R & D PROTOTYPING METHODOLOGY APPLIED TO POWER AND DISTRIBUTION TRANSFORMERS

THESIS

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Chapter 1

1. Introduction

1.1 Context

The electrical energy is a resource that is used everywhere and it has played a very important role since it was discovered and developed by men. Electricity can be found in a simple light bulb of a house or in a very complicated machine for a medical diagnostic.

The production of electricity is a complicated process that involves several elements as can be seen in the Figure 1, such as a Power Plant with sub elements like Electrical Generators, Turbines, etc. Other elements of the grid are the transmission lines, power substation, transformers, etc. Getting focused into the Power Substations, one of its main elements, are the Power Transformers.

Fig.1 The Power Distribution Grid [E]

The September of 2001 events in United States caused that the electrical industry, in particular the transformer’s industry was doubtful about investing money on great projects,
causing that the demand of power transformers decreased and so the price of the low quantity of orders generated had to be low in order to be competitive between the manufacturers.

This situation caused in that time that the manufacturers had to look for cost reduction initiatives to manufacture transformers with lower prices that allow getting orders.

After 2005 began the increase of the electrical projects and with this the manufacturers received more orders, inclusive with a good utility margin.

During 2006 and 2007 the demand of orders and good margins still keeps within the electrical industry and power transformer manufacturers and this “bubble” is expected to be maintained during the next two or three years. For this reason, is very important to keep the quality in the products and the manufacturers can obtain orders and here is where the Research and Development (R & D) projects take importance, in order to design and manufacture products with a very high quality with the lowest cost possible, in other words, designing and building competitive products with respect to other manufacturers.

Some transformer manufacturers work with R & D projects with the intention of becoming a competitive manufacturer, using in the most of the cases prototypes to simulate the same conditions that can be present in a real transformer and obtaining information from them that results in the continuous improvement of the products manufactured.

There are no companies that can afford the fact of missing a generation of technology and expect to remain competitive. Adding to the pressure, innovations are increasingly crossing industry boundaries. Some companies are adept at using different technologies to create new products in order to transform a certain market. Many others are floundering because
they relay on a technology strategy that no longer works in an environment that has fast changes [Clark - Wheelwright, 1994].

Some researches on process innovation, focuses on the decision of adopt new technology, rather than the process of knowing how to use a new technology when it has been taken by the organization [Tyre, 1991].

The introduction of new technology in the companies is a complicated issue. Several factors can be involved and can affect in the context. The understanding of this factors, needs a deep analysis of each individual case [Tyre, 1991].

On Fig.2 [Tyre, 1991] we can see how the variables involved in the introduction of a new technology, can be organized in a model that shows how the inputs of the new process can be related.

![Diagram of Key factors in the management of technological process change](image)

When is necessary to get intelligence on technological innovations, the most of the companies do a bad job. They normally focus on their competitors and rely on a limited number of channels for gathering information. They miss the breadth of knowledge required.
for a technology strategy. A company must have a very sophisticated tool for picking up and analyzing the information. What most companies need is an instrument that collects information across the complete spectrum of both visible and invisible competitors [Clark-Wheelwright, 1994].

Here is the importance of the prototypes used in R & D projects, they must be selected and developed in a way that they highlight the technology strategy of the company and so, the company becomes more advanced compared with its competitors. Intelligence gathering can increase the awareness of outside technology, but to round out the strategy, companies need to be involved in cross industry R & D projects. If they have done a good job articulating demand and getting intelligence, the choice of partners and projects should be relatively easy to implement [Clark-Wheelwright, 1994].

In the most of the companies, R & D projects are driven by the Technology and Research departments, proposing projects considered “Differentiators” to improve their competitive advantages.

In these days, these initiatives are present with the intention of improving the quality of the product from an operative point of view and trying to reach also technologic advances through the use of materials with a high performance without increasing cost, which is difficult some times.

With this in mind, the NPI and NTI processes, seem to be related when they are applied for a specific project, in this case, for R & D projects, which is the idea of this work, using the Methodology proposed, to extract the benefits of every R & D project where is applied, minimizing the risks and the negative cost effects.
The intention of this thesis is to propose a methodology to develop prototypes for R & D projects, contributing on the selection of the best way to evaluate if a prototype is needed and if so, which is the best route to drive with it, in order to get valuable information from it to contribute in the best form of design a power transformer considering issues like low cost, high quality, and obviously, customer satisfaction.

This methodology is intended to be developed using as a framework the R & D and NTI processes, previous steps of the New Product Introduction (NPI) Process.

1.2 Problem definition
In the most of the companies there is a need of developing R & D and Technology projects. These projects the many times demand the validation of their concepts through prototyping. Some companies don’t have methods, prepared people and infrastructure needed to develop these prototypes and even don’t have physical space to develop and test their prototypes.

This absence of physical space, for example a Develop and Testing Laboratory, derivates on the fact that they have to use the Production plant infrastructure to develop their prototypes and this cause in some cases, delays on the projects, because the production orders have priority and prototypes have to wait for a space in the plant to be manufactured and tested.

Many companies, when they introduce new research ideas, they not only fail in getting the benefits, and they also experience leakage of human and capital resources. Some times, the difficulties in introducing new manufacturing equipment, results in losses equal or exceeding the original costs of the equipment, and the effects of this can persist per years [Tyre, 1991].
Regarding R & D projects, there is a need too in some companies of a defined a method to
develop their prototypes and how this method is implemented (process), so the intents of this
work, are to propose a Methodology for this need.

