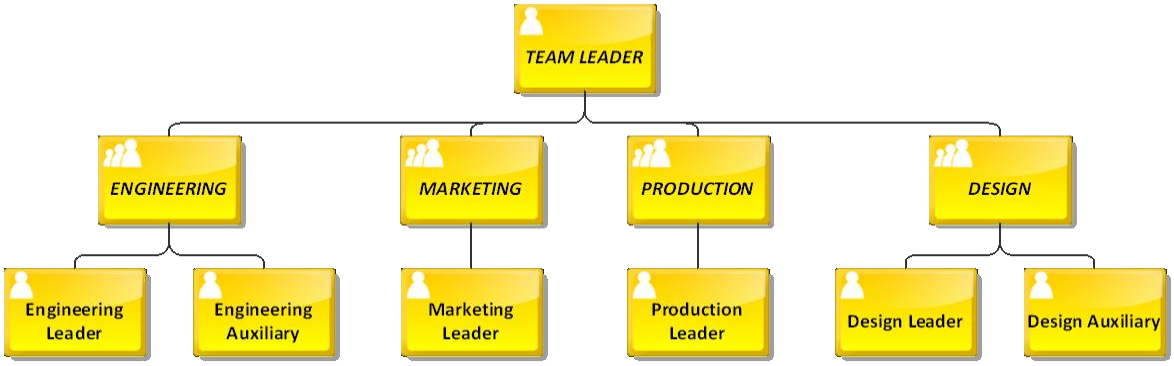


Figure 16: Organizational Structure devised for Project-8
Source: Own Elaboration

The following sub-sections will describe in detail Project 8's TO-BE Process Design Model.

7.1.2.1. Design Requirements Phase

The first phase of the project is defining the design requirements for the product. A project starts with a design opportunity already stated by professors[4] (Figure 17-I). Students are told the first week of classes which kind of product they are going to

[4] A preliminary set of activities, called "Needs Identification", that appears in EAFIT'S General Design Methodology, are not part of Project-8's scope. Those activities are the aim at "Project-7", and they may be analyzed with this approach in further developments of this project.

develop. In the case of the two pilot groups that worked with PLM the product they were told to develop is an electrical bicycle. This, however, frequently changes and the following semester student´s might be assigned to develop a different product. After this, students must do a market analysis (Figure 17-II) and a benchmarking (Figure 17-III) to find available products in the market, substitute products and have a basic idea of the competition. After this is done they must report results (Figure 17-IV) in a Design Brief that states the project's background, justification, objectives, target client, context, and chronogram. Additionally this document must contain a list of client requirements, which is the activity that follows (Figure 18-V).

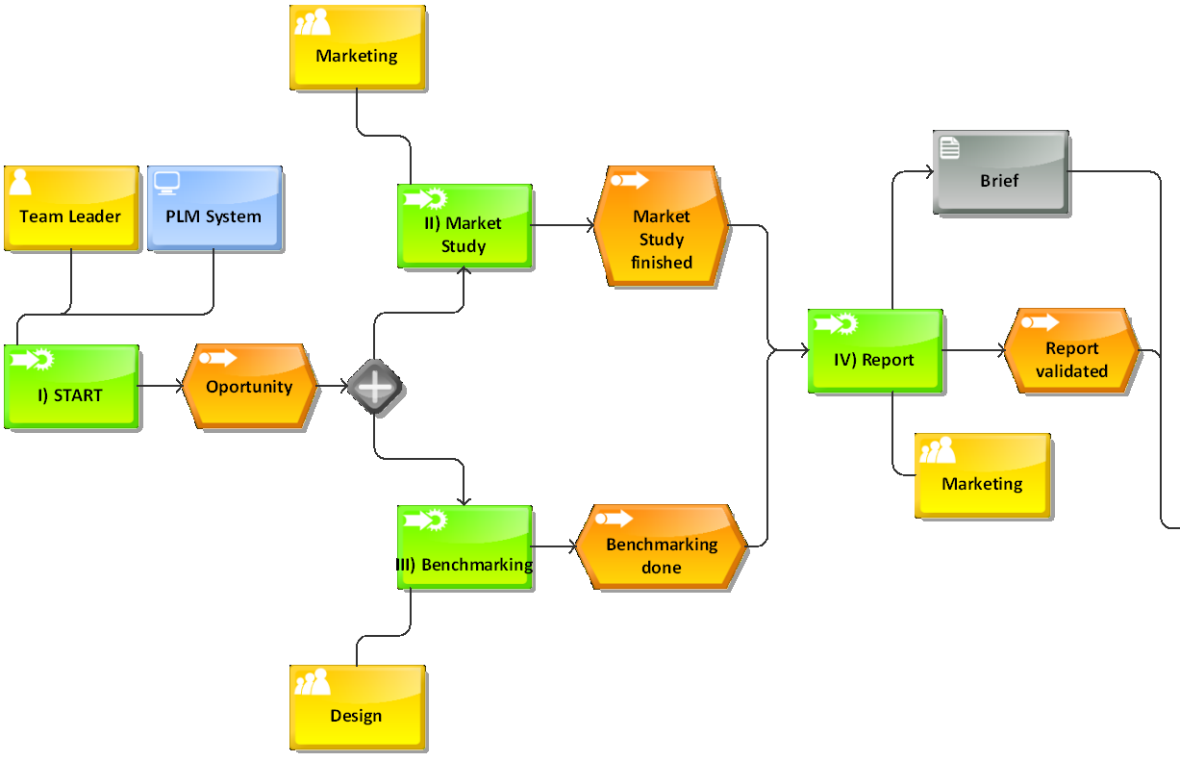


Figure 17: Design Requirements Phase, part 1.
Source: Own Elaboration

After this list is done it must be completed with more design requirements (Figure 18-VI) and these must be interpreted and quantified by the design group in a document called the Product Design Specifications (PDS). With this document completed, the group can proceed to do a design formal synthesis (Figure 18-VII) and functional synthesis (Figure 18-VIII). The formal synthesis gathers all the formal and visual elements that will eventually generate ideas for the design. These are based on creative tools such as mood-

boards, visual alphabets, etc. The functional synthesis gathers all the functional and technical elements that will be considered in the design alternatives. These are based on a number of tools such as a functional analysis, black box analysis, calculations, technical standards, etc.

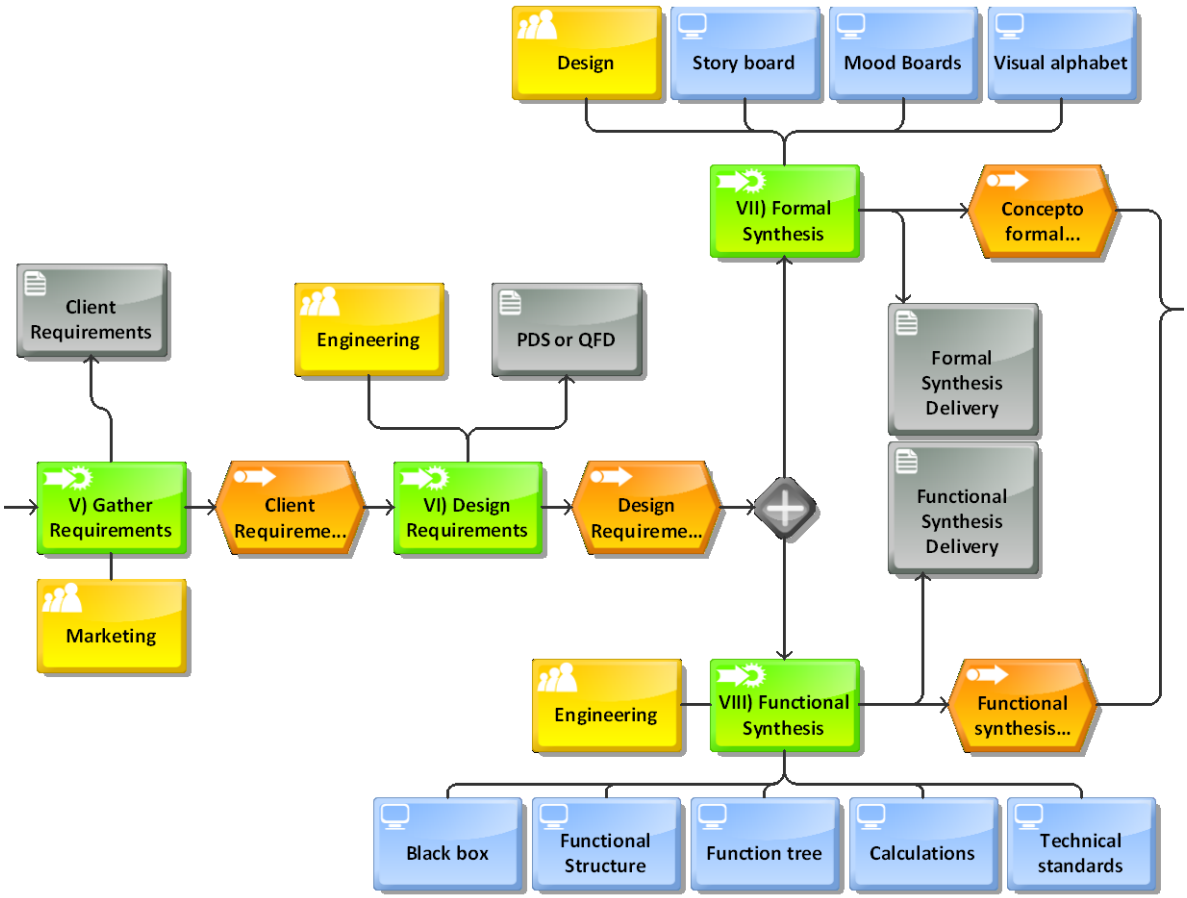


Figure 18: Design Requirements Phase, part 2
Source: Own Elaboration

After this phase is completed the design group must have all the necessary elements to start generating ideas. The project must be sufficiently clear to them and the design alternatives that will be generated will start off from a clear set of design requirements and specifications that will hopefully give them the right direction.

7.1.2.2. Conceptualization Phase

The phase that follows is called conceptualization because it's where the design concept will be generated. The first steps are an internal and external development, which are aimed at finding solutions to the proposed design problem. The internal development (Figure 19-IX) uses tools to generate ideas from the interior of the product, by developing its possible components and arranging them. The external development (Figure 19-X) is about generating ideas freely and further on evaluating them. After a good number of solutions are obtained by either or both methods they are further developed into design concepts (Figure 19-XI). At this point all group members must contribute with at least one design concept. The next step is to select some of those concepts to be analyzed (Figure 19-XII). Tools such as the Pugh's matrix and an evaluation with the PDS can be used to achieve this activity.

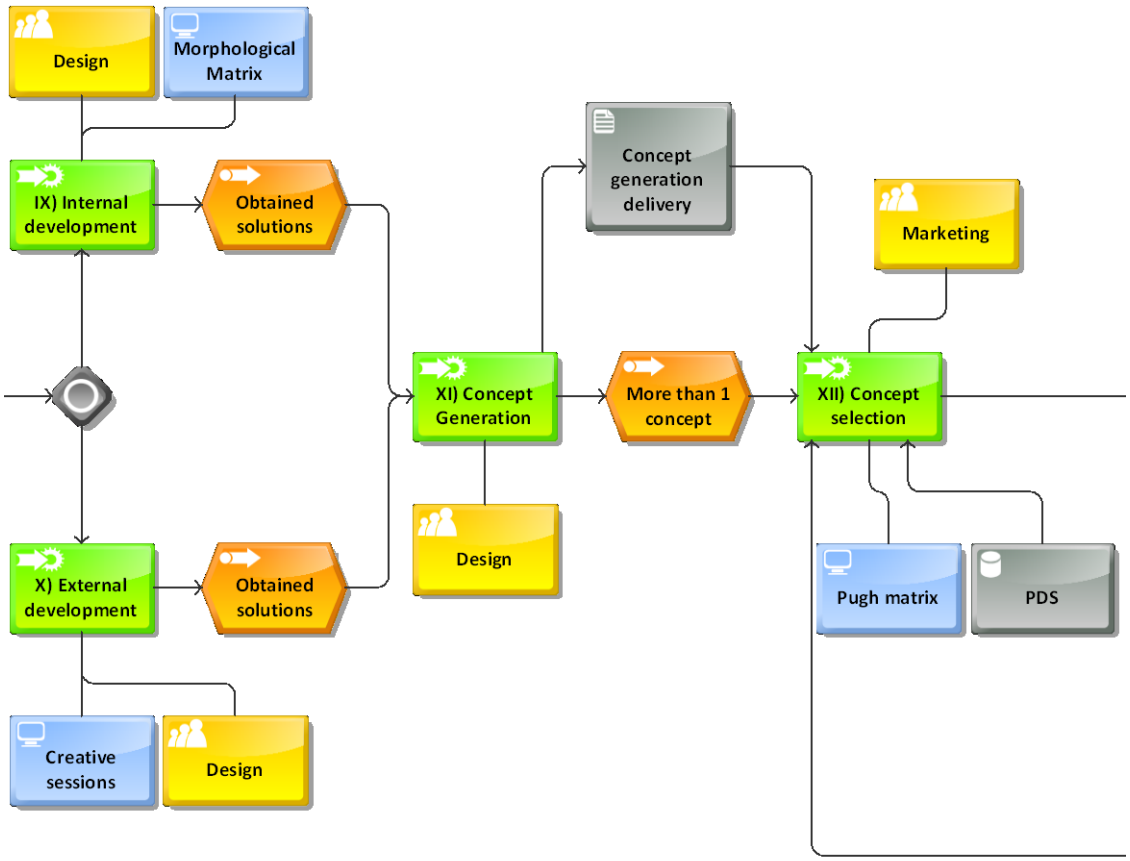


Figure 19: Conceptualization Phase, Part 1
Source: Own Elaboration

The activity that follows, after having selected some of the concepts, is evaluating them (Figure 20-XIII). This activity is aimed at identifying the strengths and weaknesses of these concepts as well as the possibility to merge them into a definitive concept or select the best one. The end result must be a design concept that is approved by all team members and has been selected to be further developed.

The dimensions, proportions and 3D aspect of the chosen concept can be tested by creating a mock-up or model of it (Figure 20-XIV). After this activity is done the group must decide if the concept is approved and continues or if it requires changes. If it does require changes, the group must perform corresponding modifications and return to the concept selection or evaluation, depending on the changes that were performed (Figure 20-XV). If the concept is approved though, the group can move on to the detailed design phase.

