EXTENDING A COLLABORATIVE SYSTEM FOR CONCEPTUAL DESIGN STAGE IN THE PRODUCT DEVELOPMENT PROCESS

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Abstract. *The ever increasing rate of social, economic, and technologic changes that resulted from the business globalization process requires from the organizations a greater agility in the sharing of information and knowledge that related to the product development process (PDP), in order to reduce the time of releasing new products in the market. This reduction in the product development lead time should, however, not have a negative influence in quality and cost of the product under development. The Internet and the Web have been playing a part of growing importance in the product development environments. Such technologies have made it possible to create new collaborative computational tools to support the product development process. This paper aims to present the development work of a collaborative system called 'GEPP-net Conceptual'. This system, developed based in the requirements and an architecture proposed by Gomes Ferreira (2006), look for support, through the web, to collaborative work of DP team members in the specific phase of Conceptual Design. The Conceptual Design (CD) it is the phase of the product design that aims to obtain a product concept (essentially, the qualitative definition of the same) from a list of User Requirements and Design Specification obtained during the phase of Informational Design. The Design Process (that includes Informational Design, Conceptual Design and Detail Design) is part of the global process of DP that Rozenfeld et al. (2006). The 'GEPP-net Conceptual' collaborative system provide the necessary tools to support the collaborative work on CD: in functional modeling (definition of the total function, functional modeling and select the model through Decision Matrix), find for principles of solutions (Morphological Concept Generator), development the alternatives of solutions (Morphological Concept Assessor) and selection the solution (Decision Matrix).*

Keywords: *Conceptual Design (CD), Collaborative Product Development, Internet and Web*

1. INTRODUCTION

The ever increasing rate of social, economic, and technologic changes that result from the globalization of business requires from organizations a greater agility in the sharing of information and knowledge that relate to the product development process (PDP), in order to reduce the product development lead time. This reduction should not, however, have a negative impact on the quality or the cost of the product under development.

The introduction of new design methods and tools and the wide use of personal computers inside product development environments lead to the cost reduction of the product, while maintaining or even improving its quality. The time to launch the product in the market was also positively affected by this process.

New technologies related to the Internet and the Web has been playing a part of growing importance in the product development environments. Such technologies have made it possible to create new collaborative computational tools to support the product development process.

However, following a general tendency with respect to collaborative systems and environments, the collaborative tools thus far developed have focused only on the final stages of the PDP, to the detriment of the earlier stages: those that provide a greater potential to reduce the product development time, the product costs, and to improve its quality. According to

Wang et al. (2002): "the concept generated at the early stages of product development affects the basic shape generation and material selection of the product concerned. In the subsequent phase of detailed design, it becomes extremely difficult or even impossible to compensate or to correct the shortcomings of a poor design concept developed in the early stages of the design process". Figure 1 depicts the high impact of the conceptual design decisions on manufacturing productivity and product quality.

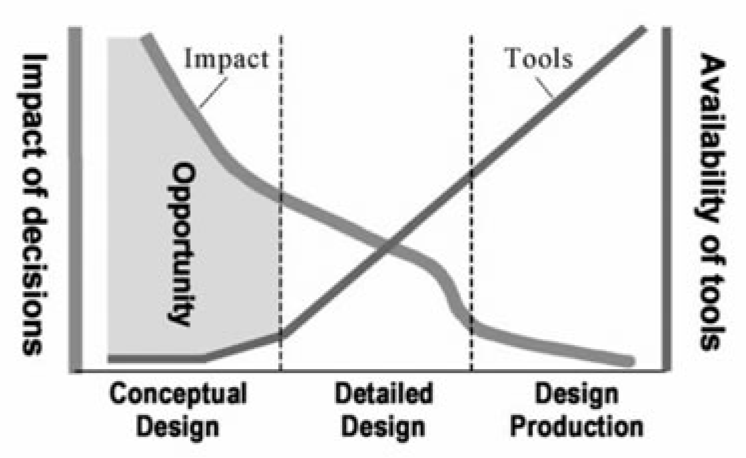

Figure 1. Opportunity in early design stage. (WANG et al., 2002)

This paper presents the 'Conceptual GEPP-net', a Web-based collaborative system developed with the aim of supporting the distributed work during the conceptual design phase of the PDP. This system is intended to complement the 'Informational GEPP-net': a Web-based collaborative system previous developed in our research group to support 'informational design'. Both systems have been developed based on the requirements and the architecture proposed by Gomes Ferreira (2006).