1.3 Aim and Objectives

The aim of this work is to create a new methodology to develop prototypes for R & D
projects, considering factors as follows:

- Customer satisfaction
- Quality
- Cost reduction
- Resources availability
- Technologies involved
- Manufacturability
- Standardization

With this concepts in mind, the methodology can be applied to evaluate if a prototype for a R
& D project is needed and if so, which is the way to create it an develop it.

According to this aim, the objectives of this thesis can be stated as follows:

I. To research about the different methodologies for prototypes development used
for R & D projects in the industry.

II. To explore about the different types of prototypes available for design purposes.

III. To develop a methodology to define if a prototype is needed or not and in case it
is needed, to test and simulate the real behavior of certain characteristics in R &
D projects.
IV. To validate the methodology with a particular R & D project of a transformer manufacturer company.

V. To offer the results of the validation to the company, in order to try to get their approval and implement the methodology as a useable tool in the company.

1.4 Scope

The processes that involve the conceptualization of a product can be separated in three big stages, as shown of Figure 3:

![Fig.3 Product Stages](image)

The scope of this work is to develop a methodology for R & D projects and the intention with this methodology is, for a specific and predefined R & D project, give an idea to the user about if a prototype is needed and which are the steps to develop it. The intention of the methodology is to be used for R & D projects in general for the industry, in the case of study will be applied to a project of a distribution transformer.

This thesis focuses on finding a way to develop a R & D Prototype. This way will be known later as Methodology. Also the focus will be directed to schemes where the methodology can operate, looking for the activities sequence (process) and resources needed for the method implementation.

This methodology will be validated with a case of study of a project already finished with the intention of finding improvements for a realized job.
The main intention of this methodology proposed is to finish appropriates R & D projects, using adequate prototypes, in order to help on becoming a successful company. This methodology will be validated with a case of study of a project already finished with the intention of finding improvements for a realized job.

The main values added by this thesis can be listed as follows:

- It was discovered that there is no specific method to develop prototypes for R & D projects in the industry. There are methods for prototypes of products managed in later stages of the life cycle of a product, but there was not found for R & D. The methodology proposed is a way that can be followed in order to develop a prototype for a R & D project. In this case it was applied to a distribution transformer but the method can be adjusted as needed, depends of the type of product.

- The creation of a Prototype Development Laboratory is a specific value that can be adopted by Company A or any other companies that don’t have a laboratory or research center for their R & D projects. As it was mentioned on section 1.2 the use of a production slot in a company is critical and the insertion of a R & D prototype is very complicated. The development of an R & D prototype in a laboratory like this, gives the company ability to invest time as the project demands it without the interruption of the manufacturing processes of a plant.

1.5 Structure of the Thesis

The structure of this thesis is organized in five chapters:

Chapter 1 is the introduction to the research contribution, the aims, objectives, scope of the research, and a description of the research environment of the tools used in the research.
Chapter 2 presents a literature review of the relevant areas of related work. It starts with New Technology Processes, R & D projects, Methodology and Prototype definition and types of prototypes according to different authors.

Chapter 3 proposes the contribution of the work regarding the methodology for R & D projects in the context of the problem area that the research has addressed.

Chapter 4 presents a Case of Study where the methodology proposed on chapter 3 is evaluated with a real project previously developed for Company A, and is compared with the experiences that the company had during the process of the project. The intention is to detect the strong points of the methodology proposed and to add value for future projects.

Chapter 5 presents the results, conclusions and further work.
Chapter 2

2. Literature Review

2.1 Introduction

A poor design can cost companies a big amount of money directly through attending to user calls for service and complains, and through returned goods. Indirectly costs can also be obtained through reduced sales due to poor consumer acceptance and poor product image and through the associated follow-on effects of consumer perceptions of the manufacturing company itself [Hall, 2001].

According to Alexander [Alexander, C. 1964]:
“…Every design problem begins with an effort to achieve fitness between two entities: the form in question and its context. The form is the solution to the problem; the context defines the problem. In other words, when we speak of design, the real object of discussion is not the form alone but the ensemble comprising the form and its context. Good fit is a desired property of this ensemble into form and context…”.

Most companies look to research departments for the new products when they know they need them. The new product development must fit the outline devised in the statement of corporate strategy. [Brooke - Mills, 2003].

The use of prototypes is a very important facet of the product design and development process. It can reduce the design risk without committing to the time and cost of a complete production of a certain product. Prototypes can be an effective way to compare design alternatives an aid in concept selection [Yang - Epstein, 2005].
A prototype is an early embodiment of a design concept. It can be as simple as a sketch representing design thinking or a sophisticated rapid prototyping design that is practically identical from a manufactured product. By definition, a prototype is not a manufacturing stage design [ Yang - Epstein, 2005 ].

The idea of a prototype is to give to the user something real or at least something that has the appearance of being real. The prototype makes the product real enough that the potential users can think of requirements that can be otherwise missing. [ Robertson - Robertson, 1999 ].

2.2 Technology Development Life Cycle

The bellow scheme showed on Figure 4 helps to visualize the concept of Technology Development Life Cycle. It includes first a stage of Research where ideas are generated, then investigated and intellectually protected; a concept is validated by a prototype and finally is designed and commercialized. Later, in an Operating stage, the product then can be designed at full scale and later manufactured for full production. Nevertheless, there is an “adaption link” between the stages of intellectual property protection and commercial development where the pilot - prototyping development can fit in order to complement this life cycle. This stage of concept an industrial feasibility is the validation of the concept.

