An Approach to Conceptual and Embodiment Design within a New Product Development Lifecycle Framework

ABSTRACT:

The design of new innovative products is the result of an accurate and precise management of knowledge sources all over its lifecycle, such as technology, market, competitors and suppliers. The work contributes with a framework that shows how the knowledge sources influence in the state-of-the-art and market needs so that they become opportunities for innovating products addressing the whole product lifecycle. It provides a systematic path from the early generation of ideas to the production of a new product proposal. Through a deep analysis of previous research works of new product innovation lifecycle development frameworks and linking it with knowledge management, strategic planning and scorecards we came out a structured contribution. The result considers the concurrent activities and its relationships all the way through the Product Lifecycle that can help in creativity and innovation, combined with a process management proposal. Managing the sources of knowledge in highly dynamic markets and technologies is one of the major difficulties involved in innovative products design and development. The emerging knowledge from external sources is confronted with organization internal knowledge and experience in order to achieve the first product correct.

Keywords: product lifecycle management, collaborative engineering, knowledge management, production modelling, innovation management

1. Introduction

Our world has reached a high level of maturity in terms of product creation. New products are born to solve a problem, perhaps from the analysis of an idea or after detecting or creating new needs in consumers' demands. Consequently, companies are involved in a continuous product design and development competition where every single decision could have a butterfly effect on the final result perceived by the costumer. Under these circumstances we believe that it is very important to develop a product correctly the very first time. To achieve this aim and, therefore, to be a competitive company, it is essential to manage the product innovation process.

From the point of view of product design activities, many requirements must be taken into account. It could be said that the product manager should be able to align necessities from different perspectives such as product functionality, manufacturing costs, gadget performance, visual appearance or other features that depend on changes in fashions.

As an example, from the product materialization point of view, engineers and manufacturers are constantly searching for new materials and manufacturing processes that can allow them to maintain a competitive advantage and maximize their profit margin. Therefore, the process of selecting appropriate materials requires an integrated definition that considers not only the mechanical specifications of the components and the relation of compatibility between them but also aesthetic empathy (Albiñana & Vila, 2012). This is due to the fact that the number of materials and new manufacturing processes is constantly on the rise, thereby making it more difficult to detect an innovation and apply it. Another important point, sometimes overlooked, is that the geometry of the product's parts, the selection of materials, and the integrated definition of the manufacturing processes must be done by hand.

In the same way, the perspective of product service or product withdrawal and recycling has to be designed taking into account the end-of-life of the product and its reuse and recycling.

Consequently, during the early stages of the product design and development process, strategic decisions can ensure success in many innovative aspects. It is usually claimed that creative and aesthetic design is the key to product innovation, but it should also be noted that other aspects will have positive effects on the product novelty (Acur et al., 2010). A new innovative product may have novel aspects to meet functionalities and would be desired by costumers.

During the product innovation process, the path from abstraction to concretion or from creativity to focalization is not independent from the procedure that is adopted. A correct procedure will make it possible to obtain a more optimized solution that will satisfy all the initial requirements of innovation and functionality.

The importance of this lies in the fact that a broader view of product development management is needed that will lead us to observe the lifecycle of the product as a whole and to understand that every action has an influence on the innovation.

This fact leads us to define a framework and associated procedures that minimize the errors throughout all the stages of the process. This framework is focused on general aspects of product development but not on design activities. The present work tries to make a contribution in the field of product innovation management by proposing a framework for product design and development that considers all the stages of the product lifecycle and their interactions with the aim of achieving first product correct.

The interaction of knowledge sources in the generation of innovative products has been addressed in the new product innovation design and development framework. To focus this study a related research has been conducted in previous contributions in product design, product development, product innovation, product lifecycle and product knowledge management (Kandemir et al., 2006).

2. Related research in New Product Development Management and Innovation

The New Product Development (NPD) Process involves the task of collecting knowledge, putting it all together, and making it work with the objective of creating new things in a similar way to the approach followed by a scientific research team. This process can be said to be a cyclical activity since each new product will in turn provide the basis for a future process improvement or new developments.

During this process, organizations capture, encode, represent, and manage information, transforming it into knowledge which they can reuse at their convenience in the future. Consequently, knowledge is, essentially, a description that tells us how data, information, and things relate to experience.

This process is also a source of innovation, since it incorporates the acquired knowledge into the organization. This knowledge comes through the design process itself, ideas, suppliers, sectorial studies, and the knowledge gained through quality systems and customer service. Technological learning and concurrent engineering practices improve NPD success outcomes. (Geum et al., 2013) recently developed a systematic framework to guide partner selection, evaluating indexes in four categories: Technology strength, R&D

openness, R&D linkage, and Collaboration effects. Many parts or products are developed by external suppliers or collaborators that, at the same time, compete against the firm's own products. The ability of a company to collaborate and outsource NPD activities is related to the potential of internal staff to assimilate and manage external ideas as well as to the size of the SME. (Teirlinck & Spithoven, 2013)

One of the major difficulties involved in the development of innovative products is, definitely, the set of risks due to lack of information in highly dynamic markets and technologies. In his contribution Wang et al. (2010) propose a risk management framework for NPD processes that links corporate strategy, through a performance measurement system, that allows to improve the success rate of innovation projects and to achieve corporate strategic objectives.

Therefore NPD could be modelled as a system of innovation through knowledge management but, at the same time, it must be structured on the management approach of different practices. To group all of the design trends within a first approach, it could be said that there are three clearly defined schools.

In Japan in 1950, Genichi Taguchi developed a method to improve product and process quality throughout the whole product lifecycle, which is essentially an approach to robust design (Taguchi, 1986). He proposed different approaches to reduce variation function as a key strategy for the improvement of reliability and productivity in the product development cycle. The reduction of variation in a particular stage of the lifecycle can prevent failures in later stages. A similar structure is used to control systems with an input signal, a response associated with the design concept, control variables accessible to the designer, and other inputs called noise that cannot be handled. With all these, the ideal behaviour and a loss of quality function are defined and used to quantify the loss suffered by the user due to deviation from target performance.

Contemporaries of Taguchi, Yoji Akao and Shigeru Mizuno (1990) developed the methodology of Quality Function Deployment (QFD) in 1966. Dr. Hiroyuki Yoshikawa produced the General Design Theory in 1980, and this job was completed by Tetsuo Tomiyama. He summarized the Design Theories and Methodologies in an attempt to evaluate them by collecting neutral information from the perspective of design education and design practice (Tomiyama et al., 2009).

In Europe we must highlight the contribution conducted by German researchers, among many others, such as Albers et al (2008); Hubka & Eder (1996); Müller et al. (2012); Pahl el al. (2007) or Roth (1994).

In the United States, Boothroyd et al. (1994) developed the design for manufacture and assembly (DFMA) methodology, which focuses on eliminating inefficiency in design, simplifying the structure, cutting costs, and quantifying improvements. Swift and Booker started a methodology that also involved design for manufacturing considerations from the batch size perspective (Swift, 1987). Correspondingly, by focusing on various specific design goals and other lifecycle issues, a collection of Design for X (DfX) methodologies can be found (Kuo et al., 2001).

During the same decade, Suh developed his famous axiomatic design theory, which addressed fundamental issues that arise when applying Taguchi methods (Suh, 1990). The product design and development proposal by Ulrich and Eppinger (Ulrich & Eppinger, 2012), and the mechanical approach to the design process by Ullman, Dixon and Poli (Ullman, 2010) should also be highlighted.