2. THE CONCEPTUAL DESIGN

According to Rozenfeld et al. (2006): "to develop a product comprehends a group of activities through which, starting from the market needs and from the technological possibilities and restrictions, and taking into account the product and competitive strategies of the company, the design specifications of a product and of its production process are reached, for the manufacturer to be able to produce it, and to follow the product after its launching, in order to make any necessary changes in the specifications, to plan the discontinuity of the product in the market, and to incorporate the lessons learned through the life-cycle of the product".

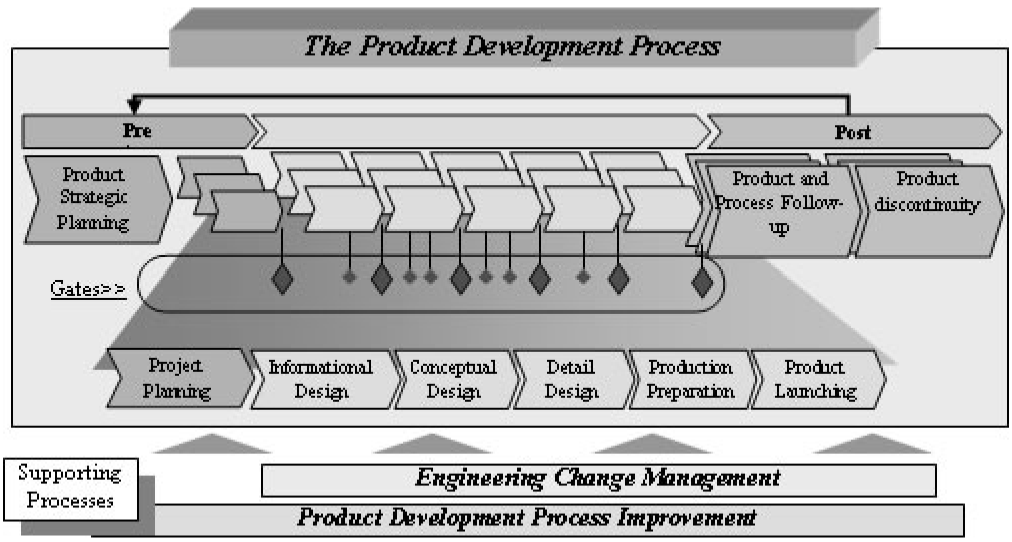

Figure 2. General aspect of the Unified Reference Model for the PDP. (ROZENFELD et al., 2006)

Models of the design process have been developed since the early 1960s. In engineering design, this development seems to have converged into a phase model. In Pahl and Beitz (1996) these design phases (or stages) are: 'clarification of the task', 'conceptual design', 'embodiment design' (or 'preliminary design') and 'detail design'. Emphasizing the importance of the full analysis of the design problem (and related requirements) through to the final quality of the product, Fonseca (2000) denominate the first stage of the design process as 'informational design'. Informational design and conceptual design represent together the 'early stages of the design process'. The URM (Unified Reference Model), presented in Fig 2, was recently proposed by Rozenfeld et al. (2006) for the Product Development Process. This model is divided into three macro-phases: predevelopment, development, and post-development. Each of these three macro-phases is subdivided into stages (or phases), and these stages, in turn, into activities.

The Conceptual Design (CD), is the phase of the product design that aims to obtain a product concept (essentially, its qualitative definition) from a list of User Requirements and Design Specifications obtained during the Informational Design phase.

Figure 3 shows the main relations between the conceptual design activities, and the GEPP-net system carrying out the main activities of this stage as will be detailed in Section 6.

