A review of strategies for knowledge management in the early stages of the product development process

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Abstract: This paper reviews the evolution of three general strategies for Knowledge Management (KM) in the context of the Product Development Process (PDP) Early Stages. The first strategy, 'storage and mapping', focused on the reuse of simple product information (Requirements, Functions, Solution Principles). Today this strategy approaches specialized forms of knowledge reuse: Decisions Taken, Best Practices and Lessons Learned during the PDP. The second strategy focuses on the 'sharing and transference' of knowledge among the PDP members. The development of Internet Portals and Internet-based systems to support collaborative work in the PDP represent this strategy. The third strategy, 'New Knowledge Creation' is associated with the use of Creativity Techniques in design, and highlights the importance of human beings as objectives of KM. It is concluded that the referred three strategies are not supposed to replace one another; and are therefore, complementary. These strategies are not static either; thus evolving according to the ever-changing business and technological environments. Finally, due to the interest boom concerning collaboration and innovation issues, as well as the availability of new supporting technologies, more research can be done in order to improve the KM in the PDP.

Keywords: knowledge management, product development process, informational design, conceptual design

1. Introduction

Knowledge Management is a business process that approaches the development and best use of the organization Intellectual Capital (data, information and knowledge), in order to improve its market performance by engendering the company good economic results as well as the benefits for collaborators. It should be considered a key part of the organizational strategy, with the aim of creating a sustainable competitive advantage in today's ever-changing business environment. According to BERGERON (2003), Knowledge Management entails a web of eight interrelated processes, as depicted in Figure 1. As a discipline, it is essentially multidisciplinary, making use of concepts from Computer Science, Economy, Sociology, Administration and Librarianship.

MOURA (2004) – based on NONAKA & TAKEUCHI (1997), and on VON KROGH et al. (2001) – analyzes the evolution of Knowledge Management general strategies during the last decades. Three main strategies are identified by the author in Figure 2. As a first step, an attempt was made to minimize the organization risk of loosing its knowledge by storing it in databases (whether physically or electronically), as well as mapping its sources. The second step aimed at sharing and transferring knowledge between/among the organization members (and even beyond its borders). That seemed to be the key for the process of transforming implicit and not well-structured knowledge of individuals (in their minds) into explicit and well-structured knowledge (organizational knowledge) as described by NONAKA & TAKEUCHI (1997) in their 'Spiral Model' for the Organizational Knowledge Creation. The third and more recent step or strategy focuses the creation of new

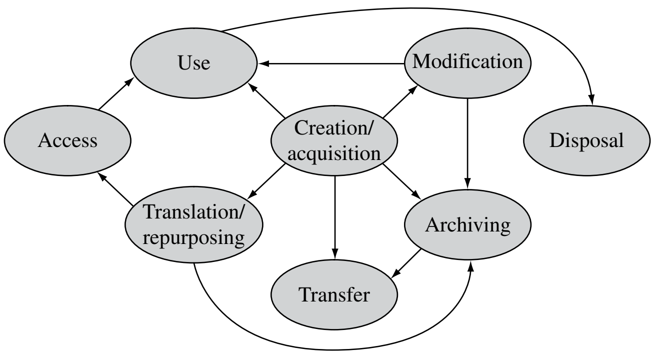

Figure 1. Interrelated processes of the Knowledge Management (BERGERON, 2003).

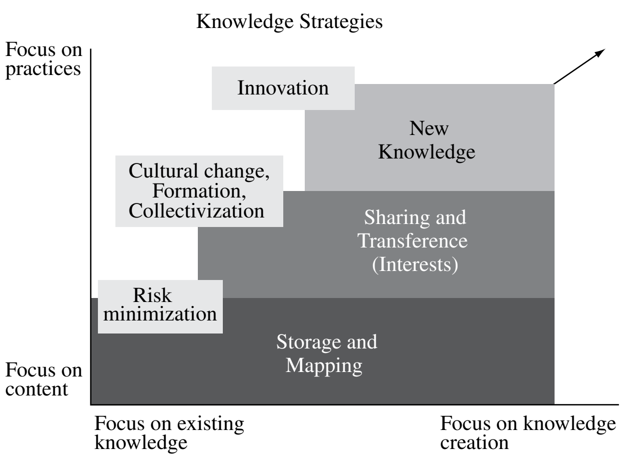

Figure 2. Strategies for Knowledge Management (MOURA, 2004, our translation and adaptation).

knowledge – in other words, it focuses innovation inside the organization.