One of the first general *design methodologies* was established by Pugh with his Total Design (Pugh, 1990), which provided a design framework for a structured design process model. Total design may be construed as having a central core of activities, all of which are imperative for any design, regardless of the domain. This design core consists of market/user needs, product design specifications, conceptual design, detailed design, manufacture, and sales. A contribution that should be stressed is the concept comparison and evaluation matrix, which compares the concepts that are generated both with each other and against the criteria for evaluation. Armstrong (2001) and Ullman (2010) made a contribution more focused on mechanical applications rather than on systematic design.

Regarding to *design procedures*, one of the most widely used is Quality Function Deployment (QFD), developed by Mizuno and Akao in 1960 in Japan (Akao, 1990). This can be seen as a complementary method to determine how and where priorities are assigned in product development. It consists in translating customer wishes into design features for each stage of product development, often based on subjective criteria to be converted into quantified targets that can be measured so that they can be used to design and manufacture.

Suh defined the principles of Axiomatic Design (AD) (Suh, 1990): “Maximum independence of the functional elements”, and “Minimum information content”. The method says that if ‘good design’ is to be achieved, the Design Parameters must be allowed to influence the form and content of the Functional Requirements.

Pahl et al., (2007) recognized the repeatability of product development, considering this activity the backbone of the product lifecycle. The development process is further broken down into four main phases: Planning and clarifying, conceptual design, embodiment design, and detailed design.

Finally, *design tools* used for NPD can be selected from many different proposals. For example, brainstorming and mind-mapping stress the provision of the right circumstances and methods for ideation and its implementation. Design Structure Matrix (DSM) and Property-Driven Development/Design (PDD) developed by Weber (2005) are based mainly on the distinction between the characteristics and properties of a product. The characteristics can be determined directly by the designer, but the properties depend on the chosen characteristics and other factors that cannot always be influenced by the designer.

In the field of innovation diverse theories can be highlighted, such as TRIZ, axiomatic design, brainstorming, and mind-mapping. TRIZ (Gundlach & Nähler, 2006). It implies a systematic direction to integrate new competences and technologies pointing to predict the evolution of technical systems (Ilevbare et al. 2013). These theories increase creativity and these outcome inventive approaches. Albers' Contact and Channel Model (C&CM) (Albers & Alink, 2008) was developed at the Karlsruhe Institute of Technology (KIT), and focuses on obtaining patterns for modelling the often unstructured process to find solutions.

Emergent Synthesis (Ueda et al., 2008) manages complex system artefacts, where local interactions influence the global behaviour through a bottom-up development to achieve the purpose of the whole system. From another perspective there are works that explore the process of whole system design. Charnley et al. (2011) presented a framework that included those factors that could influence in the success of a sustainable and innovative design form the whole system approach. Bizzard and Klotz (2012) defined a framework that integrates processes, principles and methods that can help the whole system design although it is focused only around the design phase without considering later phases.

Noble and Kumar (2010) provided an interesting framework for the creation of design value in new consumer products, and identified the main variables or issues and the possible causal relationships between them.

Many contributions have been made but there are still few works in systematic innovation methodologies, however, that could fully integrate those proposals presented with the different activities carried out during the product development, and moreover with NPD. Therefore, it becomes necessary to manage the design and to do so in a way that is even more integrated with the management of the product lifecycle and the business processes of companies.

It is very important to incorporate the lessons learned in every product development. Thus the integration of knowledge through the NPD process must be structured to contribute to increase intangible assets. Therefore the organizational learning and the organizational memory processes could retrieve it to be used in the promotion of new projects. By studying product development projects, that contribution shows evidence of the benefits that a more integrated approach to knowledge processes can provide organizations with (Urwin & Young, 2014).

Project teams are an essential element in the NPD process success. In this respect having effective teams is essential and this requires complete integration. Baiden and Price (2011) explored the impact that integration can have on teamwork effectiveness within construction project delivery teams. The study comes to the conclusion that integration is desirable and helpful, and has the potential to impact upon teamwork effectiveness.

Some studies have considered the use of cross-functional teams in the innovation process and its effect on innovation outcomes. Using optimal combinations on potential complementarities that can arise when using cross-functional teams, increases success in the innovation process. These complementarities are more uniform between design and engineering with little influence among the more technical phases in the innovation process and the development of marketing strategy (Love & Roper, 2009).

Our goal in this research work deals with the dimensions above referred and to define and to plan the NPD strategy. Initial product concepts are screened out through NPD stages, phases and corresponding activities. A gate-based criterion will be established for moving products to be launched. In the proposed model many items are going to be considered such market research, knowledge management, lifecycle management, human resources and team-related initiatives, metrics and performance.

Summarizing, NPD design approaches can be grouped into three main categories according to the level of abstraction: methodologies, procedures and tools. Design methodologies and theories are generalized forms of addressing processes, and usually adapt to the culture of organizations. A greater level of detail is found in the design procedures which embody more specific issues, such as implementation of a methodology. Finally, design tools, usually implemented in software, capture the information available to evaluate possible solutions allowing for optimum configuration. We find that is missing in the literature review a framework that shows how the knowledge sources influence in the state-of-the-art and market needs so that they become opportunities for innovating products addressing the whole product lifecycle, providing a systematic path from the early generation of ideas to the production of a new product proposal.

Once analysed all this approaches, our scientific question is if it is possible to obtain a new product proposal considering all the interactions during the early design process considering the whole product life cycle and including all the different stages.

3. Product Lifecycle Management Approach

The world's awareness about product design and development has changed and many actions for achieving better products can be found in every innovative design process (Grieves, 2009). Therefore, due to increasing consumer demand and rapid product development, companies have invested great amounts of money in acquiring high technologies and skills in order to improve their core business and in externalizing certain activities in order to optimize internal costs (Xu et al., 2013). The consolidation of the company means not only satisfying all the market requirements but also being prepared to satisfy environmental legislations all over the world. Chiang and Trappey (2007) proposed a value chain collaborative model for the product lifecycle prior to implementing a computer-aided tool. They pointed out that efficient value chain management can provide an opportunity for companies to identify their core abilities and position themselves competitively in the market.

This generally assumed vision implies thinking and defining a long-term strategy around product development and sustainability for all the activities in the company, among many other items. At the present time, Product Lifecycle requires management but it depends on a real commitment of collaboration not only inside the organization but also with suppliers, partners, and society (Chen eta al., 2008).

It is obvious that collaboration affords an opportunity to organize the knowledge on sustainable development topics, thus allowing the companies to be more resource-efficient. Therefore, new product design, development and innovation must be determined by a procedure within a product lifecycle management strategy framework. A product lifecycle management strategy for NPD could be defined briefly as follows:

Mission Company supplies products that satisfy customer needs taking advantage of their innovation, quality, and sustainable production system carried out within a sustainable supply chain, and assessing all the lifecycle impacts.

Vision Data, information, and knowledge generated within the organization are managed from different perspectives of sustainable product design, development manufacturing and recycling. The company will coordinate the generation, change, and storage of all the product-relative metadata with metrics.

Objective All the driving forces involved within the product lifecycle process (internal and external) will share data, information, and knowledge about all the stages of the product lifecycle, thus encouraging collaboration among clients, stakeholders, and suppliers in order to enable product innovation.

The real problem is the cultural change of the organization and how to let everybody know the strategy. Research organizations should promote actions to build the initial blocks for changing the companies' culture. This idea can be summarized in a number of considerations that can lead us to concrete actions for today's research, applied to companies, from the manufacturing perspective that pushes the new factory.