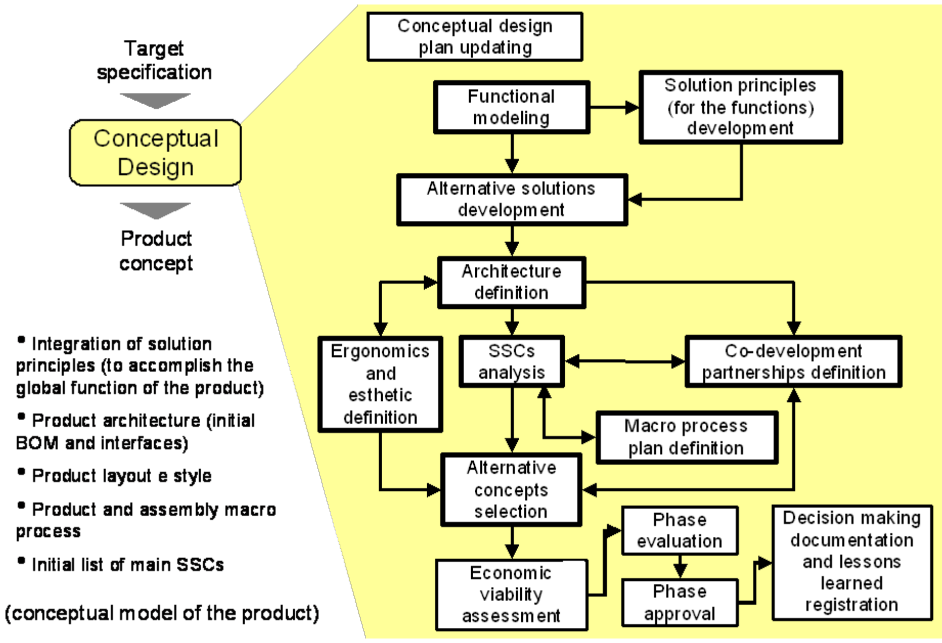

Figure 3. Main information and relations between the activities of the Conceptual Design. (ROZENFELD et al., 2006)

3. COLLABORATIVE DESIGN

There is collaboration when a group of people work together voluntarily to accomplish a certain task. Therefore, when a product is designed through the joint efforts of a group of people (including product designers), this process can be entitled 'collaborative design'. According to Chiu (2002), collaboration implies a durable relationship and a strong commitment to a common goal.

Collaborative Design can be defined as a business strategy that makes use of computer networks and software to support the members of a design team working together in the development of products.

Also known as collaborative product development, it is build upon the nature of cross-functional product development teams introduced in the realm of concurrent engineering. In essence, it is the marriage of concurrent engineering to the concept of highly effective and well-supported team collaboration, including not only the act of collaboration itself, but also the infrastructures and environments that enable and nurture it. As such, collaborative engineering is an evolution of the principles and practices of concurrent engineering (MILLS, 1998).

The product development process is characterized by a large number of people who work together in a space and time distributed environment. Time and space are two dimensions frequently used to study collaboration and the technologies employed to support it.

4. COLLABORATIVE SYSTEMS FOR THE EARLY STAGES OF DESIGN

Wang et al. (2002) provides a comprehensive review of research projects and applications in the domain of collaborative Conceptual Design, based on Internet and Web technologies. Agents and the Web are highlighted among the emerging technologies that have been proposed to implement collaborative design systems. In the following, four projects that focus Conceptual Design are briefly reviewed.

4.1 Product Conceptualization Tool (PCT)

Developed by Roy and Kodkani (2000) at the Knowledge Based Engineering Laboratory (Syracuse University, NY, USA), the system uses enabling Web technology to support geographically dispersed designers, to develop and select the product concept, through a collaborative effort. PCT allows designers to represent their concepts and also aids them to search for existing ideas on similar products - providing a link to existing patent databases on the Web. The issue of selection of the best concept is tackled by adopting the gallery method, through a module, which computes ratings for individual drawings for a pre-discussed set of criteria.

4.2 Distributed Design Assistant (DiDEAS)

Developed by Schueller (2001) at the Stellenbosch University (South Africa), this is a three-segment system to support a distributed team of designers. The segment 'Design Methodology' places a methodology that guides designers through the Conceptual Design at their disposal and offers tools for concept generation and evaluation. The segment 'Communication and Information Transfer' coordinates the communication between the distributed designers and provides a platform for the exchange of design-related data, such as customer requirements, ideas, sketches, comments and decisions. Both segments make use of the third segment: a support service for various input devices.

4.3 Virtual (Conceptual Design) Office

A general Web-based collaborative framework developed by Huang and Mark (2003) at the University of Hong Kong is here instantiated for the Conceptual Design. The start-up home-page (Virtual Office) provides access to three Web-based Conceptual Design tools (Virtual Consultants): Functional Analyzer, Morphological Concept Generator, and Morphological Concept Assessor. These tools correspond to the three major stages of Conceptual Design, according to the authors.

4.4 ProDefine

More recently developed by Huang et al. (2003) at the University of Hong Kong, this system attempts to support early product definition. The system offers four main front-end components (Customer and Project Explorer, Requirement Analysis Explorer, Concept Generation Explorer, and Concept Evaluation Explorer) and two back-end databases (Concept Base, and Solution Base). These components are deployed and configured according to a typical three-tiered architecture for Web and Internet applications.

4.5 Informational GEPP-net

In our research group, Gomes Ferreira (2006) established the requirements and architecture for collaborative systems to support the early stages of the product design process. Based on these requirements and architecture, the GEPP-net system was implemented, with a set of design tools necessary to perform the informational design. These requirements and architecture were used as a base for the development of our collaborative system which is an extension of the collaborative system previously developed by Gomes Ferreira (2006).