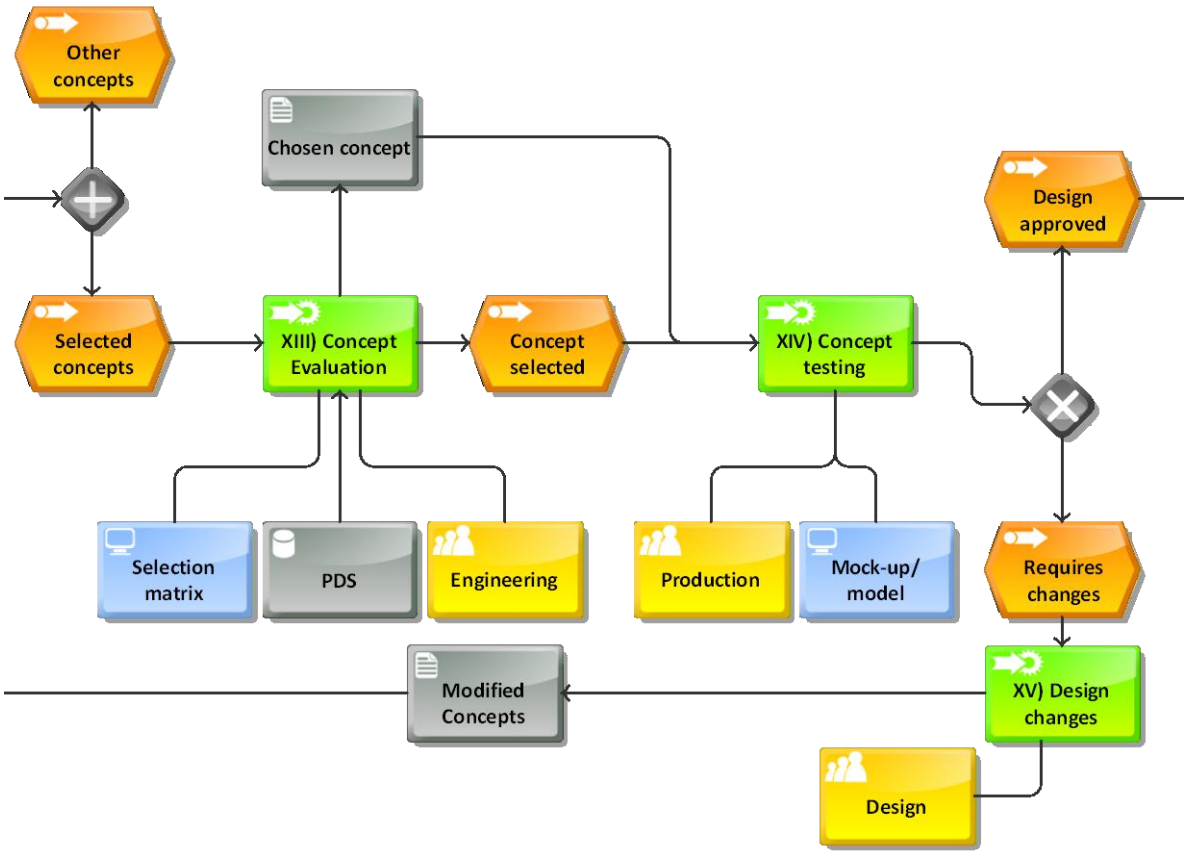


Figure 20: Conceptualization Phase, Part 2
Source: Own Elaboration

At this point professors grade the first package of deliverables, and each design group must present their results to their classmates. The evaluation formats and the description of the contents of these deliverables does not change with respect to the AS-IS model, nor does the date, which continues to be the fourth week of classes.

7.1.2.3. Detailed Design Phase

The third phase deals with a further development of the design concept; in which design details are defined. It's a phase where product engineering is much more involved and technical aspects of the product are defined. The phase consists of four simultaneous activities which are 3D Modeling, Process Design, Engineering Calculations and Validation. The reason for them being simultaneous is that the results of each of them continually act as input for the others.

3D Modeling (Figure 21-XVI) consists of generating a 3D computer model of all parts and sub-assemblies of the product, using Computer Aided Design (CAD) software, such as ProEngineer, Solidworks, etc. This model must be done on the basis of a construction tree (Model tree) and reflecting the appropriate hierarchy of components with sub-assemblies (for the Bill of Materials). Interference between the different components of the product must be avoided and for this it's advisable to model under the Top-Down Strategy Design and parameterization. The model must accurately represent the design intent for which it's indispensable to do a rendering of the model. Additional to the 3D model the deliverables of this phase must be the technical drawings of each part and assembly. The process design activity (Figure 21-XVII) consists of all the specifications of how the product will be manufactured and assembled, including tools selection, selected part suppliers and manufacturers, etc. The engineering calculations activity (Figure 21-XVIII) consists of doing all necessary theoretical and/or experimental calculations to properly choose or dimension components. This might include, for example, the force required in a spring or the power in an engine. Finally, the activity of validation (Figure 21-XIX) requires testing the 3D CAD model under normal circumstances of use. This is done by tools such as a Finite Element Analysis for mechanical stresses or

deformations and a Mechanical Simulation of the parts in movement and their relationships. Validation results may serve to optimize the design in terms of material use and mechanical properties.

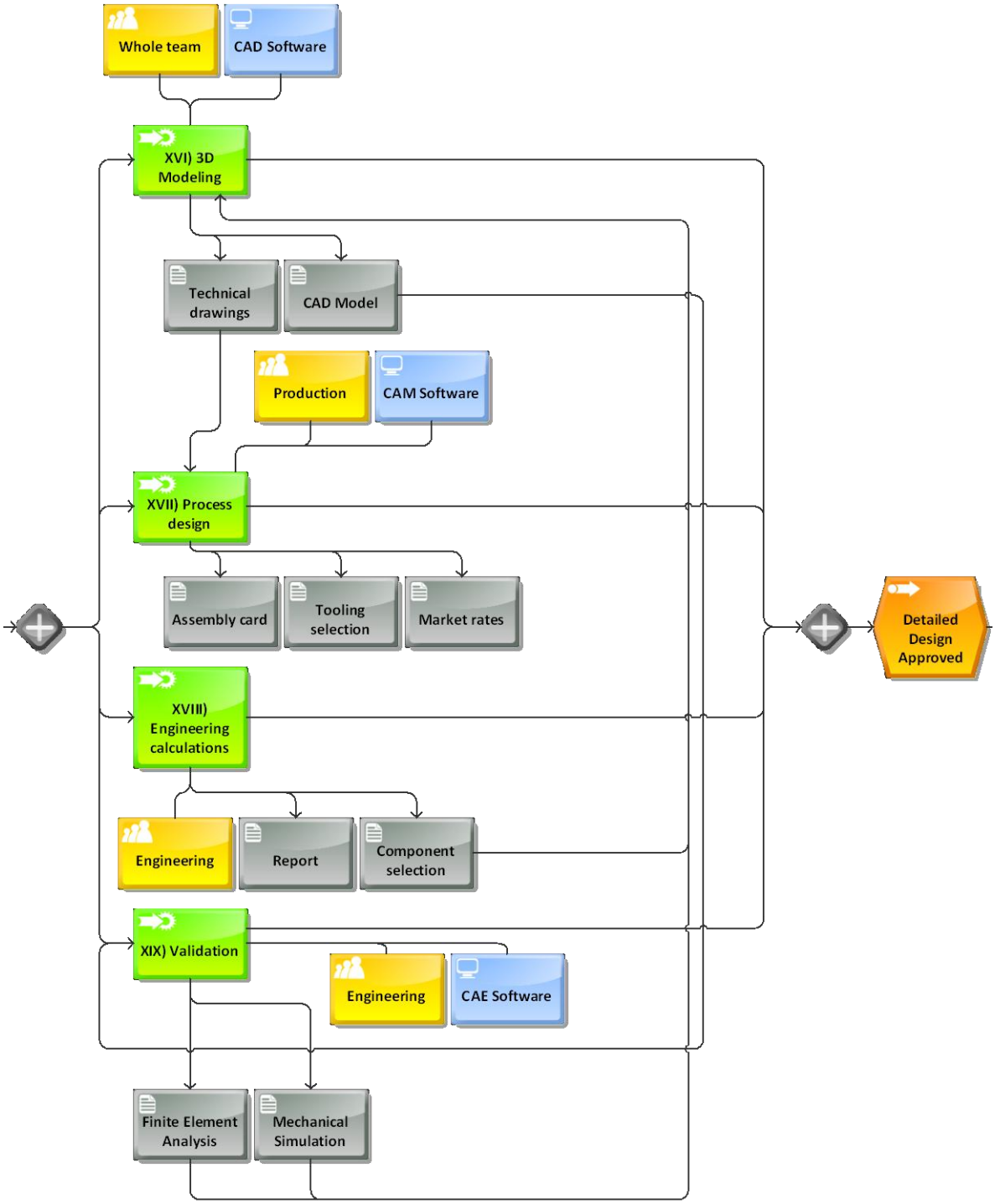


Figure 21: Detailed Design Phase
Source: Own Elaboration

Once these four steps are completed the design must be fully defined and ready for manufacturing an initial prototype or functional model. This is done in the fourth and last phase. At this point professors do their second evaluation of deliverables and groups present their results to their classmates. Again, this evaluation does not change with respect to the AS-IS model.

7.1.2.4. Product Launch Phase

The final phase of the TO-BE Project-8 Design Model is the "Product Launch". This phase consists of constructing a functional real size model of the product, perform technical and user tests on it and launch it on a public event.

The functional model (Figure 22-XX) must be constructed by all team members using the most actual materials and production processes as possible. This construction and the results must be registered with pictures and videos and a written report. These results are reviewed in the professor's third evaluation.

Next, they must perform tests to validate the design with users and under circumstances defined by technical standards and the PDS (Figure 22-XXI). Finally, the model is given the final finishes and it's presented in a public event in the University with a stand and using graphic elements to explain the design (Figure 22-XXII). Professors do their fourth and final evaluation of the group's results and the project officially ends (Figure 22-XXIII).

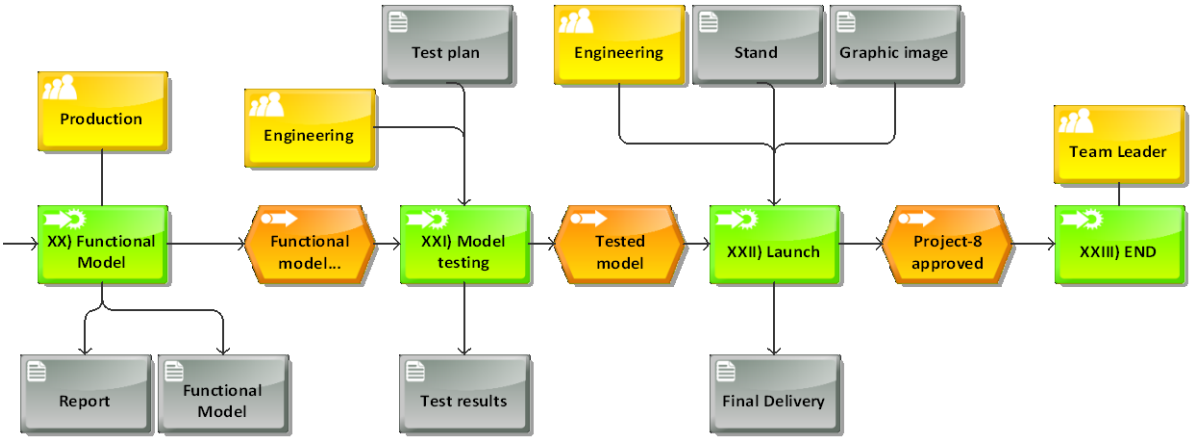


Figure 22: Product Launch Phase
Source: Own Elaboration

7.2. PLM Software

Product Lifecycle Management is much more than software; it's a concept, a strategy, a system, a philosophy. Despite this broad understanding of PLM, its successful implementation is certainly subject to proper configuration and implementation with PLM software. The software is the tool through which the whole concept takes shape and actually comes in action.

7.2.1. Software selection

There are many companies that supply software to support the PLM process. The largest commercial suppliers are Dassault Systèmes[5], Siemens[6], PTC[7], Agile Software Corporation (now part of Oracle Corporation)[8], and SofTech, Inc[9]. These companies provide the most complete software packages, usually at expensive prices. There is one company that offers open source (free download) PLM software solutions, called Aras Corp[10]. The PLM software that this company offers, called Innovator, has most of the features of commercial PLM software, and it's based on Microsoft technologies. The business model of Aras Corp does not consist on selling licenses for their software; their revenue derives from consulting, support, and training contracts [Stackpole, 2007]. This information is resumed in Figure 23.

The fact that Aras Innovator was open source, presented a huge advantage to choose it as the software to be implemented on Project-8 in EAFIT, because free software solutions, like Innovator, have possibly a greater expansion potential in the Colombian market, at least in the near future. Nevertheless, it wasn't the only thing considered. The main criteria taken into account, in order of importance, where the following:

a. Cost
b. Ease of use

[5] http://www.3ds.com/
[6] http://www.siemens.com/
[7] http://www.ptc.com/
[8] http://www.oracle.com/agile/
[9] http://www.softech.com/
[10] http://www.aras.com/

c. Speed of deployment: Time required to implement the system and use it
d. Fit user requirements: Responds to the basic needs of the users
e. Customization/ flexibility: Can adapt easily to this specific user and scenario
f. Overall functionality breadth: Enough features to apply the system to the full scope of the enterprise
g. Support for distributed teams: Capability to work correctly through internet with several users at the same time and quickly.
h. Open integration capabilities: Capability to integrate to various platforms/ software/ CAD systems
i. Workflow capabilities: The capability to manage specific processes with workflows correctly.

While Aras Innovator was extremely superior on the cost criteria and ranked well on others like ease of use, customization/flexibility, user requirements and support for distributed teams (it's a web based application); its weakness lied on the fact that there was no support for its deployment in Colombia and had no free integration or automation with the main CAD software used in EAFIT, ProEngineer and SolidWorks. Dassault Systèmes, PTC and Siemens have integrated connectors to CAD software that facilitate and make much faster the management of CAD files with PLM software. These connectors add buttons on the CAD software interface to automatically upload/download CAD files to/from the PLM platform and to edit them easily and quickly. Aras Innovator also has some of these connectors available, but at an extra cost. Nevertheless, the troubles that presented the disadvantages of Aras Innovator were far less than the trouble of finding funds to buy a commercial license for not-so-superior software such as PTC's Windchill or Siemens's Teamcenter.

Provider	Business Type	Products
aras corp	▪ Small-Medium	▪ Aras Innovator
DASSAULT SYSTEMES	▪ Small-Medium ▪ Medium-Large	▪ Enovia SmarTeam ▪ Enovia MatrixOne
PTC	▪ Small-Medium ▪ Medium-Large	▪ Windchill On-Demand ▪ Windchill
Siemens PLM Software SIEMENS	▪ Small-Medium ▪ Medium-Large	▪ Teamcenter Express ▪ Teamcenter

Figure 23: 4 major PLM providers, the business type they focus on and their respective products
Source: Special Projects PLM Course, EAFIT

7.2.2. Software installation and hardware preparation

Aras Innovator was downloaded and installed on one of the University's servers by EAFIT's IT specialists. A database was created for Project-8 for the first semester of 2010. It was decided that there would be a database for each period because in the future 100 or more students could enroll each semester and be added as users. The database was named EAFIT_IDP_P8_2010-1 which consists of the University's name, the Spanish acronym for Product Design Engineering, the acronym for the course Project-8 and the current period (View Figure 24). This name left a space for opening databases for projects for other companies, university departments, courses, periods, etc, which where all alternatives being considered for the near future.