Mainly focused on the manufacturing of discrete products, this work will define the architecture, methodologies, tools, and processes to empower product innovation in new product development management. To achieve this vision, we propose a framework that will help managers to drive the NPD process.

For this mission three basic product lifecycle stages have been defined: *Design and Development*, *Manufacturing and Production*, and Use and *Service* (Figure 1). Each stage, at the same time, has several clearly defined particular sub-stages or phases in accordance with the most relevant product and process lifecycle frameworks.

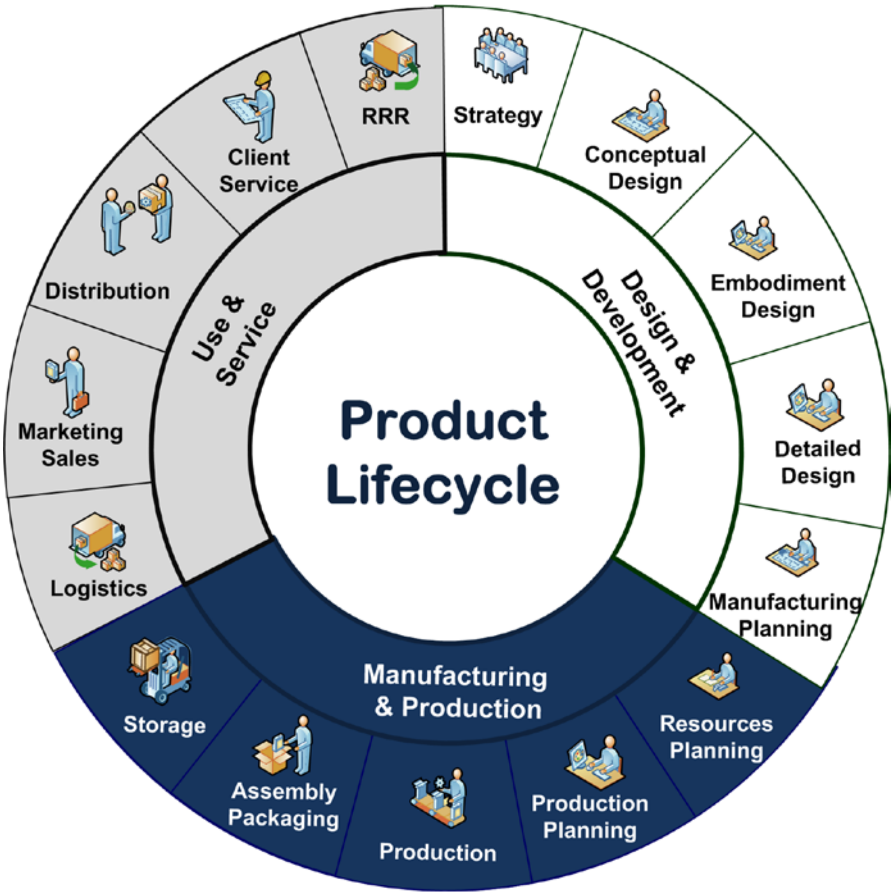

Figure 1. Product lifecycle approach.

Managing new product development projects involves detecting and solving conflicts concerning criteria, requirements, and functionalities. Each product requirement is a documented need regarding a characteristic or capability appreciated by users that is transformed in knowledge. This source of knowledge will be used as input data to establish what must be done. To achieve these objectives we will need a PLM tool that can help this product lifecycle approach and we propose to build on the framework that will help to drive innovation.

Prior to define the framework we have analysed the performances of PLM tools that can help us in this proposal. Authors studied them from different perspectives and, as a result, a brief summary of this study that has helped us to define is presented. That analysis is organized form the point of view of: Product Data Management, Decision Support Tools, Personal Data Management, Project Management, Communication and Others (Table 1).

Insert Table 1 here

4. New product innovation design framework

With all the established work previously structured and with the aim of helping NPD best practices, a model of design and development process was developed and a framework for capturing the knowledge was created in order to improve the process. A vision of the general lifecycle process is presented and, for the first stage, "Design and Development", a detailed description of the proposal is provided.

- As can be seen from the Figure 1, the Design and Development Stage has been divided into five phases: *Strategy, Conceptual Design, Embodiment Design, Detailed Design* and *Manufacturing Planning*. With this background a validation model is proposed for the design and development stage (Figure 2).

4.1. Strategy

The external environment has a significant impact on any organization that is continually evolving. That is why it is necessary to take the progress of the different factors into account, and then analyse how they may affect a company. This constitutes the strategy planning process, organizational learning, knowledge management, creativity, and their possible outcomes in new product development effectiveness, efficiency, and firm performance.

A SWOT analysis can be used to evaluate the Strengths, Weaknesses, Opportunities, and Threats. Then further actions are taken to "*Correct the Weaknesses*", "*Adapt or adjust to the Threats*", "*Maintain the Strengths*" and "*Explore the Opportunities*", which will be reflected as action plans in the CAME report.

Michael Porter's five forces (Porter, 2008) can help to make a qualitative evaluation of a firm's strategic position and then determine the intensity of competition and profitability. A Value chain model of process framework, development, customer relations, and suppliers will guide the modelling, so that the design provides the measurement of business performance and helps to execute product design requirements.

4.2. Conceptual Design

Now we focus on the Conceptual design phase. This phase has been divided into three sub-phases: *New Product Development Project Launch*, *Generation of New Products* and *New Product Concept Review* (Figure 2).

The output of the Strategy phase, "*New Product Proposal*", represents the release of development projects and, with the rising knowledge throughout the organization, the beginning of the Conceptual Design phase.

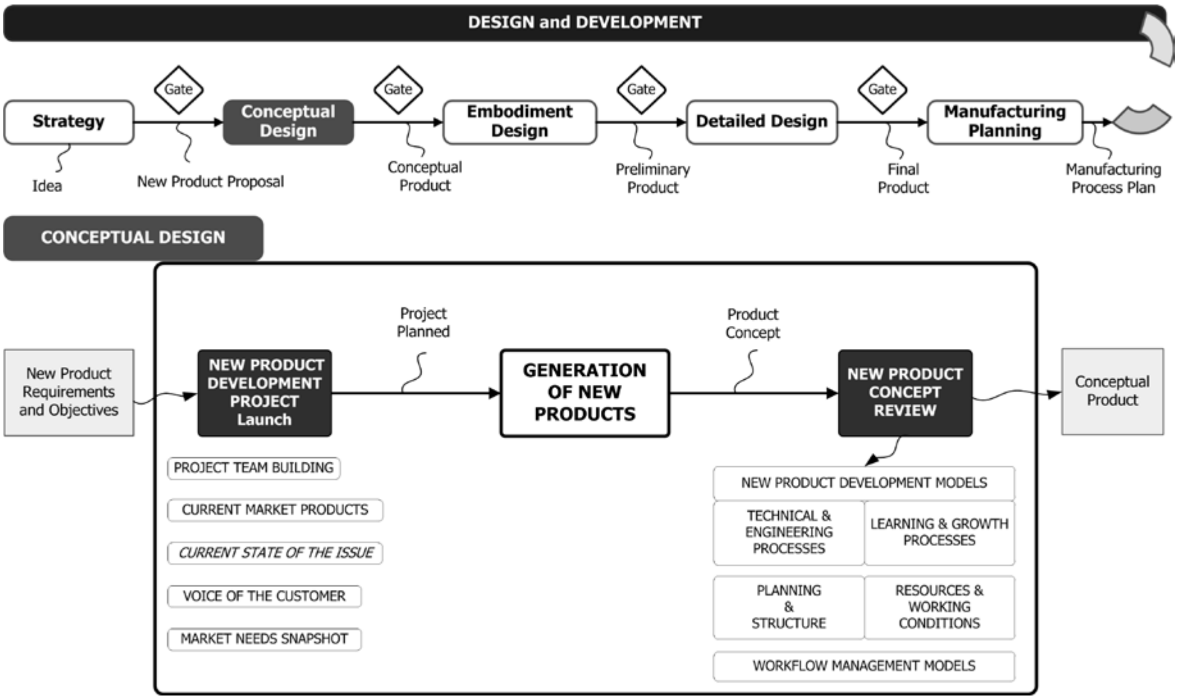

Figure 2. Conceptual Design Deployment.