Analyzing Figure 2, two simultaneous changes with focus on Knowledge Management can be observed. Along its horizontal axis, the focus changes from the retention of the existing knowledge to the creation of new knowledge; and along its vertical axis, the focus shifts from knowledge content to knowledge-related practices. Last, but not least, it is important to realize that the three distinct strategies presented in Figure 2 do not follow one another. Instead, they complement one another other with the aim of improving the way knowledge is managed inside the company.

This article makes use of the analysis provided by MOURA (2004) to revise the way information and knowledge related to Early Stages of the Product Development Process (PDP) – one of the most knowledge-intensive process inside a company – have been dealt with (or managed) during the last decades. These stages undoubtedly have a major influence in the success of products in the market. Final cost, quality and time-to-market are highly determined at these stages of the PDP, during which there is often a variety of possible design solutions, frequently coupled with bad information quality (very fuzzy and frequently incomplete).

The next section defines the Product Development Process and presents a reference model for it. The second section also analyses the Informational and the Conceptual Design: the Early Stages of the PDP when the design problem is clarified and a concept for the product is engendered. The third section, analyzes the evolution of the way information and knowledge concerning these PDP stages have been managed during the last decades. The last section presents some conclusions obtained from such analysis.

2. Early stages of the product development process

According to ROZENFELD et al. (2006, our translation): "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 in account the product and competitive strategies of the company, the design specifications of a product and of its production process are reached, for the manufacture to be able to produce it, and to follow the product after its launching, in order to make the eventual 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". Still according to the authors, "the product development has been regarded, more and more, a critical business process to the competitiveness of the companies, mainly due to the increasing globalization of the markets, the growing diversity and variety of the products and the decreasing of the life cycle of the products in the market. New products are demanded and developed with attributes to attend specific segments of the market, to incorporate diverse technologies, to be integrated into other products and uses, and to adjust it to new standards and legal restrictions". Figure 3 presents the Unified Reference Model proposed by the authors for the Product Development Process. This model is divided into three macro-phases: predevelopment, development, and post-development, each of which is subdivided into stages (or phases); and these, in turn, into activities. This study approaches the two first stages of development process, namely, Informational Design and Conceptual Design.

The Informational Design aims at organizing a list of objective and measurable product design specifications, starting from the product idea established during the product strategic planning, making use of a set of usually subjective and not measurable needs, mainly obtained from the product costumers. As said by ROOZENBURG & EEKELS (1995): "A design specification is a list of normative statements