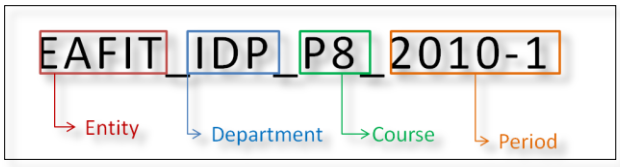


Figure 24: Project-8 Database name
Source: Own Elaboration

The Aras Innovator installation on the server gave the option to be accessed from outside and inside the University campus through internet using a web address and each user's username and password. This installation required a long and very bureaucratic

process of asking for permissions on high levels in the University and setting time for IT Specialists to do the work. These kinds of procedures are often treated with care in EAFIT because opening ports to be accessed through internet poses the threat of breaching security and hacking the University's servers. Additionally IT Specialists in EAFIT have very busy schedules and thus require that their time is scheduled with enough anticipation. These problems are all normal and common on most PLM implementations.

Aras Innovator works as Client-Server. Each remote user doesn't require downloading and installing the system on its computer but it does require configuring certain security settings before accessing Innovator through internet. This procedure was done on four computer classrooms to enable students to use the software on these computers (more than 100 in total). It was also planned to be used by students on their personal computers as well, as long as these had the following requirements:

- Microsoft Windows XP, Vista or 7.
- .Net Framework 2.0 or higher
- Internet Explorer 6.1 or higher: Innovator can only be accessed with this browser, but a plug-in can be downloaded and installed for the browser "Mozilla Firefox" to run Innovator with the Internet Explorer browser engine. Additionally, using this new browser makes Innovator faster and more stable.

7.2.3. Software configuration

Aras Innovator is a software solution that permits a great deal of customization and adaptation to different conditions. At the moment of creating a database there are two different options to choose from. There is the option of creating a database that is completely clean, where almost everything that the user requires has to be created by the system administrator. This option requires a great deal of expertise, because programming is involved and there are a great number of things to be done before the system can be really operative. There's also the option of creating a database with a lot of functionalities already included, that are in a way standard, like some user identities,

permissions, item types, etc. This was the most suitable option for this project because of the little knowledge of the software with which the project started and the speed of deployment needed. In many ways, customization is easier by editing and modifying things that already exist than by creating them from scratch.

In addition to the elements that the database brings by default, a great number of add-ons can be downloaded from the Aras website[11]. The add-ons that were downloaded for this database were:

- Aras Send To
- Document has File
- Meeting Manager
- Multi-Level BOM Tools
- Project Template Management Package
- Sample code to refresh form field on load
- Thumbnail image on Part or Document

Descriptions of what these add-ons do are also available in the website. These add-ons can also be edited and customized.

7.2.3.1. Logging In

Innovator has a standard user from which the system is configured and managed; the system administrator. This user, just as all other users created, has its own username and password to access the system. The current web address available at EAFIT's server for web access is:

http://200.12.180.20/innovatorserver

A login window is displayed (view Figure 25) and the user must type his own username and password and choose the database he will log on to. After the user logs in, the workspace of Innovator is accessed. For the system administrator user, called "Innovator admin", this workspace is shown in Figure 26. The appearance is similar to

[11] http://www.aras.com/communityProjects/

other Microsoft Windows applications because Aras Innovator is a Windows-based program. This creates an environment that is easy to assimilate for most students, since they all use or have used some version of Microsoft Windows as their operative system. The left menu is called the Table of Contents (TOC) and it holds different "categories" displayed in a tree-view. This TOC varies depending on the user. For the Innovator admin, the main difference is that he can access the "Administration" category, which contains all of the tools to edit and customize Innovator[12]. The window will open by default on the item called "My InBasket" although this can also be edited for each user. "My InBasket" shows all of the activities assigned to the user and that are pending or active.

Figure 25: Aras Innovator login window
Source: Own Elaboration

[12] These tools are necessary to perform the steps described in numerals 7.2.3.2 to 7.2.3.7.

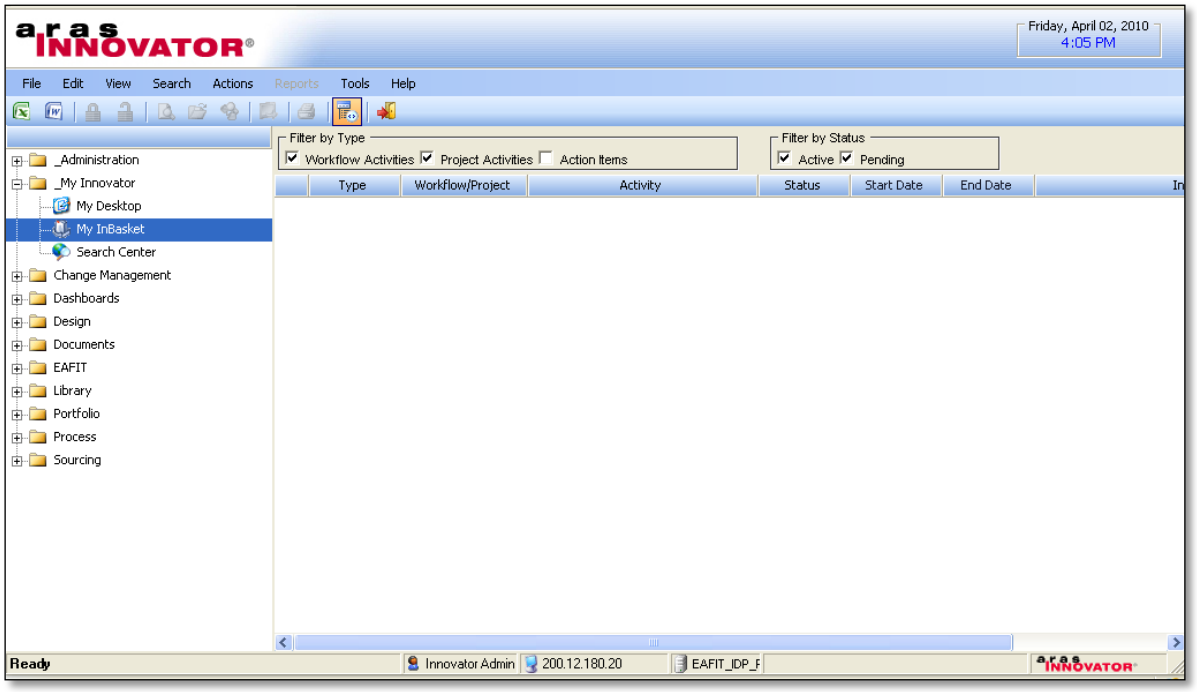


Figure 26: Aras Innovator workspace for "Innovator admin" Identity.
Source: Own Elaboration

7.2.3.2. Users and Identities

The first step to configure an Innovator database is to create its users. In this case, the users are 3 professors of Project-8, 12 students, EAFIT's dean of Engineering and the client for this particular project; an employee of a motorcycle assembly facility in Medellin. Each user must be given a username and password, as well as an email address, company name, phone number, working directory and starting page (view Figure 27). Each user may change later his password and working directory. Apart from users, Innovator has "Identities". Each user's name becomes an identity itself but can also belong to other identity. For example, a worker in a company may be listed as an identity "John Johnson" (the user) or under the identity "marketing assistant" and this identity can be part of a group identity called "marketing department". This is useful because activities can be assigned to an identity that changes users over time. The group identities created for Project-8 are "Project-8 Professors 2010-1", "P8 20101 Group 3", "P8 20101 Group 5", and "Team Leaders P8" (view Figure 28). Group 3 and Group 5 are the pilot groups chosen for the PLM implementation. Students were distributed accordingly in their respective group

identities, as where the professors in their group identity. “Team Leaders” has the leaders of each of the two groups. This identity has special permissions which will be detailed later.

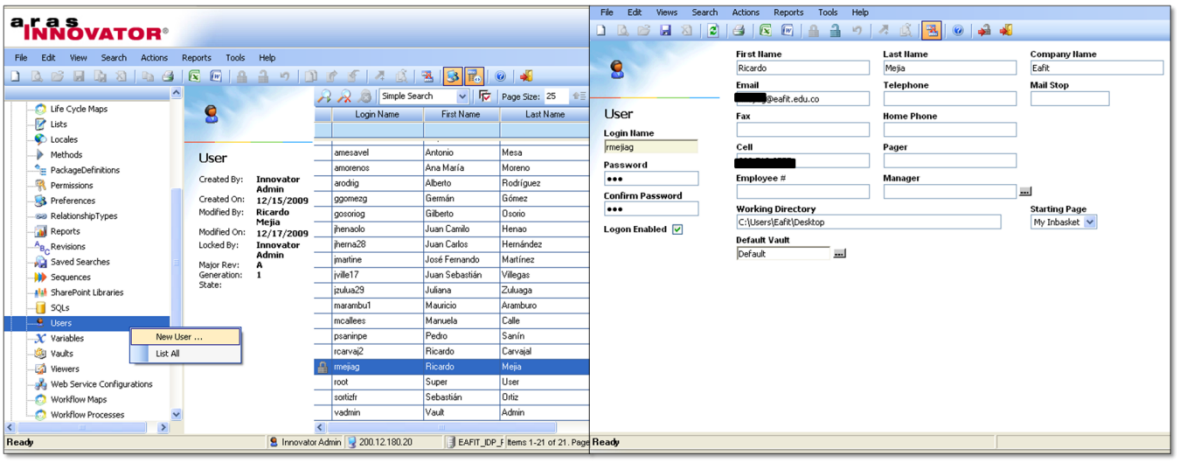


Figure 27: Creation of Users in ARAS Innovator
Source: Own Elaboration

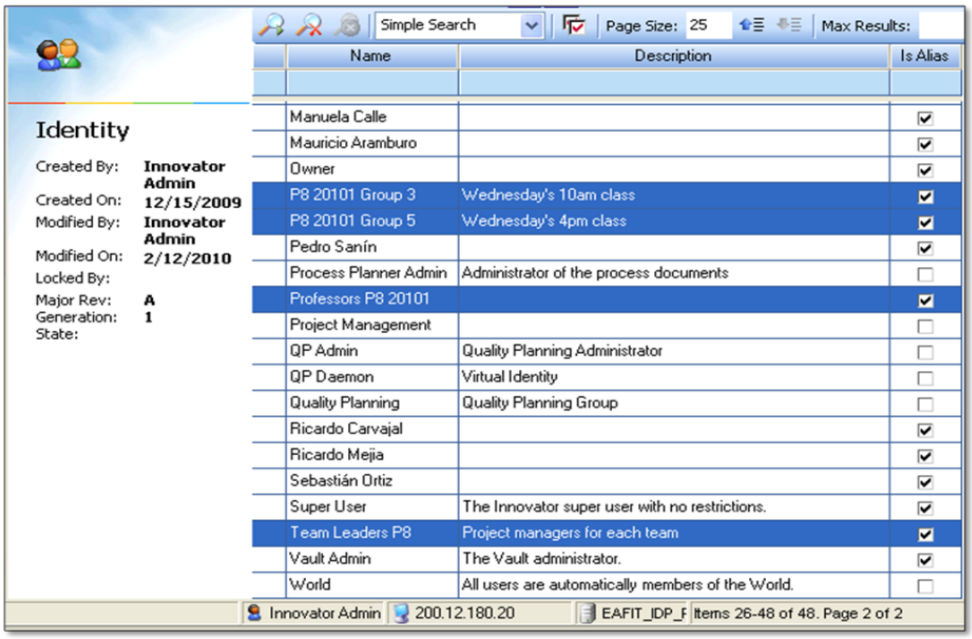


Figure 28: Group Identities in Project-8 ARAS Innovator database
Source: Own Elaboration

7.2.3.3. Item Types

An ItemType is a business object that is managed by Innovator. It is the template, or the definition for the items that are created from it. Almost everything in Innovator is defined through an ItemType. ItemTypes define properties, forms or views available for this item, lifecycle, workflows associated with the item, permissions, relationships, server and client methods and events to run on the item, and much more. The main Items used by students are: “Document”, “Part” (CAD files), “Meeting” (a meeting log), “Project”, “Project Template”, and “Activity 2” (an activity assigned in a project).

7.2.3.4. Permissions

The first thing that is usually defined for ItemTypes is permissions. Through permissions, the Innovator admin can define which users or identities have the rights to get (download), update, delete, discover or charge access to certain information stored in Innovator. This is necessary because of security reasons. It’s important to understand that permissions are assigned to ItemTypes, and not to specific instances of that ItemType. For example the permission “New document” will apply to all documents created. The most important thing considered when creating permissions was to ensure that students of one group could not access information created by other groups. The permissions called “New Document”, “New Part”, and “Meeting” were assigned to identities that are variable (do not have fixed users). The identity “Creator” changes for every document created, depending on the user that creates it. The identity “Manager” also changes for each document, depending on the user that “Creator” assigns. This ensured that if a student was neither creator nor manager of a document he couldn’t access it in any way. The two mentioned identities, as well as Project-8 Professors and the Innovator admin where given all permissions (view Figure 29).

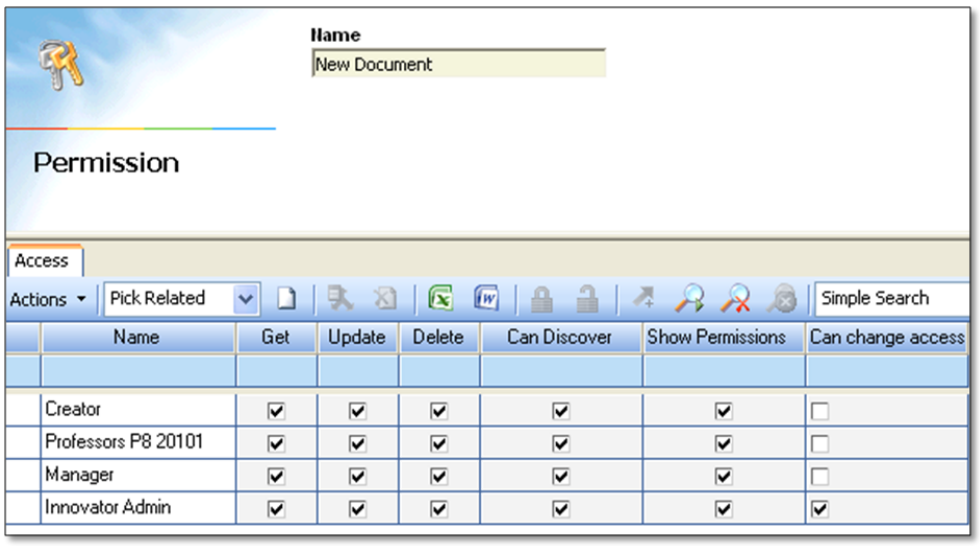


Figure 29: Permissions given to identities for Documents, Parts and Meetings
Source: Own Elaboration

7.2.3.5. Forms

The next thing to edit in the ItemType is the "form". A form is the template that must be filled out to create each new instance of a given ItemType. It's known as "meta-data" and it's composed of fields that request specific information. For example "name" is a text field that requests that a name is given to that particular item. Most forms have fields for name, number, description, thumbnail image, and some other fields that request more descriptive information of the item. They were mostly left as they came by default on Innovator. Nevertheless, an important change was done to the forms for the ItemTypes "Document", "Part" and "Meeting". A field called "Group" was created for the student to choose his group from a list of identities (view Figure 30). This automatically assigns the chosen group as the identity "Manager" for that item. According to the permissions already given to this identity in the mentioned ItemTypes, the members of the chosen group would all have permission to access the item created. This field replaced the fields "Designated User" and "Assigned Creator" that came by default.