The *New Product Development Project* launch sub-phase will include five activities. The first step will be to recruit a project team, and then available information would be captured and manipulated taking into account market needs, current market products, current state of the issue, and the voice of the costumer. The task output would be a development entitled *"Project Planned"*, whose documents would embody generic attributes that capture broad product capabilities.

<u>Project team building</u>. Teams are used in organizations because it is an acknowledged fact that they are able to outperform individuals acting alone, especially when performance requires multiple skills and judgments. Recruiting the right team members is a key to success as their efforts have to be coordinated in a cooperative manner toward a common objective. Recruiting competent staff from within an organization for an in-house project will involve some struggles as such employees are not easily released from performing their everyday tasks.

Current market products. Competitor analysis and the state of the issue will describe the product development process and collect previously developed solutions. A report must include an assessment of competitors' products.

Current state of the issue. To ensure innovation, a list of index cards of product-related patents must be drawn up on two levels: the first level with the more focused ones and the second with other less interesting patents.

Evaluation of technology, materials, and processes associated with the development of the product and its manufacture will require reports on technologies, evaluation of materials, manufacturing, manufacturing strategy, and supply chain.

Voice of the costumer. It is a continuous, change-oriented process that anticipates the capture of changing requirements over time in order to obtain feedback from internal and external customers, and thus provide the best quality in a product or service, while ensuring satisfaction as the fulfilment of all expectations.

It can be said to be a continuous process of learning from different groups, including current satisfied customers, current unsatisfied clients, lost customers, competitors' customers and potential customers.

It is very important to obtain typical customer structures, as we often find that only part of them constitute the bulk of the income and the costs of maintaining the others make them unprofitable.

Market needs snapshot. It aims to provide market research. Customers' current and future needs must be identified. Above all, both the needs and their importance to the user will show the preferences structure with different options and features.

The output of all these activities is a *"Project Planned"*, that is, a series of documents and key performance indicators for the project management, which will ensure that we have all the necessary elements to proceed with the creative phase of product design.

Having reached this point, the creative sub-phase called *Generation of New Products* starts with a development Project Planned (Figure 3) where it splits into two paths running in parallel, which represent current and future products.

Actual products. On the one hand, using the current state of the issue, we concentrate on the current products or, by analogy, similar solutions in other markets. The present products path of the project plan will focus on *Constraints* and on the most important *Criteria* for the *Design Concept*.

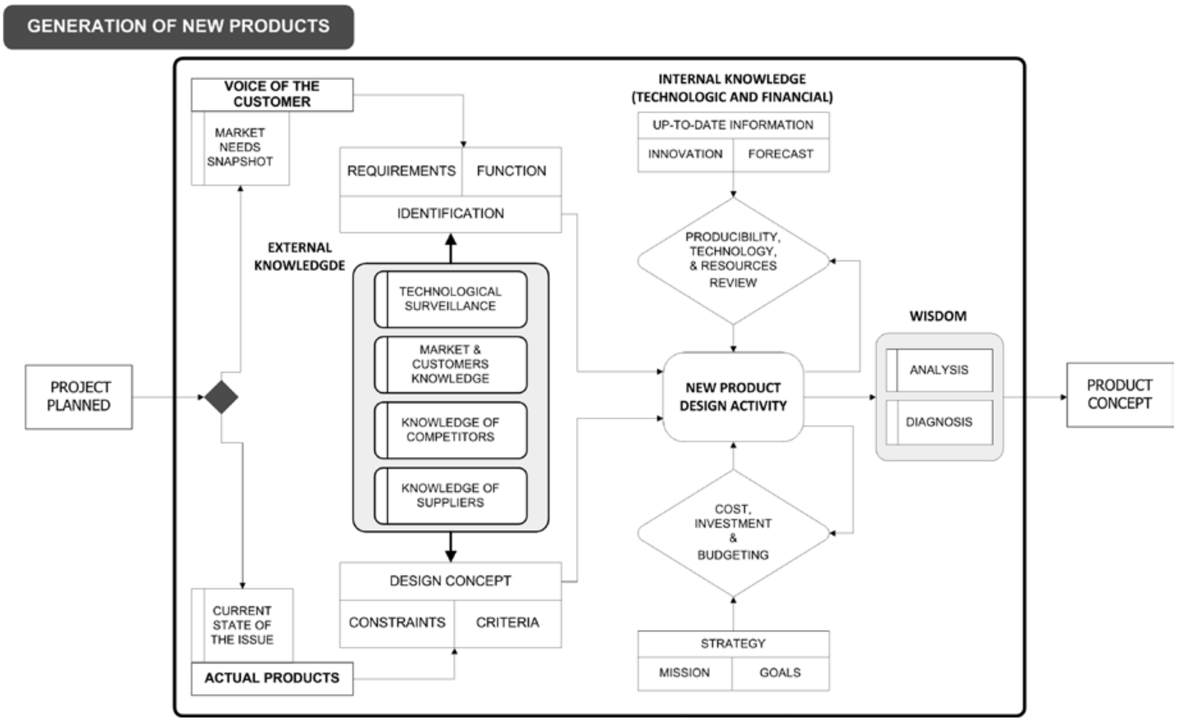

Figure 3. Generation of New Products

Voice of the customer. On the other hand, the market needs snapshot is captured from the voice of the costumer. The future products path will start a process of *Identification* of desired new *Requirements* and *Functions* for new product design activity.

External knowledge. Both *Identification* and *Design Concept* are influenced by external knowledge sources, such as *Technological Surveillance, Market & Customers Knowledge, Knowledge of Competitors* and finally *Knowledge of Suppliers* (Figure 3). Keeping these sources of knowledge up to date is strategically essential to achieve innovation.

Since these sources provide the most up-to-date knowledge, fostering its management will allow them to reach all those involved in creating new products. Computer-aided tools and schematic representation systems, such as perceptual mapping, allow extensive and complex information to be interpreted easily.

New product design activity. The new product design activity collects the documentation generated in both branches using methodologies, procedures, and tools that may depend upon the type of product. This is the knowledge that will provide the elements of analysis, verification and validation of product definition to the main features for quality and that promote the decision to purchase.

It can be concluded that the best solution in design is part of an iterative process between the different areas. The requirements give rise to interactions and conflicts in the final product. All this leads to a narrowing of the margin in the limit conditions of the whole process.

The new product design activity issues are linked to the interaction of both internal and external organization knowledge sources. This activity involves adopting a set of decisions, technical, economic and strategic, which combined with creative processes represent the product life cycle backbone sketch (Figure 4). In this figure we represent the activities that enrich the design process as part of the lifecycle and their interrelationships mainly represented by Technological Surveillance on one hand and, on the other hand, by Market, Suppliers and Competitors knowledge.

Once we have achieved a product breakdown, we will be able to apply certain validation tools, such as questionnaires, case-based reasoning, and cost-value based evaluation of users' decision to purchase.