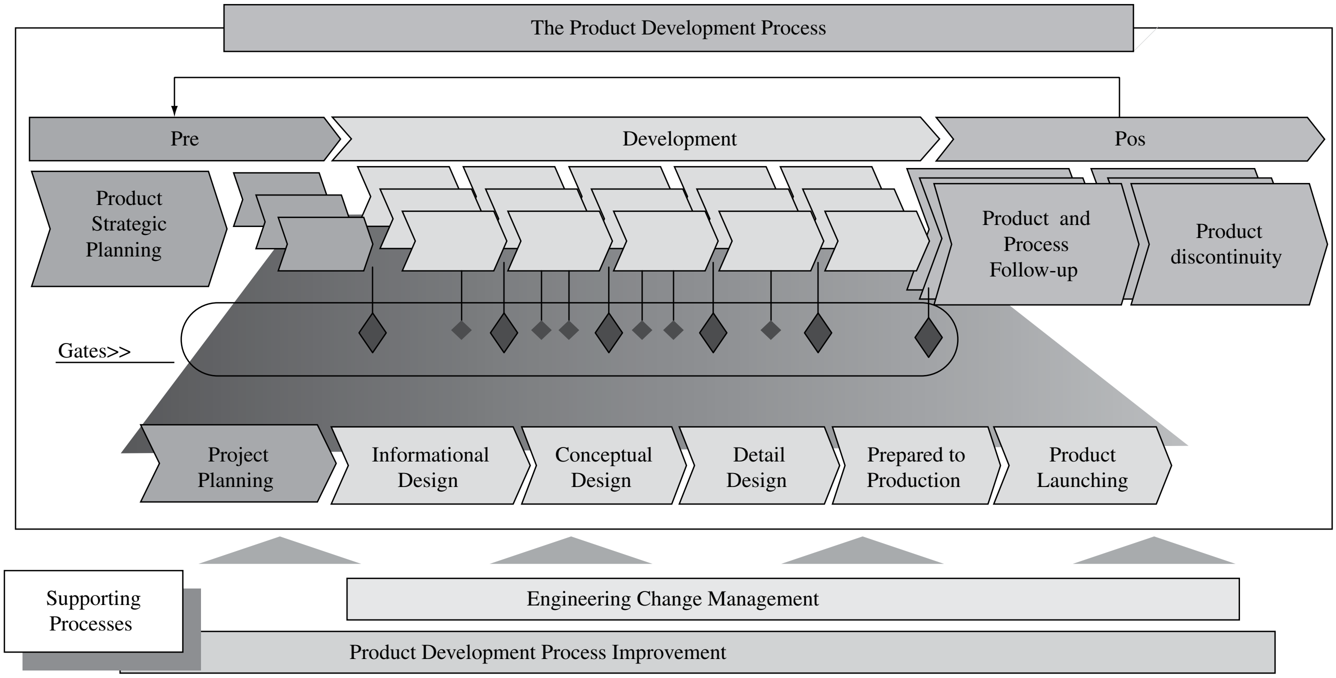

Figure 3. General aspect of the Unified Reference Model for the PDP. (ROZENFELD et al., 2006, our translation).

about the properties a new product should have, which sets limits to the solution space, and indicates which solutions are the preferred ones". FORCELLINI (2003, our translation) complements stating that: "Starting from the design specification, the functions and the requested properties for the product are defined, as well as potential restrictions regarding the designed product, and also regarding the design process itself".

The Conceptual Design is that stage of the product development process stage when concepts for the product are generated, starting from a set of costumers' needs, already clarified and converted into design specifications during the Informational Design. The development of such concepts – basically a qualitative definition for the product, usually expressed by sketches and notes – are subjected to resource limitations and design constraints. At the end of this stage, the best concept for the product is selected on the basis of the list of design specifications. Indicating a script to be followed, PAHL & BEITZ (1996) state that: "Conceptual Design is that part of the design process in which, by the identification of the essential problems through abstraction, by the establishment of function structures and by the search for appropriate working principles (structures) and their combination, the basic solution path is laid down through the elaboration of a solution principle. Conceptual Design determines the principle of a solution". According to FORCELLINI (2003, our translation): "The conceptual is regarded as the most important stage in the design process of a product, because the decisions taken during this stage affect in a very strong way the results obtained in the subsequent stages".

3. General strategies applied for the early stages of the PDP

This section analyzes the evolution of the strategies for the Knowledge Management during the Early Stages of the Product Development Process, making use of the structure proposed MOURA (2004) – as depicted in Figure 2.

3.1. Storage and mapping

The first attempts to manage information and knowledge related to Product Development Process, aim at preserving knowledge and expertise used by the organization by capturing it from people that held or manipulated it, organizing and incorporating it into databases (paper-based databases, at the beginning), for subsequent recovery and use by the other organization members. Sometimes only the information or knowledge source was stored: 'mapping strategy'. The creation of such databases was greatly stimulated in the 80's by the introduction of the Information Technologies and the first Database Management Systems into the companies. Easier organization of the information and much faster search and retrieval of the stored information are among the major reasons for adopting Electronic Database Management Systems in companies – including their product development departments.