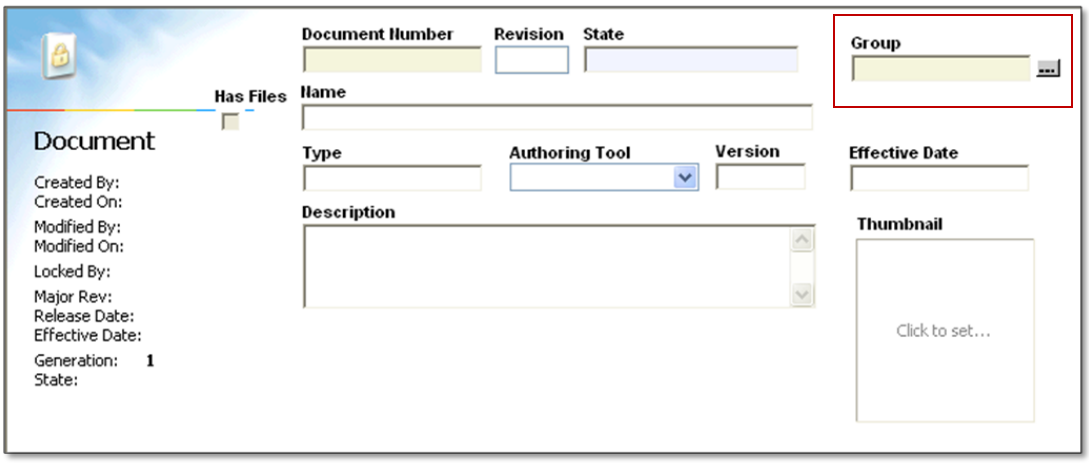


Figure 30: "Group" Field on Document Form
Source: Own Elaboration

7.2.3.6. Relationships

Each time a user creates a new item, like a document or a part, a window is opened. Apart from the item's form, this window has some tabs on the bottom. These tabs have what are called in Innovator "Relationships", which allow the binding of data between ItemTypes. Some ItemTypes are visible to users, such as "Document" or "Meeting", but others are somewhat hidden and are mostly used through relationships. For example, the ItemType "File" is usually accessed through its relationship with the ItemType "Document"; every time a user creates a new document the window that appears has a tab called "File", which is used to add the files corresponding to the document being created.

Most relationships where left as default, except for one in the ItemType "Meeting". This is an ItemType that was added to Innovator through one of the community projects (add-ons) to generate reports of each of the counseling sessions the groups have with professors throughout the semester. In those meeting reports there should be expressed the highlights of each session, participants, commitments and person responsible for them for the following week. There is a relationship for Meeting called "Action Item", which is used to report the activities assigned to participants during the session (view Figure 31). The field called "Assignee" in this relationship failed to generate correctly a list of users to assign each of these activities to. This problem was solved by

editing two of the properties of this field; the data type and data source from which information is taken to fill it. The data type appeared as “federated” and was changed to “Item” and the data source to “Identity” (view Figure 32). This made possible that users could press the key F2 in the field “Assignee” and a list of all the available identities would appear to choose the one desired.

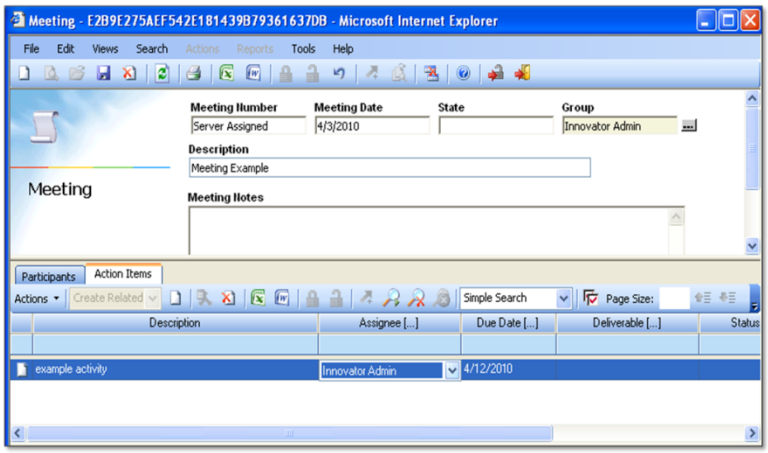


Figure 31: Action Item relationship tab in meetings
Source: Own Elaboration

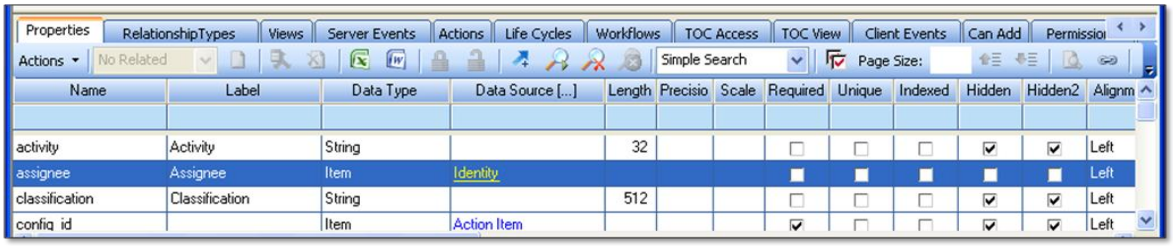


Figure 32: Property changes made to Action Item relationship
Source: Own Elaboration

7.2.3.7. Categories and TOC Access

Each Item Type can be assigned to a category into the TOC and the categories to be shown may be configured according to the Project’s needs. The aim for this project was that users had the simplest possible Innovator window, with only the ItemTypes that were strictly necessary on their Table of Contents. In order to facilitate software use, three of the default categories were left in the TOC: “My Innovator”, “Design” and “Documents”. A fourth category, called “EAFIT”, was created (view Figure 33).

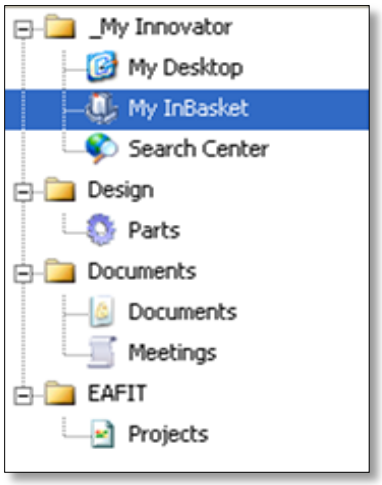


Figure 33: TOC for Project-8 ARAS Innovator Users
Source: Own Elaboration

7.3. Project Management Configuration

Innovator's main functionality is not the management of documents and files, which could be done with simpler applications; but the management and control of projects. Project-8's TO-BE Design Process Model was created to be configured into the system and controlled by the students, professors and the system administrator. Innovator has two different ways of controlling a process; "Workflows" and "Projects". Workflows diagrams have activities which have to be completed according to embedded procedural rules in order to complete the process. It's commonly used for short business processes that may be run many times, such as Engineering Change Notice approval process. Since this is not the case of Project-8, workflows were not used in this implementation. "Projects" work with Work Breakdown Structures (WBS), which allows users to break down the project into manageable pieces or phases, represented by the WBS, where each of them has a distinct deliverable, start and due date, assignee, and role. The order in which activities are completed is managed by defining predecessors and by the start and due dates given to each activity, much like in a project chronogram. This is a flexible way of controlling the process, since each activity can be marked as required or not, and activities can be completed outside of their start and due dates.

7.3.1. Project Templates

When project plans are usually repeated over time, like in the case of a project methodology that is repeatedly followed, Innovator has a tool called "Project Templates" to create a template that can be loaded every time a new project is created (view Figure 34). Templates help to standardize processes, as well as provide a reusable structure for similar projects. A project template was created for each phase of the TO-BE methodology. These templates will be loaded by students to create four "projects", each one for each phase of Project-8. They will be standard but groups can edit and customize them when they create their projects, except for some activities that will be marked as "required". They can also be exported/imported from one database to another, which means that these same templates can be used for future semesters also[13].

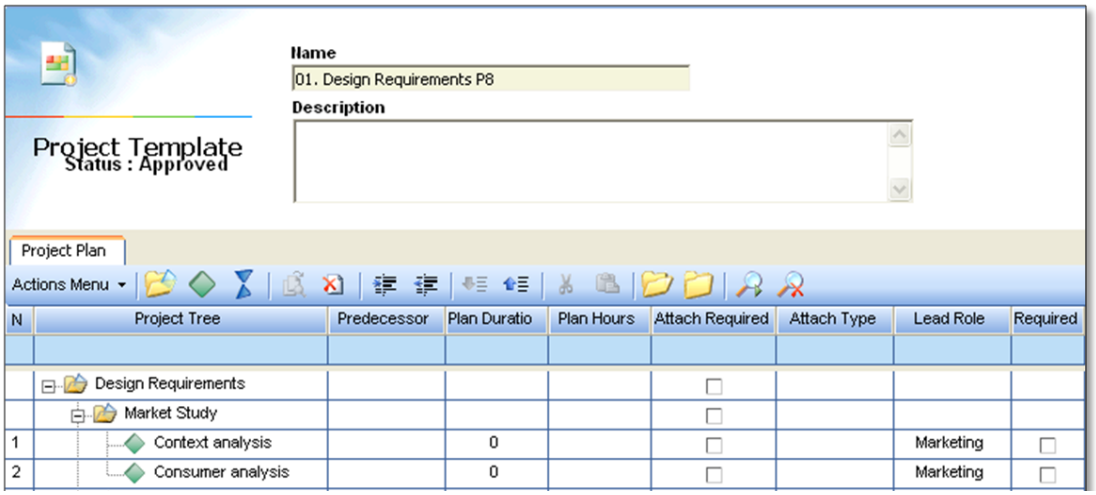


Figure 34: Project Template Form in Aras Innovator
Source: Own Elaboration

Project templates have no scheduling information. They can specify plan durations in days and hours for each activity, but scheduling start and due dates is left to be done by students at the moment of creating the project. The order of activities is defined through predecessors, which establish the activities that must be completed before starting new ones. This also helps students to schedule start and due dates. The benefit of dividing the course in four "Projects" is that students don't have to schedule their whole project at the

[13] This is only possible after installing the add-on "Project Template Management Package".

beginning of the course, but instead they schedule before they start each phase. Since conditions change as the project advances, it's very hard to foresee dates for the whole project at the start of the semester. Just as well, Project templates are only available to students when they are done a process in Innovator called "Promotion". A project template is in a pending state until it is promoted to an active state. Once this is done the template's status changes to "Approved" and the template can be used by students (View Figure 35). Only "Project Leaders" can promote them, according to the permissions given.

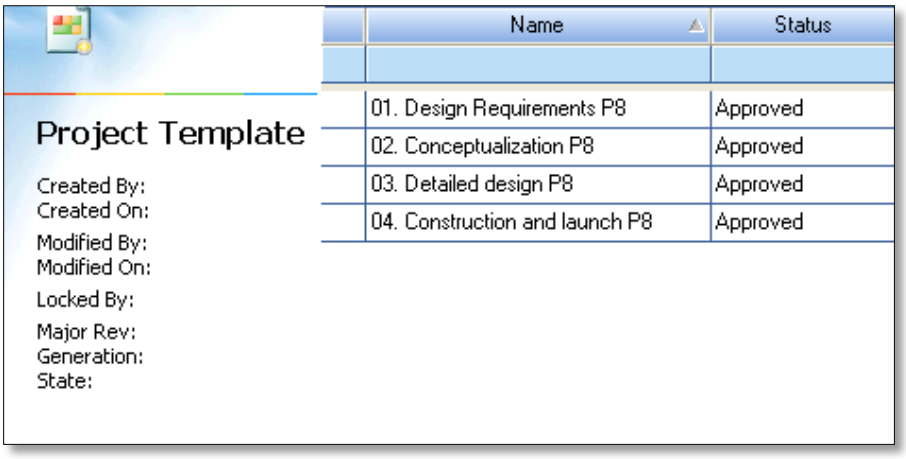


Figure 35: Approved Status of Project-8 templates
Source: Own Elaboration

Finally, templates suggest a role for each activity, but it's up to students to define which members will be assigned for each of these roles also. Four roles were created that coincide with the roles that appear in the TO-BE Model and the Organizational Structure:

- Marketing
- Design
- Engineering
- Production

With all these tools, all the elements represented in the TO-BE Model could be taken to Project Templates. The next four figures will detail the TO-BE templates defined:

Template 1: Design Requirements

	Design Requirements				☐			
	Market Study				☐			
1	Context analysis		0		☐		Marketing	☐
2	Consumer analysis		0		☐		Marketing	☐
	Benchmarking				☐			
3	Competition analysis		0		☐		Design	☐
4	Substitute products rese		0		☐		Design	☐
	Report				☐			
5	Brief	1,2,3,4	0		☐	Document	Marketing	☐
6	Brief Delivery	5	0		☑	Document	Marketing	☑
	Gather requirements				☐			
7	Interviews	5	0		☐		Marketing	☐
8	Focus groups	5	0		☐		Marketing	☐
9	Results report	7,8	0		☐	Document	Marketing	☐
10	Client Requirements deliv	9	0		☑	Document	Marketing	☑
	Design requirements				☐			
11	Requirements interpretat	10	0		☐		Engineering	☐
12	Prioritize and identify rec	11	0		☐		Engineering	☐
13	Relative importance	12	0		☐		Engineering	☐
14	Results	13	0		☐	Document	Engineering	☐
15	PDS delivery	14	0		☑	Document	Engineering	☑
	Formal synthesis				☐			
16	Mood boards	10	0		☐		Design	☐
17	Reference selection	16	0		☐		Design	☐
18	Visual alphabet	17	0		☐		Design	☐
19	Formal Synthesis Deliver	18	0		☑	Document	Design	☑
	Functional synthesis				☐			
20	Black box analysis	10	0		☐		Engineering	☐
21	Functional structure	20	0		☐		Engineering	☐
22	Function tree	20	0		☐		Engineering	☐
23	Concept arquitecture	21	0		☐		Engineering	☐
24	Technical standards res	20	0		☐		Engineering	☐
25	Physics calculations	20	0		☐		Engineering	☐
26	Functional Synthesis Del	25	0		☑	Document	Engineering	☑

Figure 36: Template 1 (Design Requirements)
Source: Own Elaboration

Template 2: Conceptualization

	Conceptualization				☐			
	Internal development				☐			
1	Morphological matrix		0		☐		Engineering	☐
2	Internal development rep	1	0		☐		Engineering	☐
	External development				☐			
3	Creative sessions		0		☐		Design	☐
4	External development re	3	0		☐		Design	☐
	Concept generation				☐			
5	Concept proposal develo	2,4	0		☐		Design	☐
6	Concept generation deliv	5	0		☑	Document	Design	☑
	Concepts selection				☐			
7	Pugh matrix	6	0		☐		Marketing	☐
8	Concepts delivery	7	0		☑	Document	Marketing	☑
	Concept evaluation				☐			
9	Selection matrix	8	0		☐		Engineering	☐
10	Delivery 1 Report and pr	9	0		☐		Engineering	☐
11	Selected concept deliver	10	0		☑	Document	Engineering	☑
12	DELIVERY No.1	11	0		☑	Document		☑
	Concept testing				☐			
13	Mock-up / soft model	11	0		☐		Production	☐
14	Results report	11	0		☐		Production	☐