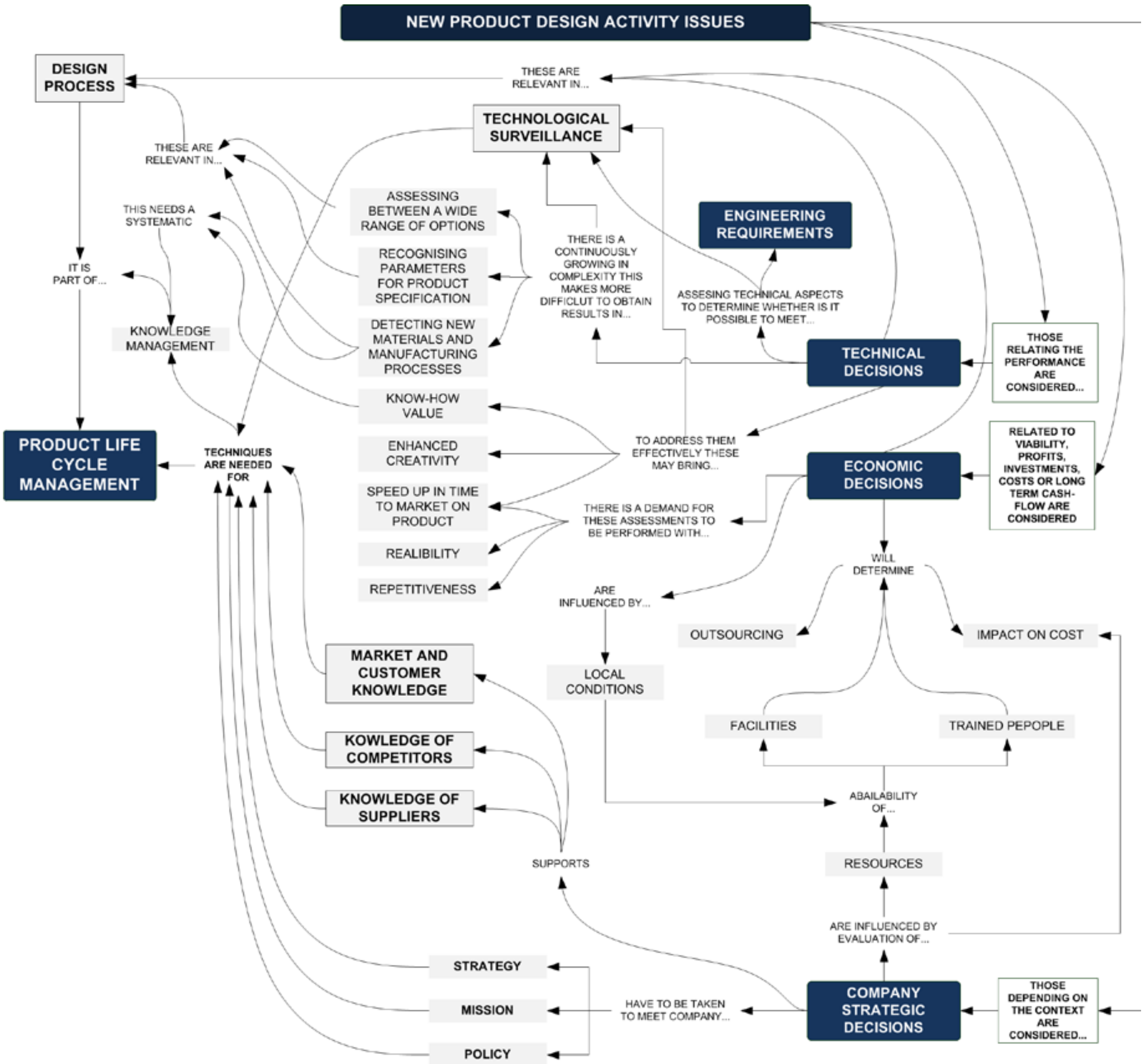

Figure 4. New Product Design Activity Issues.

Internal knowledge. At this point the internal knowledge, both technological and financial, of the organization is used.

If the technology, processes or materials are unknown, then training and experimentation should be carried out. Technological knowledge should answer questions such as: Are we capable of manufacturing the product? Do we have the material resources available and sufficient capacity at our facilities to do so? Do we know the technologies enough to deal with competitors? Do we have the trained human resources needed to ensure success? The answers obtained to the above questions have implications for costs, investments, and budgets that must be consistent with the provisions of the company's strategy, mission, and goals.

The organization inventory of knowledge has to be properly managed in order to address the design activity by suitably selecting the information. According to the organization goals or product purpose different situations can be displayed. On the one hand we have the redesign of existing products, new products, and new technologies for manufacturing. On the other we find problems more bounded purpose products as mechanical parts, engineering oriented products and design for the minimum life cycle cost techniques (Figure 5). This conceptual maps represents how during the design process technical factors as manufacturing, production and costing are considered.

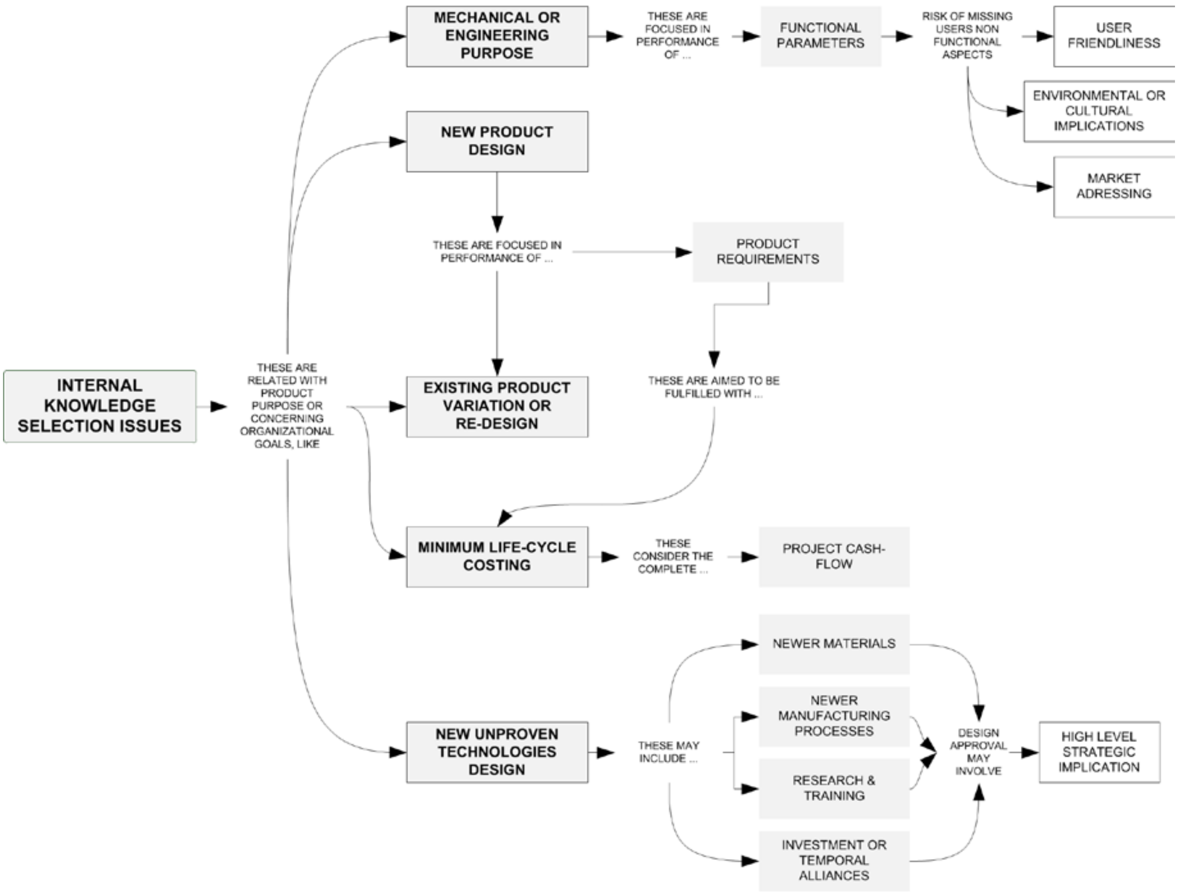

Figure 5. Internal Knowledge Selection Issues.