Fig. 4 Technology Development Life Cycle ( Adapted from [ 1 ] A White Paper on the Technology Development Lifecycle )
The loop closes when the feedback obtained from the commercial experience of a product, is implemented in the research for the improvement of the product or the research of a new one. This part is very important and researchers must be involved until the product is launched to the market, in order to get knowledge to improvements of the product.

Taking a technology from concept through commercialization requires an understanding and an appreciation of the full Technology Development Life Cycle. Not many companies understand and appreciate the above phases in a successful way. Technology development, from concept through commercialization, is often a troublesome process. Under the best circumstances; technology development is difficult; under the worst circumstances, it is inefficient.

During the concept feasibility stage, the validation of the concept is done through the use of a conceptual prototype or pilot, using CAD / CAE tools to simulate the conditions present on the future prototype. Several runs are done to the pilot in order to get feedback before a physical prototype is developed. After this, a physical prototype is ready to be developed in order to validate the industrial feasibility of the future product. On Table # 1 detailed on section 2.3.1 later on, are included the types of prototypes known as concept prototype and feasibility prototype, both of them can be considered to validate the feasibility of the concept.

There is a technology transition as represented on Figure 5 that helps solving the manufacturing and sourcing problems before companies implement an R & D project. The beginning is the project selection phase, which consists basically on the selection and evaluation of the project. The inputs of this stage are issues such as literature, materials and market data and the outputs can be patents and the detection of a prototype of the concept.
The project execution phase can be identified as the transition between R & D and the final phase of project implementation. During the execution phase is developed the prototype and is where the technology transition is done. This transition of technology is part of the life cycle showed in figure 4 and is the link between the concept research and the commercial development of a concept that in the future will become a new product.

Finally, the implementation phase involves all the issues related with production, marketing and after sales support. It has inputs such as design and suppliers and the main output is the final product itself. This phase has close relation with quality and warehouses.

Fig.5. Technology Transition Challenge Adapted from [Sivathanu – Joshi - Srinivasa, 2002]
Figure 6 illustrates the levels and core competences of an organization. The bases of the pyramid are the main activities and operations of the business. In a medium level are the business processes and methodologies and the top are the business strategies. Practical tools are needed to align business methodologies with the principles of development of technology projects. Due to the complex nature and diversity of some projects, companies cannot reach agreement about the life cycle phases of a project [Labuschagne – Brent, 2004].

![Diagram of organizational levels](image-url)

Fig.6. Different levels in an organization, Adapted from [Labuschagne – Brent, 2004]
2.2.1 Product Realization Process

2.2.1.1 Research and Development (R & D).

The difference between a successful company and a company with failures is not how much the company spends on research and development, is mainly in how it defines it, and there can be two ways. A company can invest in R & D projects that replace an older generation of technology or the other way is to be focused on combining present technology into hybrid technologies. The first option is known as “the break-through approach” and the other one as the “technology fusion approach” [Clark - Wheelwright, 1994].

Companies need to include both the breakthrough and the fusion approaches in their technology projects. Using the breakthrough alone fails because it focuses the effort too narrowly, without taking in account the possibility of combining technologies. In the past, Japanese companies as Fanuc, Nissan, NEC, Sharp and Toray developed their own versions of technology fusion, incorporating them into their overall research and product development strategies [Clark - Wheelwright, 1994].

The R & D department inside a company is a staff function to support all the executive effort needed to create a new product or service from the original idea to the marketable result. The focus of the department’s mission is in the technical field of the industry concerned. An experienced technologist might head the department. The leader of the department would probably be an experienced engineer [Brooke - Mills, 2003].

A product and development committee is also more usual in medium and large companies; it is dedicated to screen ideas and monitor progress. Members of this committee can be from various departments of the business. They are not as representatives of their areas, they are
selected due to their ability to make strong contributions with high impact [ Brooke - Mills, 2003 ].

The companies must have a consistent technology strategy and see the complete R & D process as a continuous flow of competence-building projects and not as a series of isolated efforts. Companies with success will focus on core technical areas and gradually build technology integration in those areas, this will let them to produce the innovative products that their customers want [ Clark - Wheelwright, 1994 ].

The R & D process in the most of the companies follows a familiar path. First comes basic research, where the scientists explore a new concept. Next the scientists with specific knowledge of the research area improve the concept until they identify an application for the concept. Finally, they take the job of developing a commercial product and its manufacturing process to engineers down the factory [ Clark - Wheelwright, 1994 ].

There are several motives for initiating and conducting development research. A basic motive comes from the experience that traditional research approaches (experiments, surveys, etc.) with their focus on descriptive knowledge, hardly provide prescriptions with solutions for different kind of design and development problems. Maybe the greatest challenge for designers is how to face with uncertainties in their complex tasks. If they do seek support from research in order to reduce those uncertainties, some frustrations arise: answers are to narrow to be meaningful and sometimes come late to be useful. Designers do appreciate adequate information to create solid ideas for their choices and more timely feedback to improve their products. Moreover, developers would be helped by a growing body of knowledge of theoretical and empirical tested design principles and methods [ Van den Akker, 1999 ].
There can be two types of approaches for development research: Type I refer to an approach in which the roles of the designer and the researcher match within a specific development context. Such research usually occurs throughout the complete development cycle. In Type II, however, the relationship is more loose: the researchers do not involve in the design and development process themselves, but they study the process, with the tools and models involved, as practiced by others; getting conclusions concerning design principles of general nature [Jonassen, 1996].