Figure 37: Template 2 (Conceptualization)
Source: Own Elaboration

Template 3: Detailed Design

	Detailed design				☐			
	3D Modelation				☐			
1	CAD model		0		☐		Design	☑
2	Technical drawings	1	0		☐	Document	Design	☑
3	3D Modelation Delivery	2	0		☑	Document	Design	☑
	Production process design				☐			
4	Assembly card		0		☐	Document	Production	☐
5	Tooling selection		0		☐	Document	Production	☐
7	Manufacturing Montage	5	0		☐	Document	Production	☐
6	Market rates	4	0		☐	Document	Production	☐
8	Production Plan Delivery	6	0		☑	Document	Production	☑
	Engineering calculations				☐			
9	Component selection		0		☐		Engineering	☐
10	Eng. Calculations Deliver	9	0		☑	Document	Engineering	☑
	Validation				☐			
11	Finite Element Analysis	1	0		☐		Engineering	☐
12	Mechanical Simulation	1	0		☐		Engineering	☐
13	Validation Delivery	11,12	0		☑	Document	Engineering	☑
14	DELIVERY No.2	3,8,10,13	0		☑	Document	Engineering	☑

Figure 38: Template 3 (Detailed Design)
Source: Own Elaboration

Template 4: Construction and Launch

	Construction and launch				☐			
	Functional model				☐			
1	Purchase materials		0		☐		Production	☐
2	Manufacture parts	1	0		☐		Production	☐
3	Assemble parts	2	0		☐		Production	☐
4	Painting and finishes	2	0		☐		Production	☐
5	Construction report	1,2,3,4	0		☐		Production	☐
6	DELIVERY No.3 Functior	5	0		☑	Document	Production	☑
	Testing				☐			
7	User test plans		0		☐		Engineering	☐
8	Technical test plans		0		☐		Engineering	☐
9	User tests	7	0		☐		Engineering	☐
10	Technical tests	8	0		☐		Engineering	☐
11	Testing report	10,9	0		☐		Engineering	☐
12	Testing Delivery	11	0		☑	Document	Engineering	☑
	Launch				☐			
13	Presentation stand desig		0		☐		Design	☐
14	Graphic image design	13	0		☐		Design	☐
15	Posters and infographics	14,13	0		☐		Design	☐
16	Presentation stand cons	15	0		☐		Production	☐
17	Eafit presentation	13,14,15,16	0		☐		Design	☐
18	DELIVERY No.4 Launch	17	0		☑	Document	Design	☑

Figure 39: Template 4 (Construction and Launch)
Source: Own Elaboration

7.3.2. Projects

As stated previously, Project-8 was designed to be executed by four Innovator projects, which represent the four phases. One member of each group must be chosen as "team leader" and this member is responsible for creating these projects. He/she is the only one with permission to do so, apart from professors and Innovator admin. This is established in a tab of the ItemType's window called "can add". The Identities that were chosen in this tab were:

- Professors P8 20101
- Team Leaders P8
- Innovator admin

This process was done for the ItemTypes "Project", "WBS Element" and "Activity2". The team leader will also be the only one with permission to edit the project later. To do this, a permission called "Project" was created and assigned to the same

ItemTypes. “Team Leader” must be accompanied by his entire team and a planning session must be done in order to agree on due dates and assignees when he creates the project. This is a crucial activity since the work for the upcoming month is planned.

When a new project is created, the corresponding project template for the project must be chosen and then the start and due date for the project defined (view Figure 40). After this, a form is displayed with all the information that was loaded from the project template and some fields for new information to be filled (view Figure 41). There are four tabs on the bottom. Two of these tabs are for adding available documents and parts that may be pertinent for the project’s realization. Another tab, called “Team” is where the team members must appoint themselves to one of the 4 roles. Since teams are composed of 6 members and there are only 4 roles available, they may rotate throughout the semester and the two remaining members must serve as support for one of the existing roles. This was decided as a mean to give more flexibility and freedom to the assignment of tasks and to have students rotate the roles they have in their teams.

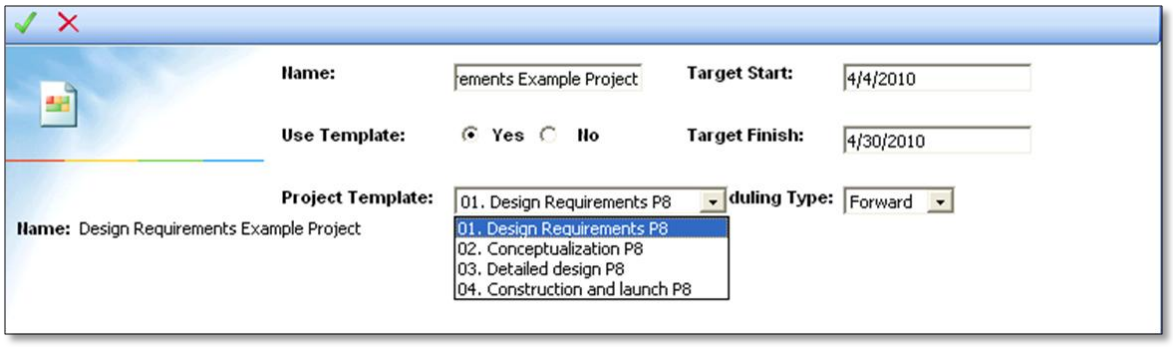


Figure 40: Selection of template and start and due dates for new projects
Source: Own Elaboration

After roles are assigned, the project plan must be filled out. At this point students can edit/erase/add activities and they must assign them to group members. All start and due dates for each activity must be defined. The result of this project plan may be visible through a Gantt Diagram. The tool for project plans in Innovator is very similar to “Microsoft Project”, to the point that one of the add-ons available at the Aras website is a tool to Import/Export project plans to and from Microsoft Project.

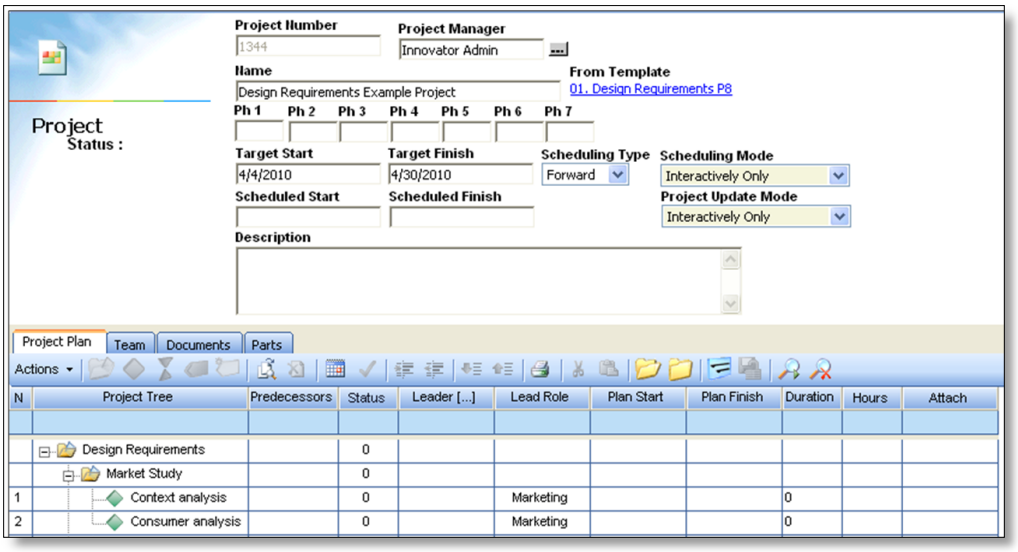


Figure 41: New Project Form
Source: Own Elaboration

7.4. Numbering and Nomenclature

Another important issue to properly implement PLM in Project-8 was the numbering and nomenclature of projects, documents, parts, and meetings. This is essential in order to keep order and standardization in the information displayed.

7.4.1. Projects

Projects must be named with the Project-8 phase it represents and the group number (view Figure 42). They're numbered and arranged automatically according to the order in which they're created.

Figure 42: Nomenclature of Projects
Source: Own Elaboration

7.4.2. Documents

The numbering and nomenclature for documents is described in Figure 43.

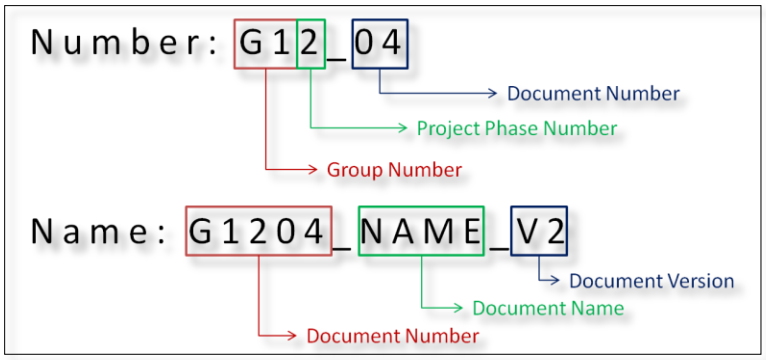


Figure 43: Numbering and nomenclature of documents
Source: Own Elaboration

7.4.3. Parts

The numbering and nomenclature of Parts is described in Figure 44.

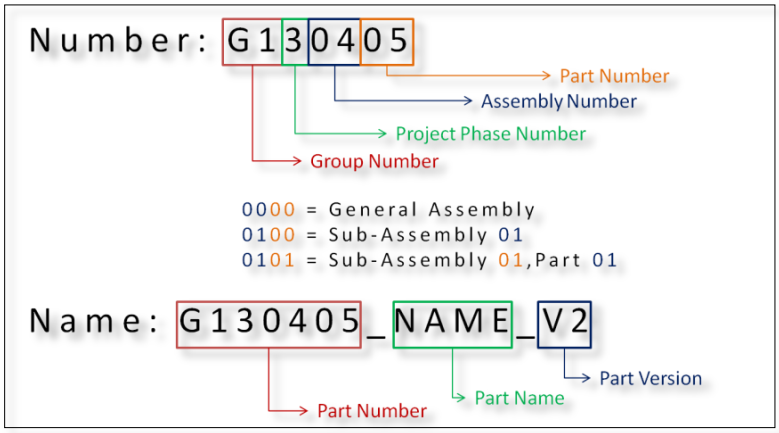


Figure 44: Numbering and nomenclature of parts
Source: Own Elaboration

7.4.4. Meetings

As those meetings to be controlled were performed in a weekly basis, meetings must be named with the prefix 'Meeting Log' and the week number (view Figure 45). They're numbered and arranged automatically according to the order they're created in.

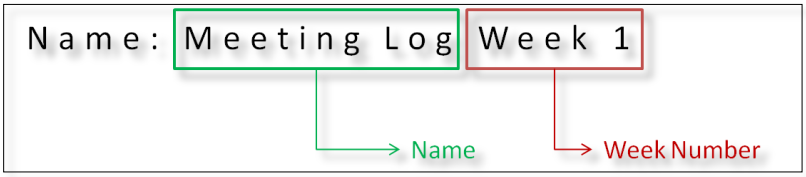


Figure 45: Nomenclature of parts
Source: Own Elaboration

8. EXECUTION

The following chapter explains all the activities of teaching PLM and ARAS Innovator to students, helping them to install and operate the system, as well as the details to execute the Design Requirements, Conceptualization and Detailed Design phases in Project-8. A monitoring of students was made throughout the development of these phases.

This chapter also describes the results obtained by both pilot groups in terms of project management, deliveries and meeting control. A feedback and evaluation given by the students themselves, showing their impression of this implementation's results, is also included. Finally, a comparison is made with the results observed in the group that was supervised during Project-8 2009-2.

8.1. Introduction of the PLM Strategy

The weeks previous to kickoff of Project-8 a lot of planning was done on how selected students, that would enter the course, would be introduced to PLM and prepared to assume this new methodology and novel way of working. This represented a huge challenge because these students had been working with the same methods for more than 3 years, some of them with the same team partners, and none of them had any idea of PLM. They had only been briefed in some previous courses on concurrent engineering or collaborative design but never formally educated on this matter. It was predictable that some concepts would result hard to comprehend for them, and adopting them, could be equally challenging.

The first week of classes, students formed in groups of six freely. Two of these groups were chosen by professors to be the pilot groups to work with PLM; groups 3 and 5. Only 4 of the students in these 2 groups were briefed on the project a couple of months earlier. These students had been working together on the course Project-7 and showed commitment and enthusiasm towards new projects and assignments. The remaining 8 students were chosen by their "Project-5" results. The introduction was planned on the basis of 3 tutorial sessions, 2 tutorial documents, 5 tutorial videos and a new Project-8 guide.

8.1.1. New Project-8 Guide

As stated previously in this report, every Project course has a guide booklet created by professors and faculty members with the basic guidelines of the course; expectations, grading methods, formats and a basic working plan with deliverables and their corresponding due dates. One of the objectives of this project was to modify this guide booklet to include the new elements created for Project-8; the TO-BE model, PLM Strategy and expectations with regards to the use of ARAS Innovator. A new evaluation format was also created to evaluate the use of Innovator. Because only 12 of the students in Project-8 2010-1 would work with this guide, and those students were only chosen on the first week of classes, this guide was available to these students only then. However in the future it could be available to students with up to 1 month before kickoff, to give them a 'head's up' on the project.

It wasn't necessary to change the entire guide. Most of the content remains the same as before, including sections such as the introduction, "Course Generalities" (objectives, justification, etc.) and "Course Strategy" (structure, evaluation, discipline rules, etc.). The section of the guide that was mostly modified is "Course Deliverables". This section used to have only short phrases to describe the course's deliverables. These phrases were kept, but a table of activities (identical to the project template on Aras Innovator) was added at the end of each set of deliverables (each delivery). This complemented the information given about the deliverables and prepared students for the moment they had to program their projects. Another modification made, was the section called "execution controls". This section used to have two parts; one that described how to fill out meeting logs manually and another that described a meeting prior to each delivery where a big advance of that delivery had to be shown. Aras Innovator controls both of these necessities, since meeting logs are now created through the system and the project advance can be monitored constantly by professors. This section was then modified to include Innovator's meeting manager and to address how activities in Innovator must be completed. Finally the last addition made to the Project-8

guide is a format to evaluate de development and use of Aras Innovator throughout the semester.[14]

8.1.2. Tutorial Sessions, Documents and Videos

The time to implement PLM in Project-8 was roughly 2 weeks; the Project-8 calendar starts from the first week of classes and by the fourth week they must be handing in the first two phases of the project. In this schedule, quickness to get students ready to work with ARAS Innovator, plan their project and upload documents was imperative. In order to achieve this, two introductory sessions were planned, both on the second week of classes. A third session, covering the topic of CAD Management in ARAS Innovator, was planned for the fifth week (when students start to work on CAD models).