The initial efforts to manage knowledge related to the Informational Design stage referred to the storage of information needed to write down Engineering Requirements. According to FONSECA (2002), such Product Requirement checklists – from simpler ones, such as presented by PAHL & BEITZ (1996, first German edition 1979), to more sophisticated ones, such as proposed by BLANCHARD & FABRICK (1990) – represented a fast, easy and economic approach to the creation of Target Specifications lists for the products. Still according to this author, that was an effective approach for the development of products where the interaction between the product (Technical System) and the human beings was not so intensive, as in a motor coupling or in a hydraulic pump; and also for some redesign cases, when the design team already had some expertise with the kind of product to be developed. Recently, with the increasing acceptance of the QFD in the West and use of the Customers' Voice as the main primary requirements source for product development, the importance of using checklists for the elaboration of the design requirements is actually decreasing. Alternatively, FONSECA (2000) suggests a group of structured questionnaires specially designed for the capture of needs that relate to each stage of the Product Life-Cycle (Production, Assembly, Distribution, Use, Service, End-of-Life, and so on), and also another group of questions that facilitate the gathering of such needs with the help of some product primary attributes (function, ergonomics, aesthetics, safety, environment, among others).

For the Conceptual Design stage, the first attempts to manage its intellectual assets, in respect to the storage of information and knowledge, were related to the creation of Solution Principles (Physical Effect plus Working Principle – as defined PAHL & BEITZ (1996)) catalogs to some basic design functions. ROTH (1982) and KOLLER (1985) were the two first authors to systematically catalog Physical Effects and Working Principles to a set of Basic Operations (Elementary Functions). Such Basic Operations (physical) would form a base upon which any Technical System could be functionally structured. In their catalogs, ROTH (1982) and KOLLER (1985) present several Physical Effects which enable the execution of Basic Operations, taking into account the technology to be used (Electricity, Hydraulics, Optics, and so on) – see Figure 4 as an example. These authors also offer Working Principle lists that consider the kind of flow manipulated by Physical Effects. More recently, RAMOS (1993) presented a collection of Solution Principles that can be found in Natural Systems together with their application in Technical Systems.

In the 90's, some computational systems were developed to support the designers (in their individual work) during the Early Stages of the Design Process. For most of these systems, a Design Methodology – the VDI 2221 (1987), for instance – was used as backbone, and some design tools were available by making use of previously developed information and knowledge databases. The computational system developed by HUNDAL & LANGHOLTZ (1992) also made use of a base of functions to help the designers in the functional modeling of the product – see Figure 5.

In the Production and Systems Engineering Department of this university, FIOD NETO (1993), making use of a checklist of Product Design Requirements and of a base of Physical Effects based on ROTH (1982) and KOLLER (1985), developed the SADEPRO system (to run in the DOS operating system) to support designers in the Conceptual Design of industrial products. Improving the methodology proposed by FIOD NETO (1993), DA SILVA (1995) developed the WINSAPPI system, this time developed to run in the MS-Windows operating environment. Differently from the SADEPRO system, the WINSAPPI presents a more comprehensive database of Physical Effects and Working Principles to be associated with the Elementary Functions (Basic Operations from ROTH (1982)) of the alternative Functional Structures – see Figure 6.

Some years later, in the Mechanical Engineering Department of this university, OGLIARI (1999) developed the SACRO, a system to assist the conception of new products and its further application for the development of injection molded plastic components. At the same department, FONSECA (2000) systematized the process of obtaining Design Specifications for Industrial Products and developed a prototype system to assist the design in these activities. MARIBONDO (2000) developed the SISMOD system with focus on the development of modular products. At last, FERREIRA (2002) implemented the SISCOI system, based on the systems Sacro and Sismod, previously developed by OGLIARI (1999) and MARIBONDO (2000) respectively.