Development research is normally initiated for complex and innovative tasks for which only very few validated principles are available to structure and support the design and development activities. The image and impact of the intervention to be developed is often unclear, the research focuses on doing limited but promising examples of those interventions. The goal is not to elaborate and implement complete interventions, is to develop successive prototypes that meet the innovative aspirations and requirements. The process is normally cyclic: analysis, design, evaluation and revision activities are iterated until a satisfying balance between ideals and realization has been searched [Van den Akker, 1999].

Product development performance generally is measured by the lead time to develop the product, the cost of the development effort, the cost of manufacturing the product and the quality of the product or attractiveness in the market [Krishnan - Ulrich, 2001].

Product definition, development, launch and project management methodologies are highly contingent on the market uncertainty and other environmental issues. Insights on customizing product development practices to diverse environments like small companies or
varied industries help to increase the relevance and applicability of product development [Krishnan - Ulrich, 2001].

On Figure 7 can be seen the lifecycle of a typical R & D project. The project begins with the perceived customer requirements; these proposals are screened, evaluated and selected using project selection methods with certain criteria. After that the selected project arrives to a project execution phase where the technologies and products are developed and the performance is demonstrated. The designs and technologies developed are transferred to production. After the successful termination of the design and development phase, production, marketing and sales begin to recover the investment made and to have another intangible benefits originated at the project selection stage. So, a project will become successful only if the objectives and expectative defined at the time of the project selection are reached [Sivathanu – Joshi - Srinivasa, 2002].
Fig. 7  R & D project life cycle [Sivathanu – Joshi - Srinivasa, 2002]

2.2.1.2 New Technology Introduction.

New Technology can be defined as a new product, new knowledge, or a combination of both, that meets the same functional need as a present technology. This definition permits classify new technology not in terms of its consequences but in terms of its relative similarity to the present technology. Specifically, can be distinguished between an evolved technology and a novel technology. An evolved technology has a new product or artifact based on advances of knowledge. A novel technology also has a product or artifact, but is based on a new
technology base that represents a completely new way of matching a functional need [Bas - Van der Ven, 2000].

When selecting a technology, a customer applies evaluation criteria and chooses a particular technology if it develops specific functions well. A new technology only replaces a previous one when its superiority is established. The technology selected is one that has demonstrated high performance on several issues tested by the evaluation criteria [Bas - Van der Ven, 2000].

When new technology comes to replace an existing one, it needs to be evaluated. Changes in the product are more apparent than changes in underlying knowledge, so evolved and novel technology are easily recognized as new technology. However, they tend to be evaluated with criteria in order to compare the new and old technology directly. There are evaluation criteria that are based on older knowledge, and are tailored for present technology [Bas - Van der Ven, 2000].

Research on innovations within organizations focuses mainly on the adoption and initiation stages, in order to understand first what structural characteristics increase the number of innovations adopted by a company and after that what is the position of the elite organizations in shaping pro-innovation organizational attitudes or behavior [Leonard-Barton - Deschamps, 1988].

The introduction of new technology inside plants is a complex process. Progress may be affected by some factors related to the project and its context. The understanding of these factors typically requires a deep clinical analysis of individual cases. However, in order to identify systematic patterns among projects, this complexity must be compressed into a few
standardized measures. To reach these competing demands, there can be three kinds of data: descriptive information about projects, their history and contexts through formal or informal interviews; specific data on project characteristics and outcomes through a written report [Tyre, 1991].

Manufacturing companies are becoming more globally dispersed and they are becoming more willing to work closely together in order to become or stay competitive, so it is therefore essential that information and knowledge sharing systems are able to support the global nature of interaction between companies. While Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) are starting to offer effective support for communication, it should be recognized that this support is typically in document and process management tools which provide a valuable aid to interaction between companies [Young-Cutting-Decelle–Guerra–Gunendran–Das–Cochrane, 2005].

2.2.1.3 New Product Development

New product development (NPD) or New product Introduction (NPI) is critical for companies’ performance and competitive advantages. However, it is difficult to anticipate what certain customers will value and when changes in those preferences will emerge [Liao-Hsieh-Huang, 2006].

A failure to anticipate these changes can force suppliers into a reactionary mode, where success is determined by how quickly one can respond to new desires as they emerge. Because new products take a substantial time to develop, suppliers should anticipate changes in what customers will value as early as possible [Liao-Hsieh-Huang, 2006].
New product development through technical research can be described as follows [Brooke - Mills, 2003]:

1. Identify a project or product where the company’s skills could be most profitably employed, this is the vision of the company.

2. Decide how new this product is to be or what extent it will be a modification of a product.

3. Identify a source for the required product, can be internal or external: university, research institution, consultant, etc. It is important to remember that useful outputs from such organizations will only be obtained by a narrow and clear brief.

4. Negotiate a budget with the supplier and a profit-and-loss account convenient for the company.

2.3 Prototyping

When detailed design decisions are being made and refined, the design is also prototyped to validate, fit, function and manufacturing. Typically, the company has a choice of developing prototypes sequentially or in parallel with different costs, benefits and time implications.

When a product is launched, the company decides the timing and sequence of product introduction [Krishnan - Ulrich, 2001].