The first session was theoretical, to educate students on the basic philosophy behind PLM, on its values and how it could potentially improve their group work. This session also briefed them on the intention of implementing PLM on Project courses, on the importance EAFIT was giving to this topic and how they were a pilot group and what was expected from them. The session included a 40 minute presentation on which the topics were the following[15]:

- Introduction-Project Justification
- What is PLM?
- Product Lifecycle and Business Process Modeling
- CAD Management
- PLM Systems
- Conclusions-PLM Benefits

The second session's purpose was to teach how to use Aras Innovator. This session was taught in a classroom with video beam projector and wireless connection, for students to take their own laptops and log on to their own accounts in Innovator and follow the steps themselves at that moment (view Figure 46). This required that students

[14] A document including only the modifications made to the Project-8 guide can be seen in Appendix 3
[15] To view the presentation slides view Appendix 4

had already performed some steps to enable the use of Innovator in their computers. A guide with the steps to access Innovator was created and distributed to students a few days prior to the session[16]. The 5 topics seen in this session were the following:

- Getting Started: Log-in window, username and password, working directory, workspace, TOC, Inbox.
- Project Management: Project Templates, Work Breakdown Structure, How to create projects, Roles, Tasks, Assignees, Dates, Predecessors, Deliverables.
- Documents: How to create new, Numbering and nomenclature, Information to be included, Files (Loading new, Check-out, Check-in, and Get-Copy).
- Meeting Manager: How to fill out a meeting log, participants, action items (meeting activities).
- Completing Activities: Viewing activity descriptions, completing meeting activities, status and color indicators, completing project activities.

Figure 46: Aras Innovator tutorial session
Source: Santiago Ruiz (picture), Own Elaboration (editing)

This tutorial session is very helpful to students but it's only practical when done in small groups (less than 10 people). This would represent in the future, if PLM is taken to the approximately 60 students that enter Project-8; having to perform 6 or more sessions like this one every semester. Each session lasts about 2 hours, which means 12 hours of

[16] This guide appears as appendix 3

teaching sessions in total per semester. This is only counting Project-8, but if PLM is taken to other Project courses then the number starts to multiply. The advantage of a session like this is that students have the opportunity to ask questions at the moment. Nevertheless, it requires having a professor educated in PLM, in Aras Innovator, and in this particular project; with enough time to spend in these sessions. Additionally, students are only left after the session with the notes they take and this is often not enough. Taking into account all of these issues, 5 videos were developed covering all of the topics taught on this session[17]. A 6th video was also created to explain teachers and clients how to access and view information in Innovator. The videos are real time demos with a voice narration of all necessary steps to learn how to use Aras Innovator. These videos will be available for students and professors to view and download them from internet, and this will minimize the need for this session. The effectiveness and outcome of this change is to be proven in further development of this project.

The third session's purpose was to teach how to upload and manage CAD files in Aras Innovator. This session presented a methodical change. Students where first handed a tutorial document with the step by step procedure to upload a 3D model into Aras Innovator, including screenshots of an example[18]. The document also has theoretical information on Product Data Management and explains the numbering and nomenclature for Parts. This document should be read by students prior to the session, which assistance was made optional, and the session would focus more on answering questions and doubts. The result of this change was that only 3 of the 12 students attended the session, all of them from the same group. Coincidentally none of these students were assigned to upload the CAD model into Innovator in the project plan.

8.2. Monitoring

Every implementation of a software or system requires that a system administrator monitors the initial activities and the user's adaptation to the system. In this project monitoring was planned to take place during the first three phases of the project, up until

[17] To view the videos go to Appendix 6
[18] To view the tutorial document go to Appendix 7

the delivery of the Detailed Design phase on the 11th week of classes. This time was calculated to be sufficient to accompany students during their learning process and solve any doubts or issues that arose. This in turn would provide a good feedback of how successful the implementation was.

The duties involved with this monitoring included attending weekly meetings with students during the class's schedule, periodically checking the advance of the project in Innovator and having disposition to solve the student's questions and doubts both through telephone and in person. Nevertheless, students were also encouraged to solve problems themselves before appealing to the administrator's help, especially when these issues had been previously addressed during the induction.

As it could be predicted, most problems that users had were during the first few weeks. Approximately one third of the users had problems with installing and accessing Innovator in their personal computers. Innovator runs through an internet connection that requires several security settings to be configured or the system fails to connect to the server. Additionally it has system requirement limitations. In general, several technical issues had to be addressed during the first weeks of implementation[19]. Apart from these problems, some students had problems derived from improper use of the software or lack of knowledge. Although the tutorial session they had received covered most of the issues that they had problems with, many students forgot things they had learned in this session or never understood them. This is also one of the reasons that drove to the posterior realization of the tutorial videos.

By the end of the first month of use students rarely asked questions about the system's use and very few problems were notified to the system administrator. The role of monitoring became less active and more like that of an observer.

8.3. Results

According to the plan made for the pilot implementation of PLM in Project-8, students on both of the pilot groups chosen (groups 3 and 5) were expected to generate a project plan

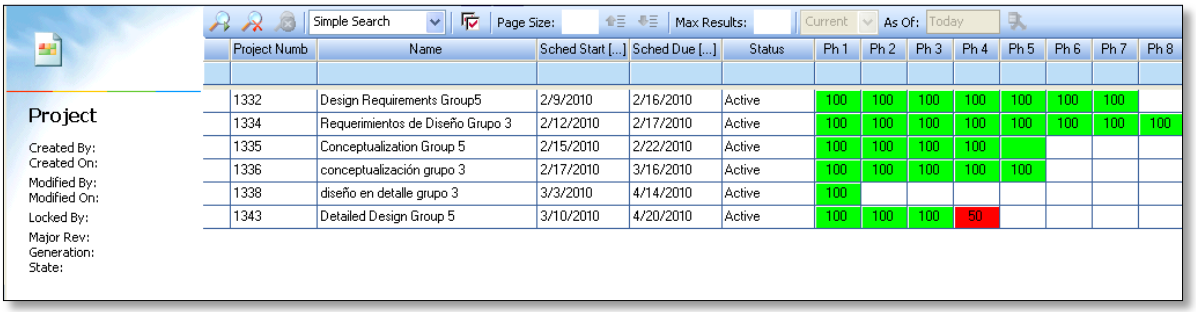
[19] View Troubleshooting section of Appendix 5

for each of the 4 phases of Project-8. This project plan should be created based on the project templates available for them in Innovator, but should then be customized for their own conditions and further development, including start and due dates, team roles and assignees for each activity. Students should execute these projects and follow their project plans in Aras Innovator by completing activities and uploading deliverables on time.

The results in Project 8 2010-1 were monitored and recorded until the end of the third phase of Project-8 (Detailed Design), according to what was stipulated on this implementation project's objectives and scope.

8.3.1. Projects

Throughout the following sections, the project's results will be described only in terms of the registry left by Aras Innovator (view Figure). The project plan dates programmed and the dates they marked activities as "completed" in Innovator don't necessarily represent the real dates in which these activities were started and completed. Although students were expected to mark activities in Innovator as "completed" as soon as they actually were, and upload deliverables as soon as they were ready, they didn't necessarily comply. However, in respect to this implementation's results, the dates that appear in Innovator are the only ones that have validity, since this is what's being evaluated.



Project Numb	Name	Sched Start [...]	Sched Due [...]	Status	Ph 1	Ph 2	Ph 3	Ph 4	Ph 5	Ph 6	Ph 7	Ph 8
1332	Design Requirements Group5	2/9/2010	2/16/2010	Active	100	100	100	100	100	100	100	
1334	Requerimientos de Diseño Grupo 3	2/12/2010	2/17/2010	Active	100	100	100	100	100	100	100	100
1335	Conceptualization Group 5	2/15/2010	2/22/2010	Active	100	100	100	100				
1336	conceptualización grupo 3	2/17/2010	3/16/2010	Active	100	100	100	100	100			
1338	diseño en detalle grupo 3	3/3/2010	4/14/2010	Active	100							
1343	Detailed Design Group 5	3/10/2010	4/20/2010	Active	100	100	100	50				

Figure 47: Scale of colors to indicate the state of completion of Projects
Source: Own Elaboration

8.3.1.1. Phase 1: Design Requirements

According to the Project-8's schedule, students had to deliver and present the results of the first two phases by the fourth week of classes, more exactly on the 17th of February, 2010. The first week of classes was spent in presentation of the course and forming the groups that would work together during the semester. As stated earlier, groups 3 and 5 of the course were chosen to be the Pilot groups that would work under the PLM methodology. They had the tutorial sessions on the second week, while starting work on their projects independently. Only by the third week of classes they had enough knowledge and training to program projects in Innovator, but this meant that they had to schedule the first two phases to be finished on one week of time, which together contained around 40 different tasks. According to students, by the third week most of the tasks that were described on the first phase were already finished, so the project plan they generated for this phase didn't consider the time lapse necessary to finish the activities; only the one necessary to upload the respective deliverables.

Table 2 synthesizes the project results for this phase[20]:

	Project creation date	Scheduled Due date	Actual Due date	Project Template modifications	# of Activities	# of Late Activities
Group 3	12-Feb	17-Feb	2-Mar	21	24	22
Group 5	9-Feb	16-Feb	27-Feb	8	25	18

Table 2: Project results for Design Requirements Phase
Source: Own Elaboration

8.3.1.2. Phase 2: Conceptualization

Students argued that before the 17th of February they didn't have enough time to plan and execute this phase properly. They finished the first phase a couple of days before that date and therefore the activities from the second phase were roughly done in a hurry, according to them with the sole intention of presenting them to professors on the 17th. Nevertheless, students commented that they knew these results would not be definitive and therefore they programmed the second phase in Innovator to be finished after the 17th. In effect, professors were not pleased with the results presented for the

[20] For a detailed report of the results of the project plans, view Appendix 8

conceptualization phase on the 17th and students were given more time to repeat this phase.

Table 3 synthesizes the project results for this phase:

	Project creation date	Scheduled Due date	Actual Due date	Project Template modifications	# of Activities	# of Late Activities
Group 3	17-Feb	16-Mar	22-Mar	15	12	6
Group 5	15-Feb	22-Feb	7-Apr	7	12	10*

Table 3: Project Results for Conceptualization Phase
Source: Own Elaboration

*Group 5 left one activity of this project (Chosen concept delivery) unfinished until the 7th of April, but all others were finished on the 27th of February. The student that completed the activity on this date mentioned that it was ready many days before but he had forgotten to upload the deliverable into Innovator on time.

8.3.1.3. Phase 3: Detailed Design

The results of this phase were critical to evaluate the real effectiveness of the PLM implementation in project management. If the first two phases had been created with slight knowledge of the software and were marked by delays attributed to lack of time; this phase would be programmed with enough experience using the software and time for planning and preparation. The second delivery was scheduled for the 11th week of classes, more exactly for the 14th of April. Results for this report were registered until the 20th of April of 2010, 6 days after the date of this delivery.

Table 4 synthesizes the project results for this phase:

	Project creation date	Scheduled Due date	Actual Due date	Project Template modifications	# of Activities	# of Late Activities
Group 3	3-Mar	14-Apr	?*	11	14	7*
Group 5	9-Mar	20-Apr	?**	5	14	4**

Table 4: Project Results for Detailed Design Phase
Source: Own Elaboration

*Two activities of Group 3 had still not been completed on the 20th of April, accumulating already 6 days of delay by then.

**One activity of Group 5 still remained incomplete on the 20th of April, but it still did not report a delay with regards to the phase's plan.

8.3.1.4. Student delays for completing activities

As stated before, not all delays in the completion of activities reported in Innovator necessarily represent delays in real life. Amongst the reasons for delays in the completion of activities mentioned by the students themselves are the following:

- Not finishing the activity on the scheduled time.
- Not marking the activity as completed in Aras Innovator despite finishing it on time.
- Technical difficulties with Aras Innovator
- Unawareness of the due date for an activity (despite having this information available in Innovator).

According to the results shown in figures 48 and 49, students presented very different results when their punctuality to complete activities in Aras Innovator was evaluated. This proves that, despite the standardization and control that Innovator provides, punctuality still remains a personal trait that students must acquire individually to avoid project delays.

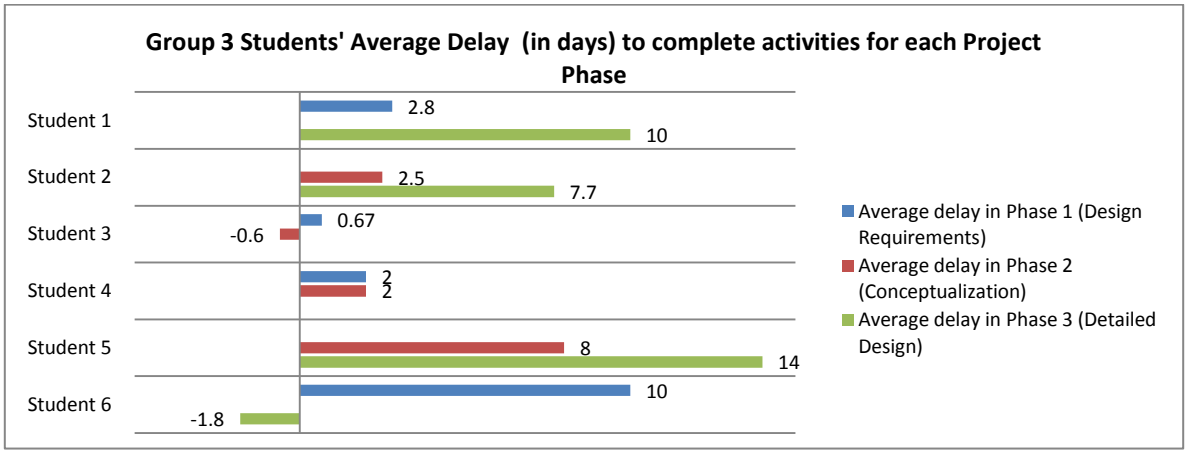


Figure 48: Graphical bar representation of Group 3 students' delays
Source: Own Elaboration

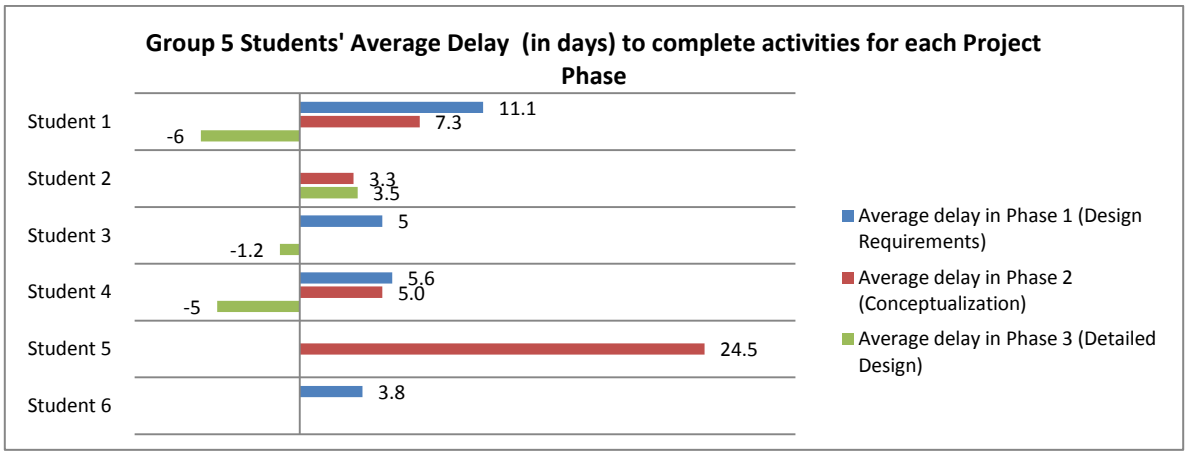


Figure 49: Graphical bar representation of Group 5 students' delays
Source: Own Elaboration

8.3.2. Deliverables

8.3.2.1. Documents

Both teams uploaded 100% of the deliverables marked as "required" in all of the three phases. Additionally, Group 3 uploaded eleven extra documents and Group 5 uploaded four[21].