Wisdom activity. Once solutions have been reached, they are subjected to the filter of organizational wisdom as a system reliability study that shows, assesses, and corrects their deficiencies. It determines all the risks that could turn into events with a particular level of cost or loss of income to the company or the customer. This may be conducted through different analysis and diagnosis techniques like questionnaire-based, failure mode and effect analysis, and cause-and-effect diagrams, ensuring that solution meets the key performance indicators that have been defined. This activity must be approved by a committee and the result is a product concept.

In the ***New Product Concept Review***, sub-phase, the product concept will be discussed in greater depth in order to plan design management and workflow models. It is time to optimize the design and prepare for the embodiment phase.

The primary goal is to prevent costs due to redesign, production loss caused by uneconomic manufacturing processes or delays due to poor engineering plant lay-out, lack of materials, spare parts unavailability, maintenance and repair expenses, or any other perspective that may have been set in the Balanced Scorecard for design. The product will be compared against the goals and its measures defined in that business area. First of all, the technical and engineering processes will be addressed.

With respect to the workflow management model, planning, structure, resources, and working conditions will be analysed. The planning and structure correspond to the creation of a hierarchical decomposition of the product into its components, assemblies, sub-assemblies, and parts, with all the listed items and relationships between them combined into one master structure.

The resources and working conditions model consists in achieving an efficient and effective deployment of all means of production, manufacturing plants, machines, training, distribution, and everything that brings the product to market. Once all these jobs have been carried out, the output thus obtained is a Conceptual Product.

4.3. Embodiment Design

In the embodiment design, the project will bring together more members from different areas, and it will become necessary to set conditions of confidentiality. For each department a person in charge will be selected and rules for external participation, exclusivity and confidentiality management will be established.

The product will be described in enough detail to address the final stages of development. Specifications, sketches, presentation, and functional analysis must be adequately documented.

In this step the project plan and the deliverables needed to run it will be developed. Deliverables to be prepared include project schedule, human resources plan, budget of the phases and steps, financial plan, manufacturing or supply chain plan, alliance management plan, work breakdown structure, PDM / PLM product information structure, preliminary design of the company's marketing program and strategy for the new product.

4.4. Detailed Design

In this stage, compliance with product functionality must be confirmed as it was defined in the previous ones. Then, design of geometry, technical analysis and assessment tests will be undertaken in order to achieve a mature product that allows the configuration to be frozen.

According to this, it will be necessary to draft detailed design reports on matters such as system architecture, preliminary list of proposed materials and components (Bill of Materials, BOM), product geometry, Tolerance Analysis, CAE analysis, and the final specifications of operating in service.

Once the product configuration has been frozen, we apply DFMA (design for manufacturing and assembly) techniques, user-oriented design, lifecycle cost of the product, a comparative matrix of conceptual design and final specifications, QFD report, and product lifecycle cost analysis. By so doing, the performance of all product attributes is optimized by ensuring compliance with all the requirements specified in the previous steps and phases.

After the product has been optimized, the configuration will be confirmed in the geometry, drawings, materials, testing, and standards that must be met. It is now time to update the embodiment design product information, build the prototype, test the product, organize the support and assistance process, and, of course, ensure intellectual property rights.

The financial plan will be confirmed or its deviations will have to be adjusted. This will incorporate the product into other business processes such as marketing program development or management of the supply chain and distribution.

The financial plan, budget, and project schedule will thus be updated. There will be a report to upgrade BOM, suppliers and production resources to prepare the supply chain. Likewise, a plan will be prepared for the distribution and marketing chain.

To confirm the detailed design of the product, analytical tools and tests will verify compliance with the functional requirements, the detail of engineering models, as well as specifications and manufacturing processes, with sufficient maturity to allow the design to be frozen. Whether or not to protect the product with an industrial property title will also be evaluated.

4.5. Manufacturing Planning

The starting point of the manufacturing plan is the approval of the design, which will be accomplished by submitting it to a product approval committee. This involves collecting product information and ensuring that all details are completed as regards drawings, preliminary design data, and tests. Under these conditions the company is ready for manufacturing and logistics.

It is necessary to ensure that the detailed design data have been reviewed and approved by authorized personnel from all disciplines that have traceability on decisions. Product requirements and the expected quality service would be confirmed and fully documented.

PDM / PLM information will be released to departments, thereby beginning the preparation for the production, distribution, and support. It must be verified that the information is correct and that there are no obsolete versions from previous design stages.

A formalization of the process, which has previously been prepared concurrently, will be carried out by reporting and coordinating departments, supply chain and distribution, through instructions for initial manufacturing, distribution, technical assistance, service, and support.

At this time the project is completed when the company departments take control of the product and draft a completion and lessons learned report.

5. Case study

With the aim of validating the proposal and refining the contribution we present a case study focused on analysing design alternatives for a catamaran boating rudder. The conceptual design phase starts with the determination data, information and knowledge related to the product. This will allow people involved in the design to prepare different alternatives considering geometries and design solutions that meet functional requirements.

5.1. Current State of the Issue.

The aim of the design, development and manufacturing process of small recreational catamaran boats is to reach an easier operating ship with better performances. Although every mechanical element is important it is critical to minimise the transmission of the strength produced by wave's bumps on rudder to the ship's hull. Consequently, a key element, the rudder head system, has to be designed bearing in mind added performance, as well as corrosion, weight and production cost.

5.2. Market Analysis

Market analysis and the identification of product constraints and design criteria revealed a great number of small catamaran models existing for recreational ships. The analysis revealed that there were few different rudder head systems that could satisfy the design requirements. The process began with the study of the designs and all the patents were analysed. The most up-to-date patent was identified as the patent US004372241 (February 8, 1983) "A rudder assembly for sail boats".

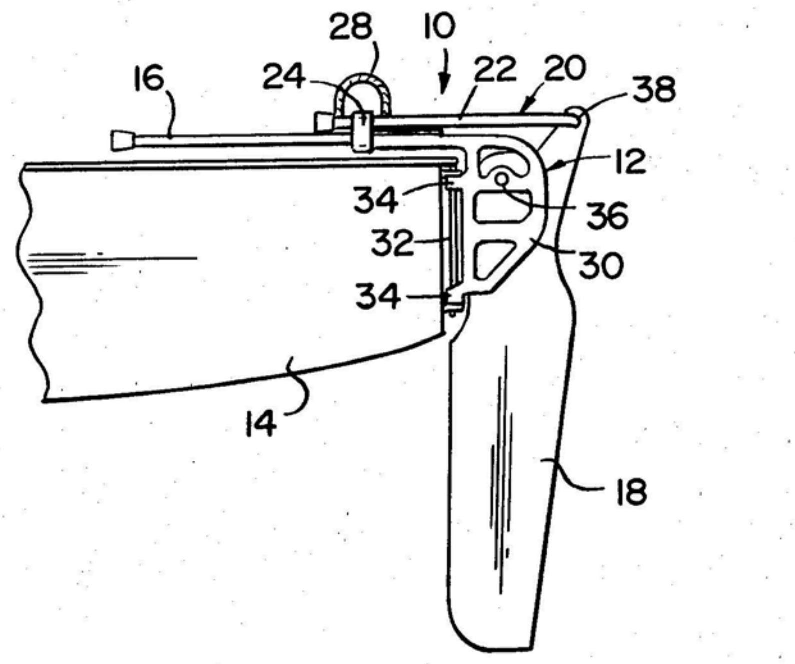

Figure 6. Patent US004372241.