5. REQUIREMENTS AND ARCHITECTURE

A set of functional and non-functional requirements that should guide the Web-based collaborative systems was established by Gomes Ferreira (2006). The functional requirements describe the several tasks that the system should do in order to satisfy the needs of it users. The functional requirements for the Conceptual GEPPnet were obtained based on Rozenfeld et al. (2006), presented in the second section of this paper. In this way, the Conceptual GEPPnet should offer the members of the design team collaborative tools that support them...

... in the determination of the total (or global) function of the product.

... in the determination of the income and outcome flows (material, energy and signal) for the total function of the product.

... in the deployment of the total function of the product into an structure of less complex sub-functions (elementary functions).

... in the determination of the income and outcome flows(material, energy and signal) for the elementary functions of the product.

... in the determination of standard operations (join, separate, guide, unguided, amplify, reduce, and so on) for the

elementary functions of the product.
... in the selection of the most promising functional structure for the product.
... in the search for solution principles for the elementary functions of the product.
... in the combination of solution principles into alternative solutions for the product.
... in the deployment of the alternative solutions into systems, subsystems and components.
... in the integration of systems, subsystems and components.
... in the aesthetic definition of the product.
... in the registering of critical aspects of the product.
... in the registering of the main parameters of the product.
... in the definition and registering of the main components materials.
... in the definition and registering of the main components production processes.
... in the definition and registering of the main components suppliers.
... in the selection of the most promising concept for the product.

The Conceptual GEPPnet presents a three layered architecture, show in Fig 4, typical of computational systems developed for the Web. The first layer (Interface Layer) represents the Web browser employed by the users to access the system on the client side. On the second layer (Middle Layer), we can find the tools and applications of the system: (Specific) Design Tools, Project Management Tools, Knowledge Management Tools, and Communication Tools. These tools make use of the data, information, and knowledge - related both to the design activities and to the product under development - that are stored on the databases from the third layer of the architecture (Data Layer).

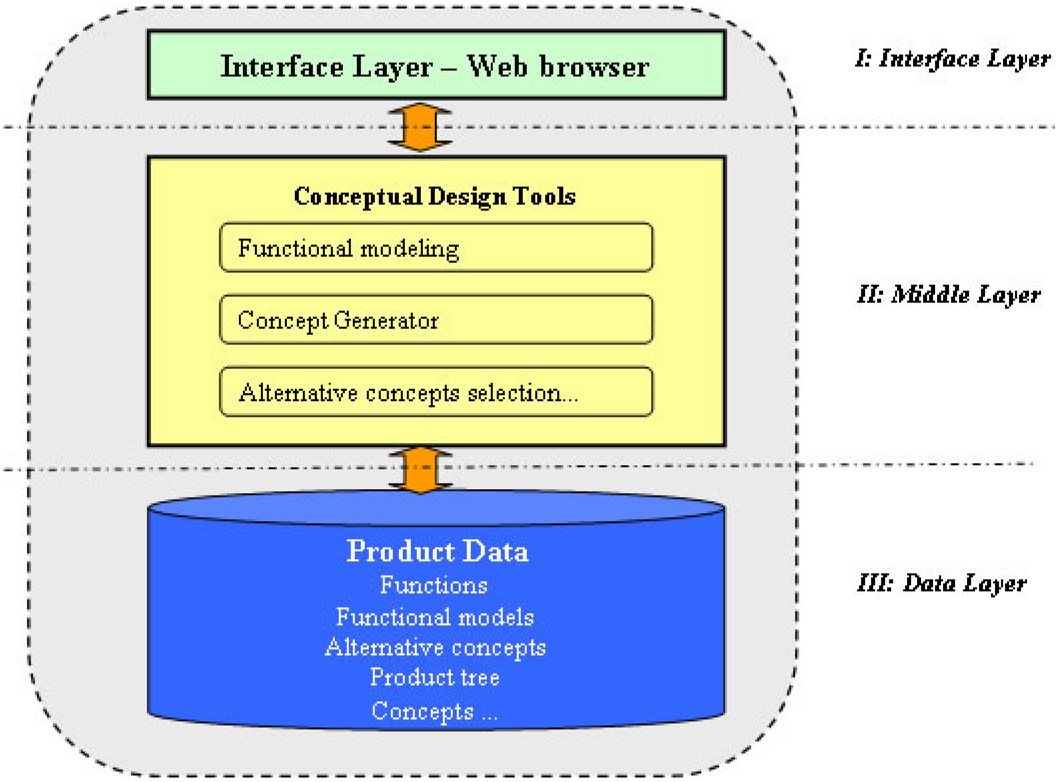

Figure 4. Architecture of GEPP-net system in the conceptual project

A collaborative design system developed with the Web as a backbone would primarily provide: (1) access to catalogues and design information on components and sub-assemblies; (2) communication between multidisciplinary design team members in multimedia formats; and (3) authenticated access to design tools, services and documents Wang (2002).