The word prototype can be defined as [G]:

1. An original model on which something is patterned; an archetype.

2. An individual that exhibits the essential features of a later type.

3. A standard or typical example.

The definition 1 can be more applicable to manufacturing, where a prototype precedes the process of fabrication a product [Naumann - Jenkins, 1982].
A prototype is a physical simulation of a product, used to resolve one or more issues or characteristics during the development of the product. Prototyping communicates the visual layout and a product's look. They help the design process because they can be visually inspected, tactilely experienced, tested, modeled, varied or simply observed as a 3D object [Otto - Wood, 2001].

In product development practice, a prototype can be defined not only as a noun, also as a verb and an adjective, for example [Ulrich - Eppinger, 2004]:

- Industrial designers produce prototypes of their concepts.
- Engineers prototype a design.
- Software developers write prototype programs.

A prototype is an approximation of a product along one or more dimensions of interest. In other words, any entity exhibiting at least one aspect of a product being of interest to the development team can be seen as a prototype [Ulrich - Eppinger, 2004].

Sometimes, prototyping is suggested as a mechanism for improving the effectiveness on analysis and design of development projects [Baskerville, 1996].

It is difficult for designers to communicate in a clear form about prototypes. Can be considered as a challenge to make a prototype, which produces feedback from users, and also design questions from them. The limited understanding of design process in the companies makes the things hard to the designer to explain their prototypes, and this is because the prototypes are not self-explanatory. Clarifying what aspects of a prototype correspond to the eventual artifact and what doesn’t is the key part of successful prototyping [Houde - Hill, 1997].
The prototype model is the representation that anticipates evaluation of the design inside its operating environment. Is not another alternative representation just like written specifications [Naumann - Jenkins, 1982].

During the product development process, prototypes serve different purposes at different moments. A physical model provides the “feel” and verifies the workability in a way that can seldom be simulated in an analytical or computer model [Hundal, 1997].

A simple form of a design process can be as follows [Baecker - Buxton 1987]:

1. Collecting information.
2. Producing a design.
3. Building a prototype.
4. Evaluate the system.
5. If not acceptable, revise 2 and/or 3 as appropriate and if is acceptable, deliver the system.

A product development process more detailed, can include the following phases [Cushman - Rosenber, 1991]:

1. Product planning.
2. Design of product.
3. Tests and verification.
4. Production.
5. Marketing and evaluation.

If we look at both above definitions, both include a part of “testing or evaluate the design”.

This part of the design process is normally called prototyping [Hall, 2001].
Stanton and Young [ Stanton - Young, 1999 ], made a distinction between the types of prototypes according to the main stages of the design process as follows:

1. Concept.
2. Design.
3. Analytical prototype.
5. Operational prototype.

An analytical prototype refers to a computer-aided design; the structural prototype corresponds to a hard build prototype. The operational prototype can be referred to the design ready to be commissioned [ Hall, 2001 ].

The items to be considered to determine what type of prototype to build include [ Borysowich, 2007 ]:

- The purpose of the prototype.
- What to prototype.
- Which medium to use.
- The expected longevity of the prototype.

In the Figure 8, we can see the different stages that the development of a prototype can present [ Maner, 1997 ]. Here, we can detect the importance of a clear definition of the prototype, using techniques as Brainstorming, previously the developing process of the prototype, and evaluation stage with the users and the implement and compare the prototype with the specifications, all this procedures are previous the final stage with the customer or end user of the product.
The main goals of prototyping are the elicitation and validation of the requirements of the product and the defect prevention due to this validation. Both goals should finish into a higher quality product [Dogs - Heppner - Klimmer - Hoa Ng, 2001].

Some benefits of a prototype can be that it can be easily changed or even discarded if needed, also that it can improve the communication between customer and developer, resulting in a higher customer satisfaction [Dogs - Heppner - Klimmer - Hoa Ng, 2001].

People can be motivated to use prototypes using the argument that they are the closest approach of all quality techniques to solve design problems and thus can avoid unnecessary work. They also limit the risk of spending too much money on the development of a product [Dogs - Heppner - Klimmer - Hoa Ng, 2001].
Prototypes are also used to experiment the consequences of the customer requirements, because they give the opportunity to understand and discuss about them, and then decide on their merits. Prototyping is much more expensive than other requirements gathering methods, and is reserved for situations where: [ Robertson - Robertson, 1999 ]

- The product doesn’t exist and is difficult to visualize it.
- The end users don’t have experience with the kind of product or the technology involved.
- The end users have done their work during some time and are stuck in the way they do it, what we know as resistance to changing.
- The end users have problems articulating their requirements.
- The requirements analyst has problems on understanding the requirements.
- The feasibility of the requirements is in due.

The prototyping activity constructs simulations of a possible product, and tests these with the end users. The intention is to give them the opportunity to work with something real, and thus having a better idea of what they need to do their work. Four key activities are: 1) Write the specifications in order to have a clear idea of the requirements, 2) Prototype the requirements, to have a real representation of the requirements, 3) Trawl for knowledge, to have a deep knowledge of the structure of the requirements and of course 4) Quality Gateway in order to have an acceptance of the prototype. [ Robertson - Robertson, 1999 ].

2.3.1 Uses and types of prototypes.

Prototypes can be classified in two dimensions. The first dimension is if the prototype is physical or analytical. The first ones are tangible and created to approximate the final
product. Analytical prototypes represent the product in a mathematical way, in other words, non-tangible. The second dimension is if the prototype is comprehensive or focused. Comprehensive prototypes consider the most of the attributes of a product; they correspond closely to the word prototype and are generally a full version of the product. Focused prototypes implement only one or few of the attributes of the product [ Ulrich - Eppinger, 2004 ].