5.3. Market needs snapshot.

The next step included the definition of the functionalities and the identification user's requirements applying methodologies that use the knowledge in a transversal way (Fig. 3). All the crosswise knowledge involved in the complete product design was documented with data mining techniques. These data included the dimensions, characteristics and friction of the hulls on water, dimensions of the sails and wind load.

The case study has been focused on designing a part of medium-sized recreational catamaran boats among all the different commercial sizes. In this market sector costumers demand this rudder part to be lighter and more resistant to corrosion. Besides, it is expected to be more robustness when fixing the rudder and in sail operation. One of the key features of this part is the tilt position. The flexibility of operating position between rudder tilt positions must be, at the most, thirty degrees and it is required is at least three rudder tilt positions.

Another issue was the overall operational time for the rudder head during the product life cycle. For this kind of products, the expected operating time should be, at least, more than five thousand hours of navigation or ten years.

Finally, from the manufacturing perspective, the requirements were determined from critical aspects such reducing material costs and optimising forming, surface treatments and assembly operations. The sustainable aspect of all the product lifecycle approach was also included.

With all these considerations, to establish design limitations and development criteria for the product we considered the maximum parameters such wind load, maximum thickness of the stern and aesthetics of catamaran boats.

5.4. New product design activity.

As soon as product requirements and functionalities were defined there was a deeper market analysis of the product that showed that there were different rudder head made of different materials mainly metallic.

At this step of the process the main part and the whole systems was analysed in order to determine an embodiment design from the conceptual ideas. A kinematic analysis with a Computer-Aided Engineering, finite elements analysis tool, of the rudder head assembly was applied. The examination of the system allowed us to determine the main part of the assembly and led us to focus on the rudder head (Table 2). The initial analysis performance helped us to determine the main mechanical features as it can be seen in the table.

Insert Table 2 here

5.5. Producibility review.

The design of the rudder head was analysed in terms of its function, purpose (which should be maximised or minimised), constraints (what conditions must be met) and the design variables that can be modified. During the materials preselection, prerequisites such geometrical appearance, aesthetical pleasing, thermal resistance, durability or mechanical properties were considered relevant for the final solution. The acquired data and the crosswise knowledge were used for the new calculations. The Jossel-Beaufoy method was used to get the value of distributed rudder force (Hyun-Jun Kim et al., 2012).

Following the proposed process a screening activity was conducted to analyse the material limit values under working conditions for diverse groups of alternative materials.

Those materials that did not reach the minimum requirements were rejected. Right after it was established functions aimed at maximising or minimising the material parameters that allowed methodologically classifying materials and sinking the number of material candidates. At this point the use of material databases that include properties, attributes and functionalities can help design engineers to consider alternatives that satisfy the preliminary analysis of materials and manufacturing engineering. In this case study, once used an indexed database, the first alternative pointed to a metal-based part and the second alternative suggested a technical plastic part.

Therefore, considering these two groups of materials, the geometry that is suitable for achieving the functionality and working requirements is designed. With this preliminary geometry of the part and materials alternative a simulation of working conditions is performed obtaining stress, modes of vibration and fatigue results and weak points.

The results of the analysis, considering the implicated costs, helped to adjust the materials selection process, the design of the geometry of the part and the determination of production feasibility.

5.6. Cost, investment and budgeting.

One of the most important issues when designing a part is the manufacturing cost. From the analysis of the ability of the part to be produced along with the embodiment design and the materials assessment we are able to check that the part meets functionalities as well as it is feasible from the technical and economical perspective.

In this activity, the engineering analysis includes correspondingly an evaluation of compatibility between materials and processes that will help in comparing manufacturing and production parameters so the decision-making process can be more reliable (cost-based decision). We can translate it to an ordered list of economical and sustainable manufacturing processes and operations.

Previous phase has provided a number of alternatives for materials and manufacturing processes. The current situation of the company along with their goals and objectives, will determine the choice alternatives as well as the decision to buy or manufacture.

5.7. Analyse and diagnose.

The main phase of our proposed methodology is the concurrent analysis. With the different alternatives achieved during the previous conceptual designs, we can now proceed to concurrently select candidate materials and manufacturing processes.

The final step of the decision process comes after a deep analysis of the alternatives that will lead the design to a detailed geometry of the part with a selected material and, hence, to an optimised product configuration.

During this process it has been proved that it is needed to consider all the alternatives and combinations between geometry, material and manufacturing process considering the effect on the design, as a whole instead, of making an independent design or selection of each one of them.

The next step involves the core analysis of alternative previous weighted materials with limit values, mechanical properties and features. In this case study, finally we compare the following materials, which satisfy all the requirements: cast aluminium alloy Aluminium 6063-T6, and polybutylene teraphthalate (PBT) with 60% long fibreglass.

Insert Table 3 here

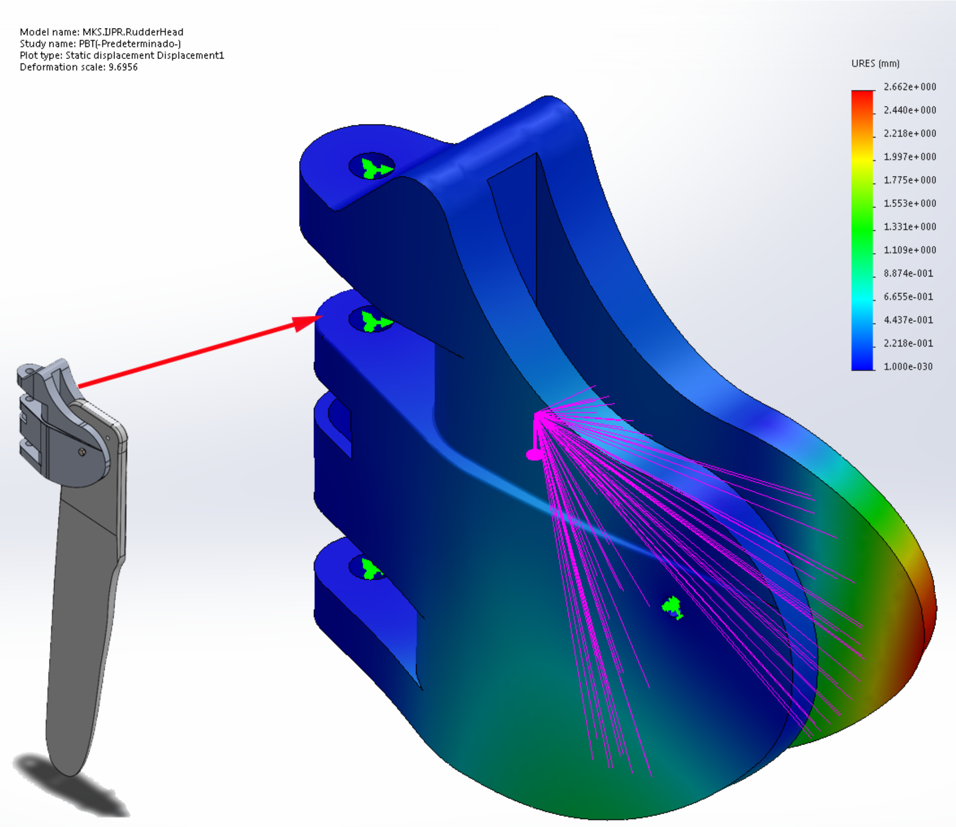

Figure 7. Case Study Embodiment Analysis.