The same communication, project management, and knowledge access tools are used during the whole product development process, and therefore, will not be duplicated, at least in this first implementation stage of our system. The same databases (product and project databases) will be used by the two complementary systems, in order to guarantee the integrity of the whole GEPP-net system (informational and conceptual).

Figure 5 presents, in a simplified way, the main elements of the GEPP-net system, as a whole, covering the early stages of the design process: informational and conceptual design. The system is composed of three general classes of computational tools: 'specific design tools', 'communication tools' and 'project management tools'.

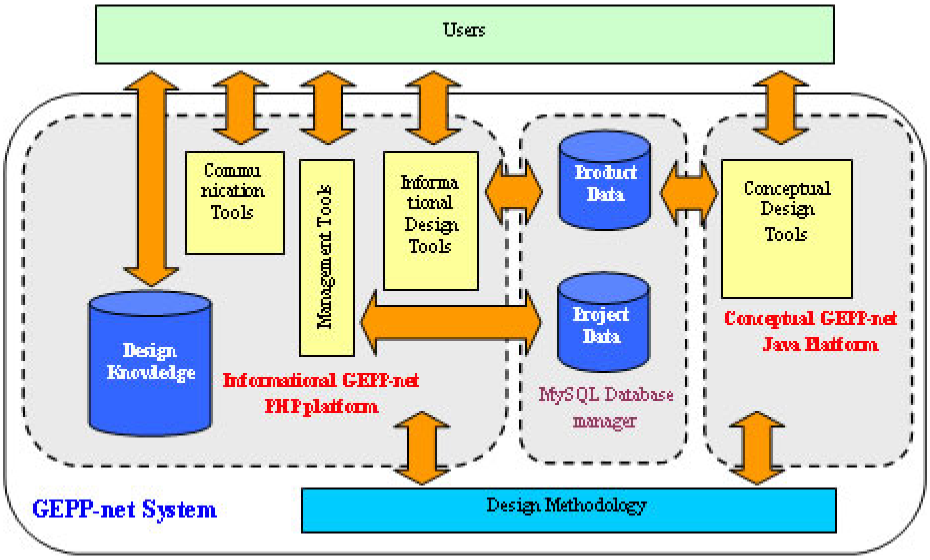

Figure 5. Architecture of GEPP-net system in the early stages of the PDP.

6. THE CONCEPTUAL GEPP-NET

The 'Conceptual GEPP-net' collaborative system provides the tools necessary to support the collaborative work in CD: functional modeling (definition of the total function, functional modeling and selecting of the model through Decision Matrix), solution principles development (Morphological Concept Generator), alternative solutions development (Morphological Concept Assessor), Architecture definition (Product Tree), SSCs analysis (Analysis of Critical Aspects, Definition of parameters), Ergonomics and esthetic definition (Document and design management), Co-development partnerships definition (List of suppliers), Macro process plan definition (Identification of processes) and Alternative concepts selection (Decision Matrix).

The whole Conceptual GEPP-net is developed to function with Web pages where the user can access the system and work on any computer which is connected to the Internet and which has a navigator. One of the great advantages of this type of system is that it is not necessary to previously install specific software on the computer. Since the system is provided by a single server the changes will be occurring simultaneously where all of the users view the changes in real time and can give opinions and debate ideas and changes through the various communication tools available on the Internet.

For the conceptual design the system, following the design methodology previously described, contains nine stages, which are divided into eleven components (web pages), as shown in Fig 6 that shows the Conceptual GEPP-net system, this window gives a general view of the stages which the designer will have to carry out during the conceptual design stage.

The following items introduce the stages of the conceptual design together with the tools provided by the GEPP-net system to support them. The last subsection discusses the programming technologies that have been used to develop the system.

Definition of the Total Function: this tool presents a central box (also known as 'black box') that symbolizes the boundaries of the system. Inside the central box the product total function is to be written. Near to the left and right limits of the central box the input and output flows (material, energy and signal) are represented by an arrow and the name of the flow. This tool also allows the users to have a fast view of functional needs and design specification, defined during the Informational Design of the product.

Functional Modeling: A function structure is obtained by breaking down the total function into sub-functions with less complexity. For the first implementation of Conceptual GEPPnet system, the functional modeling is made using the 'hierarchical function tree' method. Inside this window, the design team can create as many function structures as necessary for the product. The functional three is presented in the left side of the window and shows the total function as the origin of the structure. Figure 7 shows one of the function structure inserted for a system to clean bananas, where three levels of deployment were established: total function, partial sub-function and elementary sub-function.