A prototype or a model can encompass a wide range of possible embodiments- from a full scale working device or 100% embodiment to an analytical model or 0% no embodiment. In the first sentence, the prototype is said to be comprehensive; in the other hand, the designer only focuses on a few features of the device at a time. A prototype that simulates the product only in size and appearance is known as mockup and its use is to verify dimensions and clearances [ Hundal, 1997 ].

There are several types or classes of physical prototypes and their planned uses can be categorized rather simply, and this category minimizes the risk during the product development process. They can be listed as follows: [ Otto - Wood, 2001 ]

- Communication: for getting feedback from users, customers, suppliers, vendors and managers.
- Demonstration: to show the compliment of the goals of the project, including milestones to customers, investors and end users.
- Scheduling/milestones: to avoid terminal cycles or force preliminary decisions for the concept development and embodiment design.
- Feasibility: to determine if the specific ideas will help and the customer requirements and needs are satisfactory and to consider unpredicted phenomena. The measurements are very important and must be recorded in order to be analyzed.
- Parametric modeling: to develop a simulation of the product. Experimentation is needed and the results can help to improve the performance.
- Architectural interfacing: to determine if the interfaces work fine, to ensure the compatibility and assembly of components, and to study manufacturing processes required and part issues.

These uses, should produce, with a proper prototyping process, several benefits for the product design team, and while they are present, a number of pitfalls of prototypes, like delaying time to market introduction must be avoided of the product [Otto-Wood, 2001]:

- Reduction of costly iterations
- Acceleration of parallel activities.
- Greater freedom and care in the resources.
- Flexibility in the product choices.

Based on some key factors, just like the kind of problem to be solved or the needs of the customer, it has to be determined the purpose of the prototype and after this, it has to be selected the prototype that best satisfies the purpose [Borysovich, 2007].

Table 1 illustrates typical purposes for each kind of prototype [Adapted from Borysovich, 2007 and Otto-Wood, 2001]:
<table>
<thead>
<tr>
<th>Type of Prototype</th>
<th>Typical Purpose</th>
<th>General Characteristics</th>
<th>When to Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Prototype</td>
<td>Analyze system approaches</td>
<td>High-level, overall vision</td>
<td>Concept</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Definition Stage</td>
</tr>
<tr>
<td>Feasibility Prototype</td>
<td>Determine feasibility of various solutions</td>
<td>Proof of concept for specific issues</td>
<td>Concept</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Definition Stage</td>
</tr>
<tr>
<td>Horizontal Prototype</td>
<td>Clarify scope and requirements</td>
<td>Demonstrates outer layer of human interface only, such as windows, menus, and screens</td>
<td>Function</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Definition Stage</td>
</tr>
<tr>
<td>Vertical Prototype</td>
<td>Refine database design, test key components early</td>
<td>Demonstrates a working, though incomplete, system for key functions</td>
<td>Later portion of</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Function</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Definition Stage</td>
</tr>
<tr>
<td>Functional Storyboarding</td>
<td>Determine useable sequences for presenting information</td>
<td>Demonstrates the typical order in which information is presented</td>
<td>Function</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Definition Stage</td>
</tr>
<tr>
<td>Industrial Design</td>
<td>Detect physical characteristics</td>
<td>They demonstrate the look and feel of the product</td>
<td>Contemporary product</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>development processes</td>
</tr>
<tr>
<td>DOE ( Design of Experiments )</td>
<td>They are focused on physical models where empirical data can be parameterized in terms of a layout or shape of the product.</td>
<td>Experimental prototypes</td>
<td>Contemporary product</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>development processes</td>
</tr>
<tr>
<td>Alpha prototypes</td>
<td>They are used to answer questions about the overall layout of the product. They are fabricated with materials, geometry and layout that are seem to be used for the actual product.</td>
<td>Same material and geometry but different manufacturing</td>
<td>Contemporary product</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>development processes</td>
</tr>
</tbody>
</table>

Table 1 Type of Prototypes and Purposes [Adapted from Borysowich, 2007 and Otto - Wood, 2001]


2.3.2 Prototyping goals

Some typical goals of prototypes, can be mentioned as follows: [Otto - Wood, 2001]

- A concept model with no working characteristics with the intention of obtaining early feedback from customers.
- A rough version of the product to visualize and brainstorm possible improvements to the final product.
- A study of the product features to refine the difficult ones.
- Functional or semi-functional models.
- A simulated review of product activities.
- Creation of a photographic model or a demonstration video for marketing issues and evaluating the use of the product.
- A study of appearance of the product.
- A tool to resolve possible manufacturing problems and process variables.

2.3.3 Prototyping cycle

In the Figure 9, can be seen that prototyping begins with a need or requirement for an experiment. Design is the activity of deciding what is going to be modeled with the prototype.

Table 1 (Continues) Type of Prototypes and Purposes [Adapted from Borysowich, 2007 and Otto - Wood, 2001]

<table>
<thead>
<tr>
<th>Beta prototypes</th>
<th>Final part production with special assembly</th>
<th>Contemporary product development processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preproduction prototype</td>
<td>Pilot production, limited capacity</td>
<td>Contemporary product development processes</td>
</tr>
</tbody>
</table>

José Gerardo Martínez Sánchez
Then the user tests the prototype and the results are analyzed, where can be the case that the prototype needs modifications. The process continues until the Analyze process ceases to reveal further requirements [Robertson - Robertson, 1999].