More recently, the strategy to store information and knowledge, to be afterwards reused in the Product Development Process, far away from being abandoned, has changed its focus. According to SMITH & DUFFY (2001), the reuse has previously been centered on specific and standard parts; but more recently standard components are being developed to enable both the reuse of the part and the experience associated with that part. FINGER apud SMITH & DUFFY (2001) stated that designers might reuse previous designs entirely; in other words, they might reuse an existing shape for a different function, or might reuse a feature from another design. Reinforcing this view, SMITH & DUFFY (2001) consider reuse to reflect the utilization of any knowledge obtained from a design activity and not only previous designs of artifacts. In a similar way, in the Informational and Conceptual Design an attempt is being made today not only to store Engineering Requirements, Product Functions or Working Principles, but also; and particularly, some more subtle and specialized forms of knowledge, such as the registration of Cases, Decision Making, Lessons Learned, Best Practices detected on

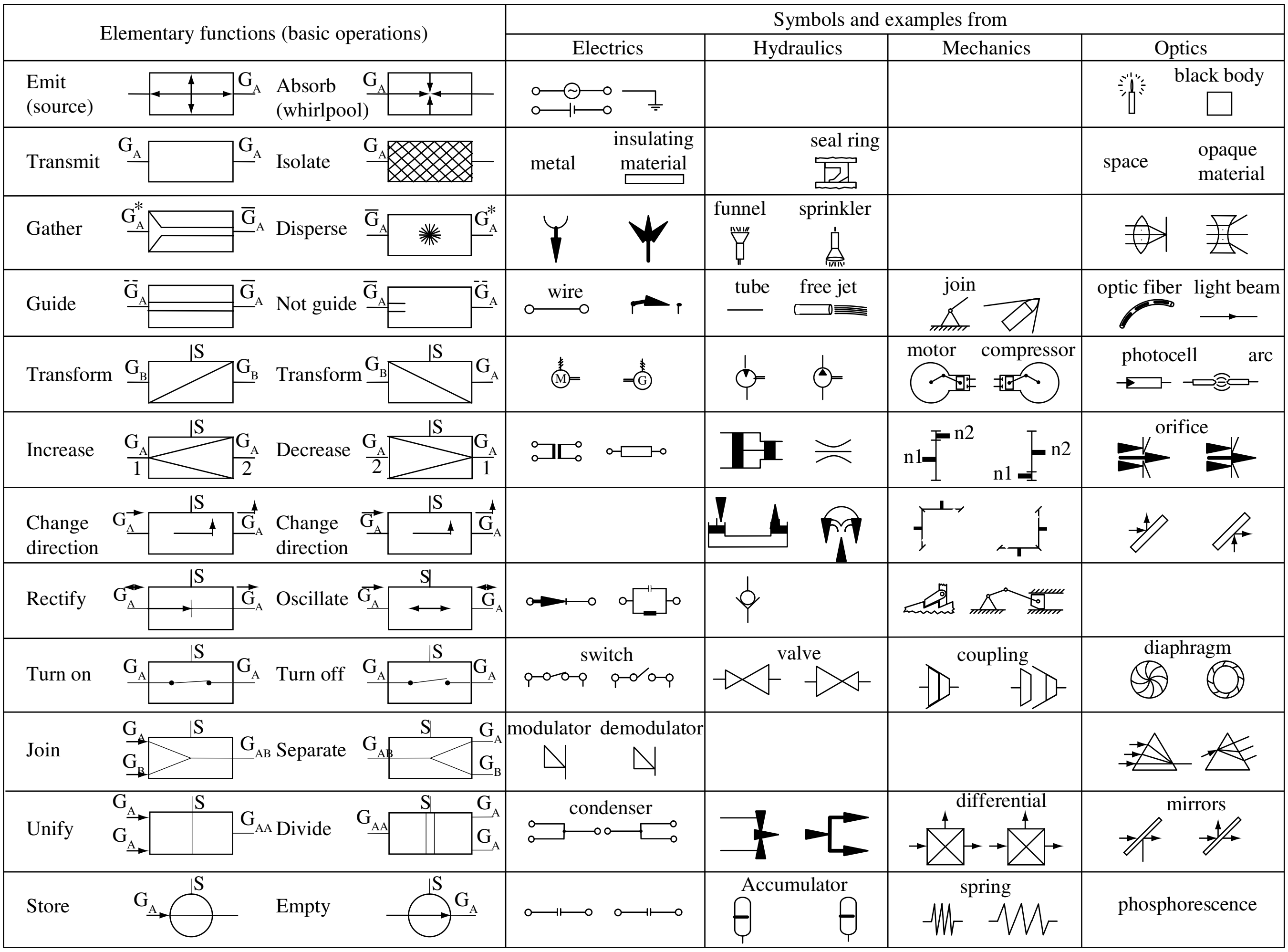

Figure 4. Examples of Physical Effects that implement the Basic Operations (BACK, 1983, our translation).

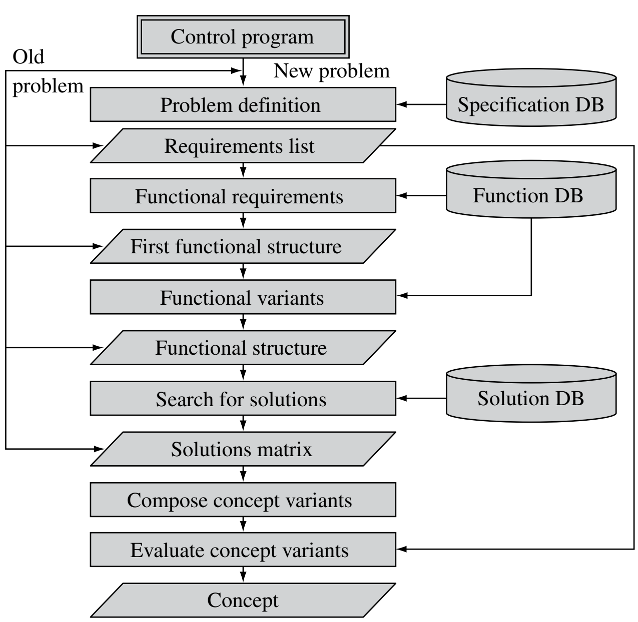

Figure 5. Computational system presented by HUNDAL & LANGHOLTZ (1992).

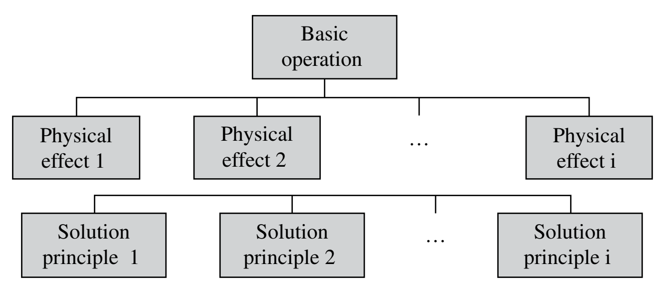

Figure 6. Hierarchical logical organization of WINSAPPI database (DA SILVA, 1995).

Product Development Process. LUCIANO (2005) has developed a new approach to the reuse of knowledge in information related to the design of friction materials for breaking systems, using Information Models and Case Based Reasoning.