Despite some few exceptions, documents were uploaded with all the required information and in an organized way. Those that weren't, were later corrected. Numbering for documents was a partial success. One of the problems was that students numbered the first documents counting with one digit instead of two (ex: 1 instead of 01). When the number reached two digits (number 10) it would then skip to the place after document 1. Additionally, students in Group 3 omitted using an underline after the "phase digit" in the number, which eventually caused that CAD files got mixed up with other files generated in the third phase. Besides these problems, the numbering and nomenclature system proposed was very helpful to keep the documents ordered and made browsing and searching files in Innovator easy.

[21] To view the whole list of documents uploaded, go to Appendix 9

8.3.3. Parts

Despite not counting with automatic connectors to CAD software, Group 5 managed to upload their CAD model to Innovator properly with the manual method. All of the parts, sub-assemblies and assemblies necessary for the correct reconstruction of the CAD model were made available[22]. This CAD Model was also given in Innovator all the relations between parts and assemblies to create the BOM[23].

Group 3 failed to upload their CAD model properly. They uploaded the sub-assemblies and defined BOM relations but didn't upload all the necessary parts to fully reconstruct the model after downloading it.

The uploading process in both teams was performed by only one team member.

8.3.4. Meetings

One of the topics discussed during the literature review was the difficulty presented in usual collaborative design meetings. Problems like:

- Team members leave with pieces of a puzzle that needs to be reconstructed at the beginning of the next meeting.
- Often critical pieces are missing, so the team is either unable to proceed or has to revisit decisions they have already made.
- Not all team members can attend all meetings; some team members miss key information and activities.

Taking this in mind one of the tools that was most important to the implementation of PLM was the management of meetings. Both teams used the meeting manager in Innovator to create logs of most of the meetings that took place. In the meeting logs created students assigned themselves activities that where completed in most cases, according to user testimonies[24]. However, both teams also missed creating several

[22] This was tested by downloading both CAD models from Innovator
[23] To view the CAD BOM uploaded in Innovator, go to Appendix 10
[24] There is no record of exactly how many were finished and when available in Innovator.

meeting logs. Group 3 missed the meeting logs for weeks 3 and 6; while Group 5 missed creating logs for weeks 4, 9 and 10, as can be seen in Table 5.

In general these logs helped students solve the problems previously mentioned, since activities distributed and meeting notes could be visible for all team members in Innovator.

Meeting Number	Description	Meeting Date	Group
MTG-109	Meeting week 3 (control)	2/10/2010	P8 20101 Group 5
MTG-110	Meeting week 4	2/17/2010	P8 20101 Group 3
MTG-118	Meeting week 5	2/24/2010	P8 20101 Group 3
MTG-119	Meeting week 5	2/24/2010	P8 20101 Group 5
MTG-120	Meeting week 6	3/3/2010	P8 20101 Group 5
MTG-121	Meeting week 7	3/10/2010	P8 20101 Group 5
MTG-122	Meeting week 7	3/15/2010	P8 20101 Group 3
MTG-123	Meeting week 8	3/17/2010	P8 20101 Group 3
MTG-124	Meeting week 8	3/17/2010	P8 20101 Group 5
MTG-127	Meeting week 9	3/24/2010	P8 20101 Group 3
MTG-128	Meeting week 10	4/7/2010	P8 20101 Group 3

Table 5: Meetings created in Aras Innovator
Source: Own Elaboration

8.4. User Feedback

One of the most important sources to review the outcome of the PLM implementation in Project-8 was the users themselves. They were asked to give feedback on the adaptation and use of the methodology and software after the first and second deliveries.

8.4.1. Feedback after the first delivery

After the first delivery, on the 10th of March of 2010, students were asked a few questions to give some feedback with regards to the implementation of PLM and the use of ARAS Innovator so far[25]. The questions were open and aimed at finding out if students found Aras Innovator easy to use; to know which problems and benefits they saw in the implementation and which recommendations they could contribute to make it better.

[25] To see the questions they were asked, view Appendix 11

The first feedback received is that all 12 students, except one, said that they considered that they'd been able to learn and use Aras Innovator so far. The other student mentioned that he had lots of problems with his personal computer and therefore he really hadn't tried using the software much. Members of his group knew about his problems and therefore he wasn't assigned any activities during the first two phases while he could get his computer fixed. Apart from this particular case, students mentioned things such as:

- *"The software is easy and handy to use; checking activities and uploading deliverables is easy".*
- *"The software is user friendly and commands aren't very complex"*
- *"The software is of quick learning and the implementation methodology has been clear"*

Most of the problems identified by users were technical problems. Amongst these were low connectivity, instability (frequent blocking), low velocity, poor compatibility with other software and browsers, and general difficulty during installation. With regards to the use of the software under normal circumstances three users identified the following difficulties:

- *"Introducing the respective codes (numbering and nomenclature) to create and upload files takes long and it's a hassle"*
- *"I haven't been able to solve by myself the problems I've encountered using the software"*
- *"With regards to the PLM methodology the problems have been changing the way of doing things; we aren't used to this and I often forget to check the activities I've been assigned".*

The first two commentaries show problems that can be considered 'normal' because they were previously expected. These students had never had to deal with numbering and nomenclature and therefore it's normal they consider it long, tiresome and difficult, despite how important and necessary it is. For the problem described in the

second commentary, Innovator includes a help section with basic information, but it still lacks a lot of "how to" information. Through practice and with the addition of better tutorials and accumulated experience it's expected that students will become more autonomous in solving their problems. The last commentary, however, is very important and it reflects an essential dilemma in any new implementation. This student identified that apart from the software, PLM required a change of attitude and work methods which are necessary for the strategy to work, and that this had been difficult to achieve so far. Many students were concentrated on evaluating the problems in the software but didn't actually evaluate their attitude and disposition towards it. However, when they were asked about the benefits they thought PLM implementation had brought for their projects and teamwork, they did go a step beyond the software.

Students evaluated the PLM strategy with respect to results they had in all 7 previous Project courses and the experience they had working with groups during University. Most of them mentioned how organization and order had improved. They also mentioned that information could be collected and accessed easier and more efficiently, and without losing any of this information at the end of the project. *"The real benefit I see is at the end of the project where all of the group will have access to the information and documents generated"* said one of the students. Another one mentioned "*trusting this information will be kept safely"*.

The improvement of project planning and control is another benefit they identified. They said that they could distribute and assign activities better and that these activities were better defined. *"Tasks and deliveries are distributed from the beginning and the software is in charge of reminding this"* said one student. Another one said PLM *"has permitted delegating and distributing work better and controlling times for delivery"*. This, according to one student, has improved punctuality to finish tasks, and according to another has guaranteed the participation of all team members. Generally, they agree that the overall documentation and registry of the process had improved.

As mentioned earlier, students were also asked to provide recommendations toward a better education and use of PLM strategy in the future. The first

recommendations were towards solving the technical problems they had identified earlier. Some of these included re-installing the software on a server with more capacity, investigating more the compatibility with other software configurations and one student even recommended implementing another software, one that's *"more complete, to avoid problems with slowness, blocking, etc."* The other recommendations they made were with regards to the implementation methods. One user said that *producing a printed manual of the software could help.* Two students said that they would "*enjoy having virtual tutorials, with a lot of graphical elements and troubleshooting sections, because a lot of details from the oral sessions were forgotten*[26]*".* One of these students also recommended that *"the use of this software at the beginning should be evaluated and graded by professors to guarantee student participation".* A student recommended that *"this methodology should be slowly introduced in previous Project courses, to integrate this knowledge into the formation of students, and to turn this into a differentiating competence of Product Design Engineers".* Finally, one of the students said that *"there should be more tutorial sessions, at least 3 or 4".*

The final recommendations given by students after the first delivery were in regards to the use of the software. They recommended adding e-mail notifications for activities. They also said that more information should be added in the activities in the project template, such as estimated times for finishing them.

8.4.2. Feedback after the second delivery

After the second delivery, on the 14th of April, students were repeated the same questions they were asked after the first delivery. The objective of this was finding out if their answers had changed after more than one month more of practice and use of PLM. The questions basically asked if they had learned anything new during the second phase, which new problems and benefits they saw and which new recommendations could they make for the education and use of this methodology and software.

[26] This last recommendation was done and the results are described in section 8.1.2 and available in Appendix 6

All students answered they had learned about CAD file management in Innovator; how to upload a complete CAD model, using the BOM tool to provide relations between parts and assemblies and create the model-tree structure. The feedback given by students contrast with the results for Group 3 described in section 8.3.3, which show that this group failed to upload the CAD model properly. According to what was described in section 8.1.2, this was taught one week after the first delivery and using a different method than the first tutorial sessions. However, the problem they had was not due to the lack of knowledge of Innovator; but to leaving the job unfinished. Therefore the methodical change proved to be successful. Accordingly, it can be concluded that live oral tutorial sessions aren't as necessary as initially thought.

After having so many technical problems described by students in the first feedback, extra efforts were made to solve them[27]. The results are visible in the second feedback given by students. Five of the students said that all the technical problems had been solved and that they were very pleased with how the software was running, especially in Mozilla Firefox browser. One student said that although this had helped, he *"still found that Innovator required too many things to be done before running properly".* This commentary is true, but unfortunately its solution is something that depends on Aras corp.

The main problem found by students during this phase was the slow and arduous process of uploading the CAD model to Innovator. Students said things such as *"it takes too much time and is very repetitive",* or *"it has too many steps".* This problem was also expected, since they had to do this process manually, whereas most other PLM softwares have automatic connectors with CAD systems. Aras offers connectors for Innovator and the CAD systems used by students (Pro Engineer and SolidWorks), but at an extra cost. They weren't bought for this implementation and the results still turned out to be good, but buying them would probably increase user satisfaction in the future since it does make the process incredibly faster and easier. Additionally, it could help avoid groups uploading their CAD models incomplete, like Group 3. Apart from this problem two users

[27] These problems and the solutions found are described in the Troubleshooting section of Appendix 5

mentioned again that they think more work needs to be done to increase the user's awareness and appropriation of the PLM philosophy.

The advantages mentioned by users were mostly the same as the ones mentioned in the previous feedback. Nevertheless, they also credited the advantage of having the CAD model uploaded and available for everyone with model-tree and thumbnail preview information, despite the difficulty of uploading it. Another advantage they saw because they used it much more during this phase was the meeting management, including the tasks they assigned to themselves through meeting logs. In general students showed to be very pleased with the methodology and the software.

Some recommendations given by students were also repeated from the last feedback. Amongst these; including Email notifications, evaluating and grading user participation, and producing more tutorials *"like the one made for CAD management in ARAS Innovator"* as one student said. Another student said that *"this software should be taught well before having to use it",* meaning that it should be part of the contents of a course previous to Project-8. Four students coincided in saying that this methodology should also be implemented in previous Project courses, to gain practice and because they found it useful.

8.5. Comparison to Project-8 previous to PLM Implementation

8.5.1. Information created (project development)

One of the greatest expectations with the implementation of PLM was improving student's planning, execution and control of their work in Project-8. As mentioned in section 6.2.3, students in Project-8 rarely plan their activities with enough anticipation; they usually improvise and plan on the run. Based on this, the PLM implementation was a great advance, since it made students generate a full chronogram of all Project's phases, assign themselves roles, activities, due dates and think of interactions between tasks. Students used to consider that the only plan they required was the Project-8 guide, but this implementation made them more aware of the complexity of the process. They

understood more the sequential nature of some design processes on which delays or faults in certain tasks have direct repercussions in subsequent tasks. They also became aware of the great amount of activities that are really required to carry out a good design process. The results show that in comparison to the group analyzed in Project-8 2009-2, both groups in Project-8 2010-1 performed more activities. However, despite performing much more activities, they only generated a two more required deliverables[28]. This means that these deliverables were reached after following a more thorough process.

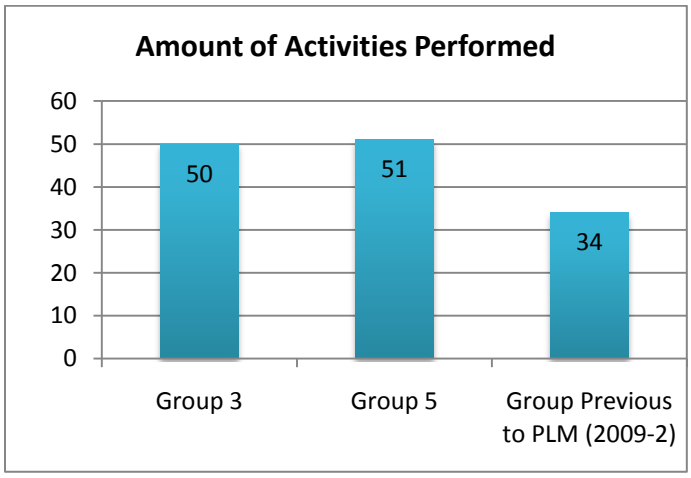


Figure 50: Amount of Activities performed by pilot groups.
Source: Own Elaboration

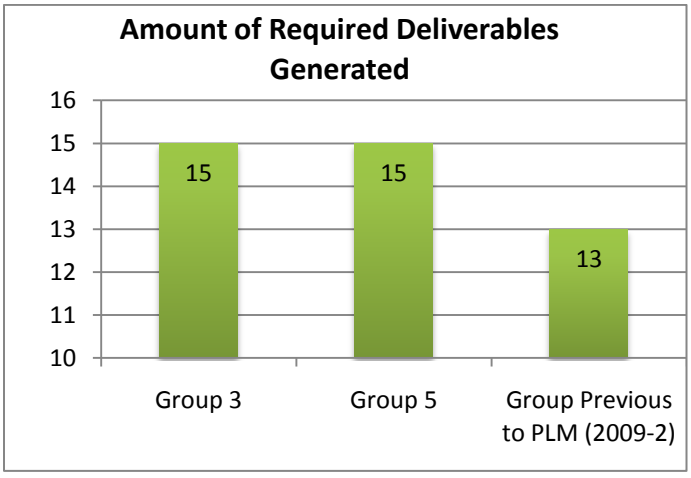


Figure 51: Amount of Required Deliverables Generated
Source: Own Elaboration

[28] Last group missed generating the production plan delivery and the concept selection delivery

One of the objectives of having students plan more their projects was reaching a better work distribution throughout the semester. PLM seeks to have more control over this work distribution, not only through project planning, but mainly through permanent monitoring. Project managers can check the project progress at any moment through PLM software like ARAS Innovator, and do the pertinent actions if something goes wrong. It's hard to expect any person to work at his highest capabilities constantly during an extended period of time. Work efforts usually fluctuate; increasing prior to delivery dates and then decreasing after having delivered. Consequently, students in Project-8 were doing most of their work in the days previous to each of the four deliveries. There was a very unbalanced work distribution throughout the semester, having weeks where almost no progress was made and then, on the week prior to each delivery, students making up for lost time with late night work and lots of stress (view Figure 53). Professors were worried about this, because it also reflected on the quality of work handed in and they especially saw that most deliverables were not backed-up with sufficient investigation and a proper work process. The increase in controls using Aras Innovator intended leveling the work distribution throughout the semester (view Figure 54-III). Although this was intended, fluctuation was still expected but the work peaks were expected to decrease by shortening the periods for relaxing and incrementing work before controls (view Figure 54-II).