Fig.9 The prototyping loop [Robertson - Robertson, 1999]

A prototype can reduce costs generated by unnecessary iterations. Investing time in building and testing a prototype allows detecting a problem that would otherwise not have been detected until after a costly development activity [Ulrich - Eppinger, 2004]. This can be seen on Figure 10, taking as an example the process of a plastic injection mold. The probability of success in a conventional process is of 0.70 and in the other hand, using a prototype, the probability of success increases to 0.95.
2.3.4 Prototyping design and planning

A method of basic procedure is needed to design a physical prototype. The next eight steps procedure gives a checklist for a systematic prototype creation [Otto - Wood, 2001]:

1. Identify the purpose of the prototype based on the customer needs.
2. Document the functionality for these customer needs.
3. Identify the physical principles needed to understand the possible experiments to perform in a physical model.
4. Understand how the physical model would be measured and if these metrics are directly related to the customer needs and correspond to specifications.
5. Decide if the prototype will be focused or comprehensive, scaled or real geometry and produced with actual materials or not.

6. Evaluate if a rapid prototyping technology can be used and if so detect which technology is appropriated. If not, what other fabrication methods can be used.

7. Consider alternative prototype concepts, based on the product concept; consider aspects like cost; appropriate scale and alternative build plans and develop a fabrication process plan.

8. Clarify how the prototype would be tested and identify the factors that would be controlled to minimize experimental errors. Define how many tests would be realized and how they would be conducted or replicated and if the tests need to be destructive or nondestructive.

Figure 11 shows an example of a kind of format that can be used for the design and planning a physical prototype, involving all the aspects mentioned above.

<table>
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<tr>
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</tbody>
</table>

Fig. 11 Example of a format for design and planning a prototype [ Otto - Wood, 2001 ]

2.3.5 Risk Analysis for Prototyping.

Risk analysis can support the management of a prototype, providing a framework for determining priorities, resources or activities during the course of a prototyping project. The
interaction between the two main activities in Figure 12 illustrates the essence of prototyping project management using risk analysis. The control of the project is influenced by interplay between risk analysis circles and prototyping circles in which different methods or strategies are used. A risk analysis evaluates the situation of the project and proposes relevant resolutions strategies, which can be used as a base for the prototyping circle and so a new version of the prototype can be developed and evaluated. The expertise obtained through the prototyping circle then forms the basis for the next risk analysis circle [Baskerville, 1996].

Risk analysis in prototyping enables collaborative expression of a subjective evaluation of the situation. The analysis of the risk shall begin with an unstructured brainstorming session with the intention of formulating the initial risk inventory. Extensive lists must be avoided since they can interfere with the creative process. When the team has exhausted their intuition, checklists are helpful to structuring the discovery of the final finding of risks [Baskerville, 1996].
2.4 The match between Prototyping and Development Projects.

Different factors can make a well-conceived traditional approach become a prototyping attractive and appropriate. A number of variables associated with different types of projects determine what pattern of prototyping choices will be the most effective. A key opportunity for management is to match the details of the design-building cycles with the requirements of each specific development project. In order to match this, an understanding of the characteristics of different prototyping patterns and the decisions that determine them is needed [Clark - Wheelwright, 1993].

There are three critical characteristics of the project’s environment that determine the appropriate dominate orientation of the prototyping process. These characteristics are: [Clark - Wheelwright, 1993]

a) The importance of advanced, innovative technical developments in driving superior product performance.

b) The importance of a balanced, total system solution to customer choice.

c) The importance of manufacturability (i.e., manufacturing cost and reliability) in competition and customer decisions.

When one of the above characteristics dominates a project's environment, the pattern of the prototype must adapt to it. Three kind of projects can be defined as follows: [Clark - Wheelwright, 1993]

- **Technical Breakthrough**: Achieving superior technical performance is the goal. Prototyping focuses on rapid service and quick turnaround to provide engineers with timely and effective feedback. Due to product pushes the state of the art; design
specifications are not frozen and remain flexible until customers have had a chance to test several versions. Control of the prototypes belongs to engineering until very late in the program and issues of manufacturability have less concern than product performance. The criteria for testing are related to technical performance.

- **Platform System**: In this “next generation” project, the essential issue is product architecture and the behavior of the product as a complete system. Prototype focuses on team learning and representativeness. Control of prototypes rests with the team doing the platform project, and testing criteria belongs to the system’s performance. Specifications are established early in the program, but are allowed to be adapted later, causing derivations in the versions of the product.

- **Incremental Refinement**: In this project cost and reliability are the objective. The new product is based on an established platform. The importance is a major improvement in manufacturability. Prototyping focuses on early involvement and input from manufacturing. The quality of prototypes is the primary performance dimension used to evaluate the prototyping activity. Design engineers play a basic role in these projects, but control over prototypes passes to manufacturing relatively early in order to take care of concepts as cost and reliability.

There can be defined three prototyping patterns [Clark - Wheelwright, 1993]:

- Rapid Response to Engineering
- Integrated System Solution
- Replicate Manufacturing Early

Table 2 summarizes the prototyping patterns indicating the problems that may arise when projects and the mode of prototype are mismatched. The type of development project (breakthrough, platform, or incremental) determines the most appropriate model of
prototyping. However, since most companies use the same model of prototype for all their development projects, it is useful to recognize the implications of each model for the various types of development projects [Clark - Wheelwright, 1993].