As another very concrete example, COELHO (1998) has developed a work which had as principle, the learning based on cases where the designer made use of a database which has information regarding problems found in similar previous projects. For instance, when the designer has the task to specify a plug-in form or a way to hook, he can consult a data base which contains a list of stories regarding decisions taken in similar previous projects. The contained information presents the successful solutions taken, problems that may occur, corrections that had been made to improve the product and tips to prevent the recurrence of such problems. In what concerns parts injected in plastic, the formation of bubbles depends on a series of rheological parameters that had been being solved through time and registered so that new projects do not present such flaws. A description of the solutions taken, the inclusion of tips to avoid the same error to occur again and suggestions for project improvement are part of the list of suggestions. Another example is the experience acquired during the assembling process of complex products. A specialist with wide experience points out the assembly critical aspects, the order for all tasks as well as the solutions that work out better according to the nature of the product. Any designer can include new information in this database so that the volume of information and the diversity of problems cover most of the knowledge acquired over time. However, before being included in the database, the information must be taken to proof by a committee to prevent repetition, contradiction, or little significance of the information in the project environment. The searching device in this database uses key words related to the name of the part, process or problem. People are stimulated to report experiences so that the amount of knowledge increases as each new project is carried out.

In parallel to the registration of new more subtle and specialized forms of knowledge described in the last paragraph, some Artificial Intelligence (AI) systems have been employed to capture, store and use some form of 'specialized knowledge and expertise' related to the Early Stages of PDP – see SHARPE (1995). In this context, some Expert Systems – a software system with a Knowledge Base and an Inference Engine that mimics an expert's reasoning process – have been developed to assist the designers to take decisions during these Stages of the PDP. DA SILVA (1998), for instance, developed a prototype Expert System to design hydraulic systems focusing on Simultaneous Engineering aspects.

3.2. Sharing and transference

Between the end of the 80's and the beginning of the 90's, pushed by the principles of the Simultaneous Engineering and the Globalization in the World market, the main focus of Knowledge Management of Product Development Process Early Stages changed from storage and mapping of information and knowledge related to the Informational and Conceptual Design to the facilitation of the sharing and transference of such intellectual assets.

Technologically speaking, this change was made possible by the appearance of the Internet that in the 70's and 80's integrated the existing computers machines and Local Networks of the design offices. The Internet became very popular in the 90's with the emergence of the World Wide Web (or just Web). With the Web, many of the several distinct protocols of the Internet can be accessed through a single and friendly interface: the Web-browser. Due to this characteristic, and also due to its ability to work with multimedia and sophisticated programming language, the Web is today the most popular component of the Internet. According to WANG et al. (2002), the ability of the Web for designers to combine multimedia to publish information relevant to the spectrum of the design process, from concept generation and prototyping to product realization and virtual manufacturing, has motivated its adoption as a design collaboration tool. It is now playing increasingly important roles in developing collaborative product development systems. The Web is used by the design team members as a medium to share data, information and knowledge, and in some cases for product data management and project management by integrating the Web with the appropriate technologies.

The first attempts to share and to transfer information and knowledge of Product Design Early Stages came with the creation of Interest Groups and Internet Portals devoted to the Product Development Process. AMARAL (2001), for instance, developed the PDPnet Portal, a virtual environment for the cooperation, exchange and sharing of explicit knowledge about the Product Development Process.

In the last ten years several Internet-based Systems were developed to support the collaborative work during the design process – mainly in respect to its final stages. A few of these systems, however, focused the Early Stages of the PDP (HUANG & MAK, 1999; ROY & KODKANI, 2000; SCHUELLER, 2002; HUANG et al., 2003). WANG et al. (2002) surveyed the State of the Art of Web-based and Agent-based Collaborative Systems to support the Conceptual Design. More recently, at this university, GOMES FERREIRA (2006) developed the GEPP-net, a prototype system to support the collaborative activities of the Early Stages of the PDP. Today, the GEPP-net offers to the product development team, besides the specific design tools necessary to accomplish the Informational Design (QFD, Mudge Diagram, TRIZ, among others), a group of collaborative tools for management of PDP and some tools to support communication between the members of the design team. GUERRA (2005) is working on the development of the specific design tools necessary to accomplish the Conceptual Design.