Select the Model: In order to select the best alternative from the function structures created during the functional modeling of the product, the system provides a decision matrix. Using this tool, the designers will evaluate each function structure in terms of the attendance to each design requirement established during the informational design. In the decision matrix, one of the function structures is chosen as reference. In this way, each alternative function structure is compared

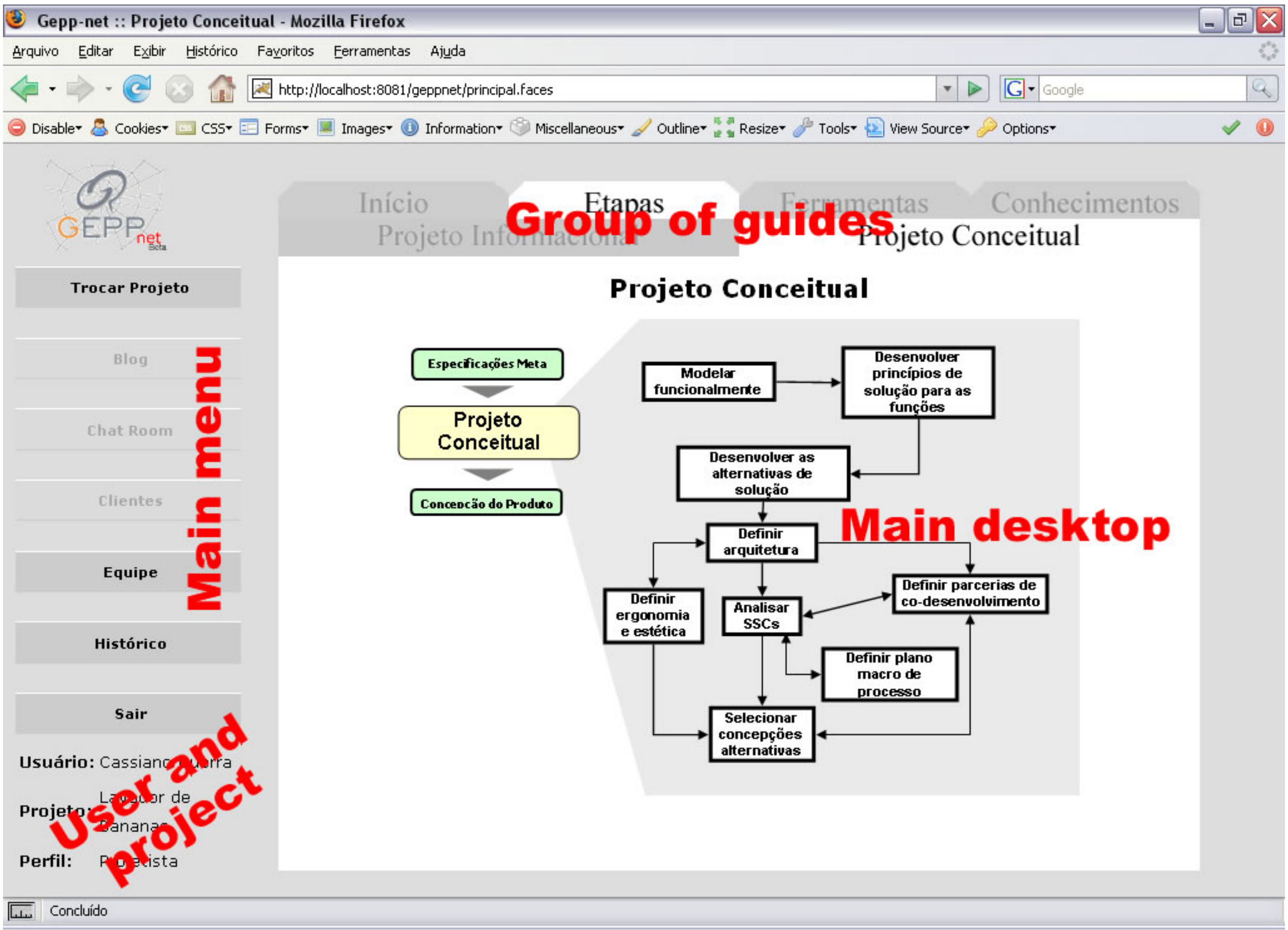

Figure 6. Conceptual GEPP-net system.

to the reference in relation to each design requirement (evaluation criteria). When the alternative function structure has a better performance than the reference one, it receives a "+1" grade; when the performance is worse, it receives a "-1" grade; and for a similar performance, the grade is "0". The total grade of each alternative structure is obtained by adding the product of each grade to the value of the respective design requirement (defined in the informational design stage with the help of the Mudge diagram). The alternative function structure with the best total grade is chosen for the continuation with the conceptual design process. If two function structures have similar total grades (best grades), the designers can use the decision matrix once more to chose the best function structure.