5.8. Case study conclusions

With the previously presented case study we have tried to cover the proposed new product development framework. Within the new product innovation design framework we have tested the workflow activities and all the management issues were faced to map all the processes involved such as project kick-off, resources assignment, data sharing procedures, revision stages and decision rules. For the product development phase a prototype is needed so the technical issues can be checked and the final previous series can be manufactured.

The case study has facilitated us to confirm the proposed framework and to verify whether it is possible to reach the design objectives. We can say that the lesson learned from this case study is that, the most important action is to manage innovation and intellectual property in order to write the final proposal product documentation.

6. Discussion

Successfully develop the right product for a potential customer on time is essential to a company's competitive advantage outreach. Technological surveillance and knowledge management have become essential elements for organizations that intend to innovate. Therefore management of technological processes of new product development and innovation must be considered as a key issue. The review of related research in NPD Management and Innovation has shown us methodologies, procedures and tools to address this process. Setting the right goals, functions, requirements and using an evaluation framework make it possible screening alternatives and finally select the one with the best score or poll results.

Some of the contributions in the related research need an existing product as a starting point for improvement or redesign. One instance of this is DfX, which focuses on eliminating inefficiency in design, simplifying the structure, cutting costs and quantifying improvements. In our opinion, a framework should consider an initial starting point with a set of technical problem definitions, especially for complex industrial products.

Another common link in many of the contributions reviewed is product breakdown by distinguishing between characteristics and properties. The designer can determine the characteristics directly based on measures of their importance to potential purchasers, but the properties depend on the chosen characteristics and other factors upon which the designer cannot act. The final result is always iteration between the characteristics and properties of the product. In this way, our proposal considers all kind of iterations in concordance with the previous works confronting present and future products.

There are different philosophies of structured design, although most focus well on particular aspects of the process but do not cover, in an integrated way, every area of management, design, and innovation (Table 4). Although we have found works that focus on specific parts of the process it seems essential to establish a general perspective with differentiated stages for easy management over decision-making and budget control.

Insert Table 4 here

From a collaborative point of view, concurrent product development of industrial products with great complexity, involves recognizing customer needs, market research, product realization and its manufacture. The product innovation development must consider the most competitive products on the market while seeing the connection between the product, the manufacturing process, and sales system all over the product lifecycle and that is the final aim of our proposal.

It can be seen from Figure 4 that the proposed NPD Process involves the task of gathering knowledge in combination with an exercise of innovation with the goal of creating new things, manufacturing them and completing their lifecycle.

Considering all the summarized above, our proposed framework is enclosed within the innovative development product lifecycle. Three stages in the lifecycle have been considered: Design & Development, Manufacturing & Production, and, finally, Use & Service; following the “cradle to grave” philosophy. In our opinion, strategic planning is the starting point of Design & Development, which provides a systematic path from the early generation of ideas to the production of a new product proposal.

With this background, a validation model is proposed by splitting stages into several phases to be submitted to review and approval processes using pre-set filters or, where appropriate, by a committee. Each phase has been split into activities that include the project team itself, as well as internal or support processes within the company.

What is really remarkable from our proposal is that the framework shows how the knowledge sources influence both the state-of-the-art and the market needs so that they become opportunities for innovating products (Figure 3). Managing and keeping these sources of knowledge up to date is strategically essential.

Finally, the milestones needed to fully define and document the product have been provided. The analysis of producibility, technology and resources in combination with cost investment and budgeting, supplies a feedback path to prepare the documents for project approval (Figure 3). This is, in our opinion, another contribution from our proposal in comparison to existing models.

7. Conclusion

This paper makes a proposal for a new product innovation development framework for complex industrial products, considering the concurrent activities and its relationships all the way through the Product Lifecycle, so as to provide an accurate and precise management of knowledge sources, such as technology, market, competitors and suppliers.

In the state of the issue, regarding research in New Product Development Management and Innovation, none of the contributions took into account the Product Lifecycle view or any connection to global knowledge management strategy and resources.

We have presented a model for Product Lifecycle Management which has been divided into three stages. The first stage, Design & Development, is the one in which the product arises as an ideation concept, but is not yet properly realized. In the second stage, Manufacturing & Production, the product is still in the factory, but it is already an entity that has resources, must be planned, manufactured, assembled, and stored. Finally, when the product leaves the company, in the Use & Service stage, the processes of marketing, sales, logistics, distribution, and customer service all come into play. These processes can be structured in a variety of forms depending on the type of product or customer, and are not strictly sequential. The stage ends with the RRR (Reduce, Reuse, Recycle) phase, which constitutes the end of the product lifecycle.

The stress of this research work is upon the product Design and Development stage, where a framework proposal for product innovation has been drawn up.

Product ideation starts in strategic planning, which will identify opportunities, analyse the impact on the environment, the internal capabilities of the company itself or the possibility of strategic alliances that facilitate new business. Identifying objectives and requirements provides opportunities to create new products. This is the starting point for organizing a development team which will address the current and future market views for this new product demand. The creative phase will consider these two views (current and future), facing them to sources of internal and external knowledge. Through processes of analysis, diagnosis, reviews, and other support facilities we get the design concept. Having obtained the design concept, in the following phases the engineering machinery starts to make the final product concurrently.

In our study it is stressed that by using this framework, the NPD process is set as a long-term strategy with visible well-defined goals for the entire organization. For this reason the development of new products is aligned with the mission and strategic plan of the company. The process of identifying customers' needs and future problems is carried out in advance, so that the strategy forces consumers to participate in it.

Another point to be emphasized is that project teams interact with business or organizational support processes as predefined groups. This makes the organization adapt its structure to this purpose, with clearly predefined criteria and measures in strategic planning.

Although the organization is NPD-process oriented, this does not mean that rigidity is adopted in the process; rather, it becomes flexible with regard to the needs, risks, and particular characteristics of the projects.

The intangible assets of knowledge and know-how are incorporated into the organization's culture through the management of documentation, innovation, forecast procedures, and technological foresight, which must be visible and accessible in the company.

8. Future work

In this contribution we have presented an approach to conceptual an embodiment design within a new product development lifecycle framework. Though, it is needed to improve further aspects and the model should undergo continuous improvement and some considerations must be added to enhance the framework. Consequently, as future work we think it should be explored:

- To create templates for the different types of documents that should include data, information and knowledge that should compulsory be used.
- For the initial design phases, to include computer aided decision-support tools to enrich the creativity process.

- After a process modelling, to define working workflows and establish the connections between preliminary product designs.
- To explore the use of a balanced scorecard deployed for each stage and with different levels of information to track the improved product development process.
- To consider the integration of Knowledge management processes and tools to incorporate generated wisdom into the intangible assets.

To conclude, we would suggest to include in future works a more aspiring objective, that would be, to consider the technological and productivity issues in the embodiment design phase. This could embrace manufacturing definition and simulation that would prepare and help the detailed design and manufacturing development phase.

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