3.3. New Knowledge

In respect to the Early Stages of the PDP, this strategy is strongly associated with the use Creativity Techniques (Brainstorming, Method 635, Delphy Method, Gallery Method, Synetics, TRIZ, and so forth) during the Conceptual Design. These Creativity Techniques, and their application to Technical Systems, have been studied since the 50's. For instance, the developer of the Brainstorming Method OSBORN (1953) synthesized the creative thinking in a seven-step model: orientation, preparation, analysis, ideation, incubation, synthesis and evaluation. More recently, with the interest boom around the Innovation issue, as well as the availability of new supporting Information Technologies, creativity has again gained attention from product development professionals as a way to improve the quality of their work.

In what concerns the TRIZ, or TIPS (Theory of Inventive Problems Solving) – a methodology, tool set, knowledge base, and model-based technology developed by ALTSHULLER (1973) in the former Soviet Union for generating innovative ideas and solutions for problem solving – FERREIRA (2002), in the SISCOI system, used the TRIZ to find creative solutions for the conflicts between Product Requirements detected in 'roof' of the House of Quality. With focus on creativity and innovation, several other researches have been developed, but it is still a fertile field for many other researches as well as for the development of supporting systems for Knowledge Management in the Early Stages of the PDP.

4. Conclusion

The first attempts to manage information and knowledge related to the Product Development Process (including the knowledge concerning its early stages) precede the interest boom around the Knowledge Management issue. It precedes even the introduction of the computers and the Internet in the product development environments. The need to maintain and disseminate the existing knowledge around the organization is, in fact, something inherent to all the existing processes inside the organization. Figure 7, summarizes the strategies, and respective approaches, for the Knowledge Management in the Early Stages of the PDP. The three general strategies proposed by MOURA (2004) are also presented here.

It is important to poimt out that the three strategies do not replace one another; they rather complement each other. A KM system applied to the Product Development Process should in fact cover the three strategies proposed by MOURA (2004): storage of existing knowledge, whether simple or subtle and specialized, with the help of computational databases; sharing and transference of knowledge, with the help of interest groups, intranets, portals and web-based

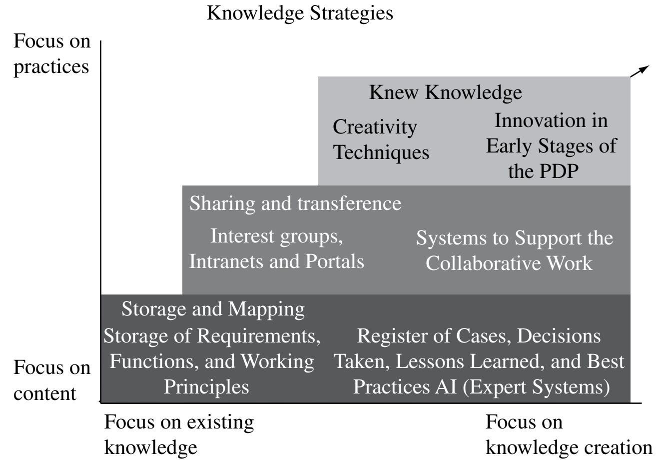

Figure 7. Strategies for the KM in the Early Stages of the PDP.

collaborative systems; and creation of new and innovative knowledge. Furthermore, these three strategies are also not static, but rather evolve according to their ever-changing business and technological environments.

In respect to the third and more recent strategy (new knowledge creation), it should be pointed out that, in the last instance, this strategy means a revaluation of the importance of the human being in what concerns technology to Knowledge Management, and also to the other company business processes, such as the Product Development Process. Under a wider point of view, that concerning Knowledge Management in the PDP as a whole, this third strategy has pinpointed the concrete importance of the Early Stages of PDP to the global competitiveness of the company, since at these stages new genuine ideas may be generated and then be converted into actual innovative and successful products in the market.

This paper does not aim at covering all the research already carried out in the field of 'Knowledge Management in the Early Stages of the PDP, nor that already carried out in this university (UFSC). Instead, it aims at presenting some works that illustrate each Knowledge Management Strategy when applied to the conception of a product.

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