Morphological Concept Generator: After selecting the best structure, the designers begin to search for solution principles (physical effect and effect carrier) that are able to carry out the lower level sub-functions of the selected function structure (elementary functions). These solution principles are organized in the first morphological matrix provided by the system. In the lines of this matrix, the designers insert as many solution principles as necessary for each elementary function of the product. The system also offers a list of all previously used solution principles for each elementary function, in order to stimulate and speed up the generation of solution principles for the product. At this stage, the designers may also analyze the competing products and the patents gathered and investigated during the informational design stage.

Morphological Concept Assessor: In this stage, the designers develop solution alternatives for the product: combinations of individual solution principles that together compose total principle solutions for the product. The tool used to accomplish this task is a morphological matrix that lists in its first column the elementary functions of the selected function tree structure of the product; and in the adjacent columns, the possible (or most likely) combination of solution principles for the product.

Architecture Definition: Here, the solution alternatives for the product are organized into systems, subsystems and components, using a hierarchical tree structure. The system provides a tool to generate such tree-like architectures. Each solution alternative generated with the help of the morphological concept assessor will have a specific architecture. For this stage, the system also provides a manager for downloads and uploads that allows the designers to save sketches that represent the architecture of each solution alternative. The designer can link each sketch to each function structure, as well as save representations of its components. In this way, the whole design team can talk about and propose changes to

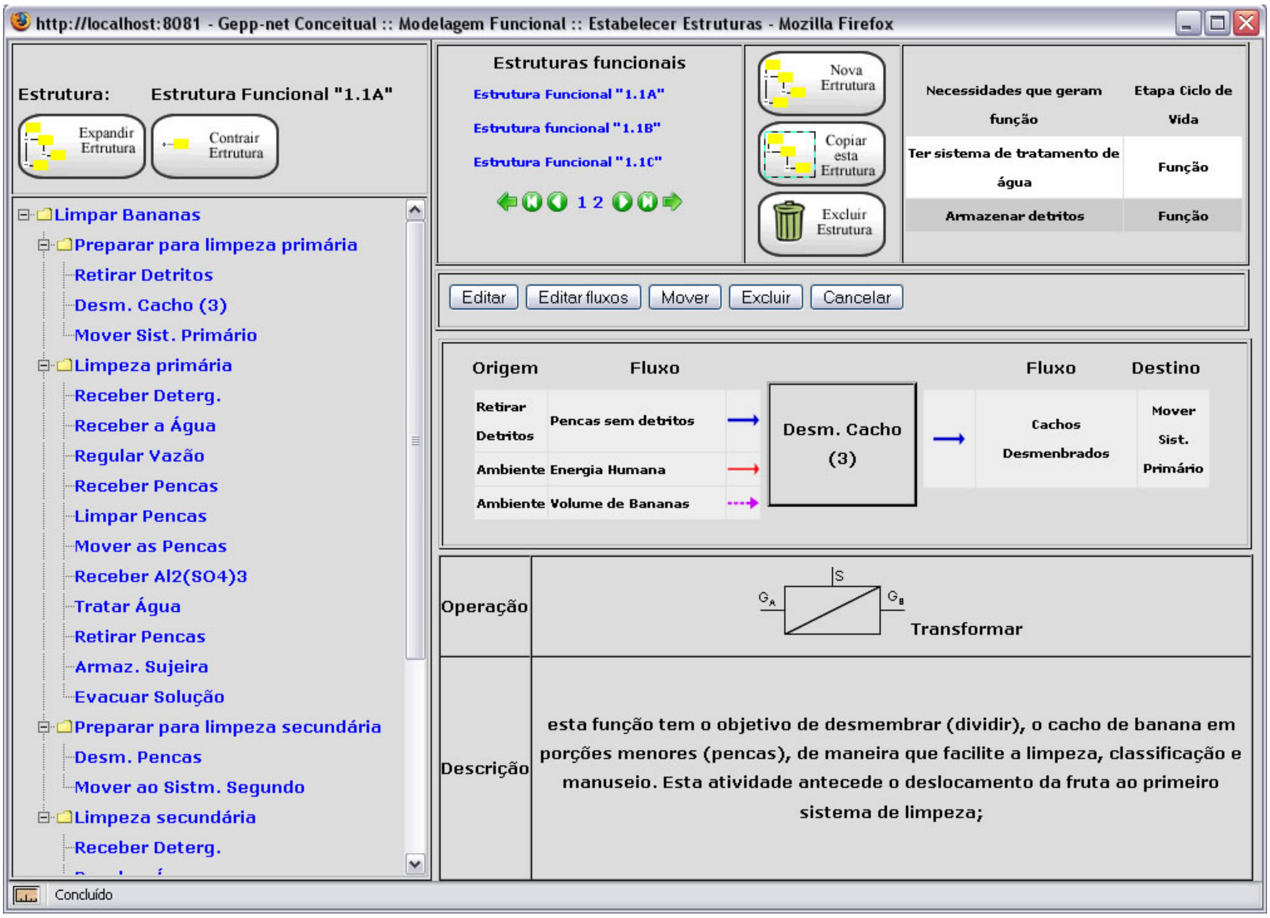

Figure 7. Window for the functional modeling of the product.

the generated architecture.