Despite the increase in controls and monitoring through Innovator, deliveries to professors continued to be priority for students, since they were only graded then. Students continued leaving more work for the week previous to these deliveries than other weeks. However, controls did produce an effect in work distribution, which was more balanced in general than on the prior project course. Controls were made on weekly meetings prior to the deliveries and work effort increased before each of these controls, decreasing pressure and effort on the week prior to each delivery and augmenting results' quality (view Figure 54-I). The result was a preservation of the overall work with a decrease in the work peaks shown in Figures 53 and 54; represented by the equation:

$$\int f(t_1) = \int f(t_2) \quad w_{\varepsilon 2} < w_{\varepsilon 1}$$

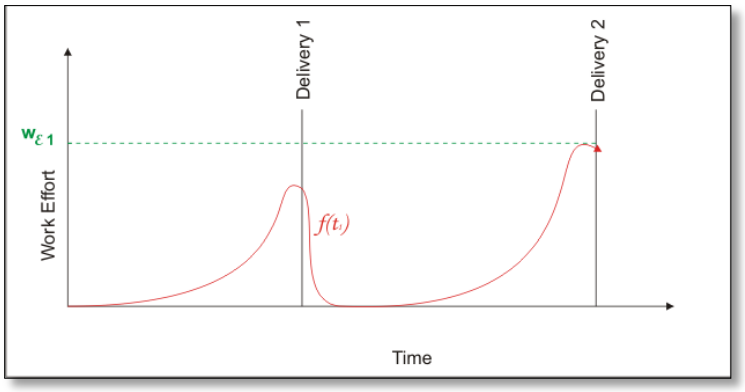


Figure 52: Approximate Graphical Representation of work distribution prior to PLM Implementation (2009-2)
Source: Own Elaboration

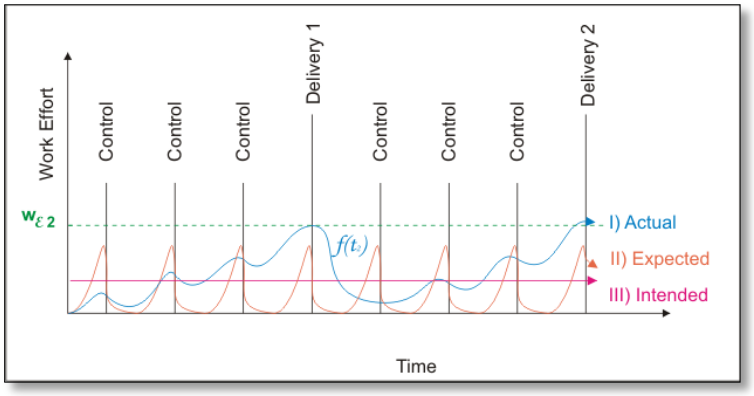


Figure 53: Approximate Graphical representation of intended, expected and actual work distribution after PLM implementation
Source: Own Elaboration

8.5.2. Information retained by students

One of the key benefits of Aras Innovator is that students, professors, clients and all other users of a database retain access to all data generated throughout the project. This is something that didn't happen with the documents generated during Project-8 2009-2. As it was mentioned in section 6.2, students of this group created a common Gmail account to share documents that they generated in the course. However, only 54% of the documents they generated ended in this account. Several of those aren't definitive versions, meaning that the information on them is incomplete or outdated. Every definitive document was printed and put in a binder, but this binder was only retained by one of the team members after the project ended. The other documents are scattered on different personal computers that belong to the team's members (view Figure 55-I).

Essential files, such as the CAD model and pictures of the prototype, were only retained by half of the team or less. In comparison, students that used PLM in Project-8 2010-1 now have a permanent backup of data they uploaded to Innovator. Group 5 uploaded all of the required documents, so all 6 members have access to 100% of the information (view Figure 55-III). Group 3 failed to upload the CAD model correctly, so, unless they correct this before the end of semester, that document (7% of all required documents) will only be kept by the 3 team members that created it (view Figure 55-II). Despite this problem, it's evident that Aras Innovator contributes to the preservation and availability of valuable information. Even if their computers are lost or stolen they will never lose access to this information through internet.

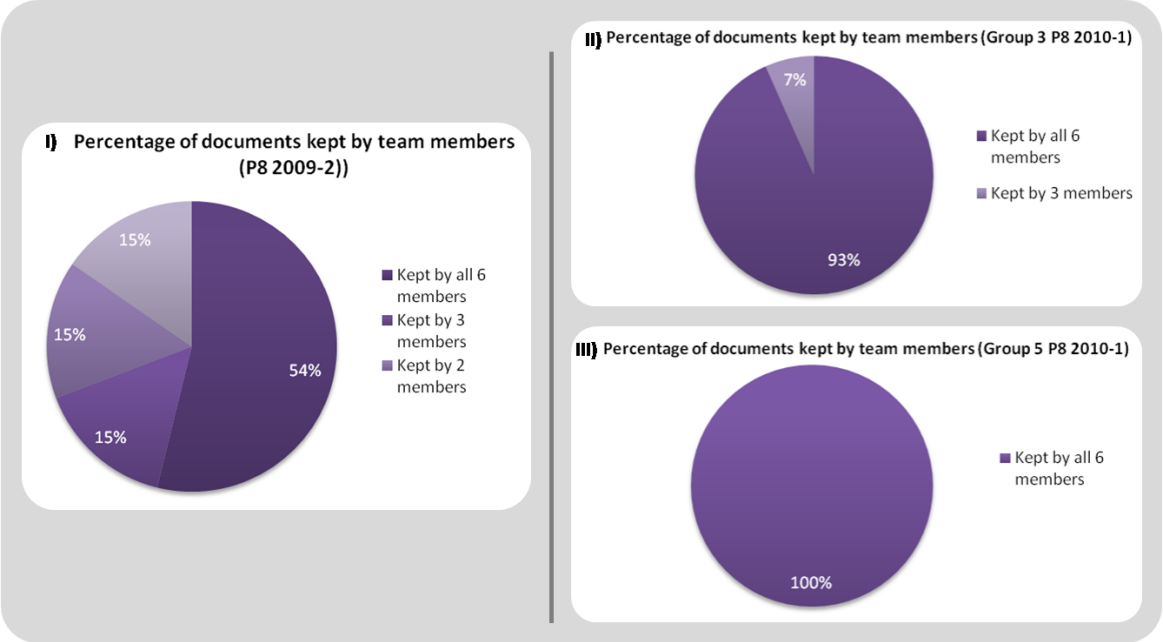


Figure 54: Pie Percentage of documents kept by team members
Source: Own Elaboration

Keeping this data is also important for the University to have a record of projects for future reference. Currently, every semester approximately 10 projects are done by students in the course Project-8. The course has been taught at EAFIT for more than 5 years, and on previous periods work teams have been sometimes smaller, meaning that more projects were made. Under rough estimates, more than 100 projects have been done in Project-8 since the course started. The estimations are not exact because nobody has kept a record of this information. There is no single person in the University that can

have access to all the data generated on all of those projects. It would require an effort of enormous proportions to recover at least half of it, probably having to contact every former student of Product Design Engineering listed in the databases of EAFIT's ex-alumni. If PLM is permanently implemented for the entire course, and more controls are implemented so students upload all of the information they create; this situation may not happen again.

8.5.3. Teamwork and collaboration

Apart from comparisons already made with Project-8 2009-2, there are some qualitative aspects that are worth analyzing to know if this pilot PLM implementation was successful. During the literature review it was established that a collaborative attitude isn't as automatic as one might think and that collaboration requires skills such as ability, aptitude, and order. It was also established that projects help collaborators acquire autonomy and self-discipline while also developing abilities for working in teams; abilities such as decision making, proper communication, problem solving and conflict resolution.

During the period in which students from Project-8 2009-2 were supervised, and according to the results obtained from the survey made to Project students; it became evident that many of these skills and abilities are not yet fully developed in many students. For example, some students can be fully informed of their individual responsibilities and still not fulfill them due to lack of commitment or responsibility, amongst other reasons. Students often complain about having uneven workloads amongst team members and having to do more work than others despite obtaining the same grade in the end. Many of them are unorganized with their time; hand in things late, arrive late to meetings and leave work to be done in the last minute. In general, despite the fact that students generally enjoy working in groups and identify it as important for their learning and professional development; many of them still lack the skills to do it in the best manner.

Quantifying students' attitude towards work, their social skills and self-discipline is very complicated and it wasn't the objective of this investigation. However, some

qualitative observations can be made based on the observation of the teams that were involved:

- In general, distribution of workloads between students improved. In Project-8 2009-2 many complaints were heard between the team members, about others being late or not participating enough in the team's work. In both groups of Project-8 2010-1 commentaries like these were seldom heard, and students in general were all involved with their projects. A reason for this might be the fact that traceability of student participation is possible in Aras Innovator. These students knew that if they were not working as hard as their teammates professors could corroborate this in Innovator by looking at activity assignees and delays. Formerly professors would receive complaints from students about unequal workloads and they could not really verify if this was true, while in Innovator there is a record of which student did what, when and how.
- Punctuality improved. Despite the delays already described in section 9.1.1.4 for students of Project-8 2010-1; delays in the previous semester were even worse[29]. Part of this was the cause for the work distribution throughout the semester being so unbalanced.
- The general harmony between team members in the two groups supervised in 2010-1 was better than that of the previous semester. Grudges between team members in 2009-2 developed because they had unequal workloads and also because roles were not assigned by a group consensus but were rather informally established as the work advanced. Some members resented having been assigned tasks without having agreed to them; by a member of the group who auto-established himself as team leader without some of the team member's consent. These problems didn't occur in Project-8 2010-1 because the activity assignation was done by consensus, with all the members' participation and the team leaders were chosen unanimously by all team members at the beginning of the semester.

[29] This can be seen in the results of Project-8 2009-2, presented in Appendix 2

9. CONLUSIONS

In this chapter conclusions are drawn on the results and outcome of this investigation. Recommendations are also made towards a full implementation of PLM in Project-8.

9.1. Final Conclusions

The mission of Product Design Engineering Department in EAFIT is "to prepare engineers with a global vision and with the ability to create new products for the benefit of individuals, companies, and the environment".

According to this mission and the objectives of this investigation, it can be concluded that:

- This implementation had an integral approach to the PLM philosophy, including rethinking of its methods and procedures; therefore there is now a greater knowledge of the design process applied in Project courses in EAFIT, more specifically on the course "Project-8", and of the University's pedagogical strategy. The acquired knowledge is essential to further develop this strategy and plan the best tactics to reach its educative purpose.
- In order for EAFIT to successfully accomplish its mission of forming professionals, it must first understand the students that will become those professionals. This investigation provided a greater knowledge of Product Design Engineering student's teamwork and collaborative design; which are documented and useful for future reference in this matter. Knowing first-hand student's opinions and desires on teamwork will help create the best strategies to form professionals that will perform better in the teams and workgroups they will surely encounter in their professional life.
- EAFIT now has documented results on the first ever PLM implementation done for educative purposes in its facility. This puts the university in the forefront of collaborative product design engineering education. International visibility can be given to these results since PLM is a topic of current interest in the scientific and commercial communities.

- Future implementations in EAFIT will part from a work already developed and documented. There's now a documented procedure for the education and introduction of PLM to students of Project-8 and all the necessary materials for this effect (tutorial documents, videos, guidebooks, presentations and a fully developed software configuration). This procedure and materials could be used on other implementations, or set the basis for creating new ones. Accumulated knowledge can transform EAFIT into a national leader in the field of PLM.
- The success of this implementation can motivate the continuation of this approach and can facilitate the investment of resources for future investigations on PLM and implementations on undergraduate courses, postgraduate programs and industrial applications.
- An opportunity has been opened to improve the storage and management of information generated by students. Most students have the idea that their work is somewhat disposable, since it's rarely used or consulted after it's finished. Although the objective of a course is more pedagogical than productive, the by-product of a formative process often ends up being valuable information that could be useful to others and should be accessible.
- Collaboration with other universities can be increased and facilitated. With the use of PLM tools, a student living in another city in Colombia or another country could participate in a Project course and have the same involvement, information and responsibilities as students in EAFIT. This will help EAFIT form students with a "global vision".

This investigation also proved that the implementation of this PLM strategy is beneficial to the education of students of Product Design Engineering, amongst other reasons because:

- It stimulated students to collaborate and increased the awareness of their interdependency and commitment to their work.

- It provided them with a tool to manage the most recurrent issues in the development of collaborative design projects; sharing and managing information, and planning and having control of the design process in all of its stages. In the future these students might impulse the use of these tools in the industry.
- It will prepare and qualify them for the changes in the industry brought by this new technology.

In general terms, the success of this implementation relies in the fact that it proved the benefits of PLM in education, and opened the way to further implementations of the PLM concept, as stated in the project's justification. The objectives of the project were all accomplished, since the methodology was implemented in the course, students learned and applied it, and the materials and methods were established to continue with it. More importantly, this investigation cleared the horizon in a topic that is still very new to EAFIT and the industry in general, but that already promises great transformations in the near future. Further implementations can now be planned with a greater certainty of their success and with a greater knowledge of the route to follow.

9.2. Recommendations towards a Full Implementation of PLM in Project-8

According to the results obtained the user's feedback and the possibility of taking PLM to a full implementation in the course Project-8 in a near future; the following recommendations are made:

- Despite the overall good results using Aras Innovator, other software solutions should also be studied in depth before selecting one for future implementations.
- In case of deciding to implement Aras Innovator, investments should be made to upgrade it; especially acquiring CAD connectors with SolidWorks and ProEngineer.
- More support from IT Specialists in EAFIT should be guaranteed and programmed.
- Better hardware should be provided by EAFIT, including installing PLM software in a server with more capacity and facilitating the use of this software in more of the University's computer labs.

- It would be good to teach PLM in a course prior to Project-8, and if possible include in it some tutoring in PLM software.
- If the previous recommendation is not possible due to curriculum limitations, there should be taught in other courses some competencies that will facilitate the adaptation to a PLM strategy, such as planning and programming projects, collaborative design and Product Data Management (PDM).
- Student's introduction to PLM strategy should be further continued using the tutorial documents and videos generated, hopefully before the first week of classes using EAFIT's virtual platform.
- The role of Innovator admin, responsible for creating and preparing each semester's database, the management of users and permissions, and the introduction and monitoring of students; could be performed by an assistant or class monitor, previously educated in PLM and PLM software.
- PLM should be evaluated and graded as an integral part of the course by professors during the whole development of the course to increase student participation.

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