SSCs Analysis: Here, the critical aspects of the product, observed during each stage of its life-cycle, are defined. The main parameters (form, materials, dimensions, and capabilities) for each component are also defined in this stage. The designers follow the architecture of the product, defining its main characteristics and linking new drawings or sketches to the components, thereby creating the initial bill of material (BOM) for the product.

Ergonomics and Esthetic Definition: For this stage, the system provides a download/upload manager that allows the designers to store and retrieve drawings and documents that relate to each of the concepts created during the previous stages. The esthetic and ergonomic aspects of the product can be developed in parallel with the previous stage where the forms for the product are defined, facilitating in this way the communication between the technical and esthetical development teams.

Co-development Partnerships Definition: The development team defines the possible partnerships and suppliers for each component of the product. Here, the design team can also define if each component will be produced inside the company or bought in from outside (make or buy decision).

Macro Process Plan Definition: The main objective of this activity is to identify possible manufacturing processes for the components. The GEPP-net system provides a tool where the designers identify, for each component, the corresponding manufacturing process, the tool that will be used, and other details about the manufacturing process of the components. This process, according to the design methodology proposed by Rozenfeld et al (2006), will be reapplied in more detail during the next stage of the design process: the detail design. Therefore, the main objective of this stage is to list the possible manufacturing processes, in order to make a better evaluation of solution alternatives possible during the next stage of the conceptual design.

Selection of the Best Solution: With all the information discussed in the previous sections, the next activity of the design process is the selection of the best solution alternative from the several concepts generated earlier. The best concept will be taken to the next stage of the design process: detail design. In this stage, the system supports the designers with a decision matrix, where the users evaluate each proposed concept taking into account its best or worse satisfying of the design requirements developed during the informational design. The application of the decision matrix provided by the system at this stage of the design process is quite similar to the application of that provided to chose the best function tree structure.

7. TECHNOLOGIES

While the 'Informational GEPP-net' was developed using the simple and easy to learn PHP programming technology, the 'Conceptual GEPP-net' was developed making use of some robust and sophisticated Java technologies, such as Java Server Faces (JSF). This technology incorporates attributes of a model-view-controller (MVC) framework for the Web. One of the most important advantages of the MVC is the clear distinction between the visualization and the business rules (model). In this way, the application is divided into three layers: model, visualization and control. As the system runs on a server, the J2EE (Java) platform was used.

Hibernate - an open code software developed in Java - was used for the access to the databases, and MySQL - a multithreaded, multi-user, SQL Database Management System - was the choice in order to assure compatibility between the 'Informational GEPP-net' and the 'Conceptual GEPP-net' systems.

8. CONCLUSION

The 'Conceptual GEPP-net' system represents an evolution in relation to the 'Informational GEPP-net', previously developed by Gomes Ferreira (2006), in the sense that it is based on a more recent and comprehensive product development methodology, the one proposed by Rozenfeld et al (2006), and also since it was developed using more sophisticated and reliable technologies for web development, such as Java Server Faces (JSF).

The next step of this project is to apply the system in some real design cases. Initially the system will be used and evaluated by the graduate students attending the Product Design course, part of the Mechanical Engineering Course, at our institution. If the results are satisfactory, our intention is to migrate the 'Informational GEPP-net' to the web development technologies used in the 'Conceptual GEPP-net', thereby unifying the two systems into just one platform.

9. SUMMARY

GEPPnet is a Web-based collaborative system that offers support in the early stages of the Product Development Process. This paper presented the 'Conceptual GEPP-net' that was developed to improve collaboration during the Conceptual Design Process. This system offers web tools to assist designers during the functional modeling, finding of solution principles, development the solution alternatives, Architecture definition, SSCs analysis, Ergonomics and esthetic definition, Co-development partnerships definition, Macro process plan and selection of the solution. The system was developed using new and free Web program technologies, like Java, Apache Tomcat, MySQL, Java Serves Faces (JSF), AJAX, HTML and JavaScript.

10. ACKNOWLEDGEMENTS

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