<table>
<thead>
<tr>
<th>PROJECT TYPE</th>
<th>Model I: Rapid Response to Engineering</th>
<th>Model II: Integrated System Solution</th>
<th>Model II: Replicate Manufacturing Early</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakthrough (Technical)</td>
<td>- Creative, innovative results</td>
<td>- System focus causes technical compromise.</td>
<td>- Slow turnaround; late introductions.</td>
</tr>
<tr>
<td></td>
<td>- Fast response enhances feedback</td>
<td>- Complexity and uncertainty slow down technical work</td>
<td>- Engineers out of loop.</td>
</tr>
<tr>
<td></td>
<td>- Manufacturing in late performance and features</td>
<td>- Constraints of system limit innovation</td>
<td>- Performance suffers, leading to many late engineering changes.</td>
</tr>
<tr>
<td></td>
<td>- Easily overcome problems with manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platform (New Architecture)</td>
<td>- Technical focus skews architecture, hurts balance.</td>
<td>- System focus achieves clear interfaces.</td>
<td>- Manufacturing focus hurts design balance.</td>
</tr>
<tr>
<td></td>
<td>- System performance suffers in field leading to design revisions.</td>
<td>- Team learning leads to early design.</td>
<td>- Performance inadequate, leading to late design revisions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Team control facilitates communication, eliminates late design changes.</td>
<td></td>
</tr>
<tr>
<td>Incremental (Stable Architecture)</td>
<td>- Lack early manufacturing involvement.</td>
<td>- Team approach is overkill; complicates project.</td>
<td>- Early involvement solves problems in design.</td>
</tr>
<tr>
<td></td>
<td>- Late revisions required for manufacturability</td>
<td>- System focus leads to late revisions because of technical (processing) problems</td>
<td>- Smooth ramp-up</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Enhanced reliability and cost performance</td>
</tr>
</tbody>
</table>

Table 2. Matching three patterns of prototyping and three types of projects [Clark - Wheelwright, 1993].

Matching the mode of prototyping, basically the focus, criteria, control and pattern of functional involvement, plays a critical role in improving development performance. No matter what type of project, certain practices and characteristics, such as quality, timeliness, efficient use of materials and processes, can contribute to superior performance. But
dimensions of control, involvement and criteria represent critical options that drive the behavior of the prototyping system. Prototyping represents a significant tool for managing development projects, and changing the prototyping process represents an important tool for improving development performance [Clark - Wheelwright, 1993].

2.5 Examples of Schemes for Prototypes Development and Research Centers.

2.5.1 GE Global Research Center (GRC)

GE Global Research has been the cornerstone of GE technology for more than 100 years. They are one of the world’s largest and most diverse industrial research labs with a presence that spans the globe [H].

They have more than 3,000 of the best and brightest researchers spread out at four multidisciplinary facilities around the world. Headquartered in Niskayuna, New York, they also have facilities in Bangalore, India; Shanghai, China; and Munich, Germany. They’re delivering the innovations and breakthroughs that are driving growth for GE’s businesses and revolutionizing markets [H].

GE Global Research is made up of 10 global laboratories organized by scientific disciplines, all focused on leveraging our technology breakthroughs across multiple GE businesses. Each labs crosses geographic borders where people from the US, Europe, China and India collaborate and build on each other’s successes. Their goal is to develop the breakthroughs that will enable GE businesses to differentiate themselves in the market and win with customers [H].

Their labs all around the world are:

- Biosciences
- Ceramics & Metallurgy Technologies
- Computing & Decision Sciences
Electronics & Energy Conversion

Energy & Propulsion Technologies

Imaging Technologies

Material Analysis & Chemical Sciences

Material Systems Technologies

Micro & Nano Structures Technologies

Polymer & Chemical Technologies

Niskayuna, N.Y. Headquarters is the home base for GE Global Research and serves as the hub of the GE rapidly expanding operations, and includes more than 1,900 employees representing all areas and disciplines of science and technology [H].

With more than 1,900 people at the Niskayuna, N.Y. Headquarters, virtually every scientific and technical discipline is represented. There are chemists, physicists, electrical and electronics engineers, microbiologists, metallurgists, information technologists and everything in between. People of different disciplines work on teams together to develop technologies in areas like electronic systems, alternative energies, biosciences, nanotechnology and polymer materials [H].

The Niskayuna GRC is in the final stage of a $100 million renovation that has added a new building wing to house their emerging nanotechnology and biosciences programs as well as state-of-the-art labs and prototype development centers. They also have modernized conference facilities, making the Niskayuna campus truly a place where GE’s businesses and customers can be together with Global Research technologists to discuss technology and drive the next innovation breakthroughs [H].
2.5.2 Nippondenso

Nippondenso, a Japanese company world leader in the automotives supplier industry, manufactures radiators and alternators, has an internal eight-year development cycle for R & D. At the beginning, the supplier’s engineers establish targets for parts characteristics (size, weight, performance, etc.), generate many ideas and by the end of first year, create prototypes. These full or partial prototypes are used for the engineer’s ideas. Next is further development by combining partial prototypes, modifying and improving designs and adding new ones. Nippondenso experiments extensively but also relies heavily on charts, graphs, test data, past experience, and professional judgment in order to decide which design will continue. Four years of developing, about three different designs stay, with five prototypes each one. By the end of fifth year (three years from start full production), the engineers are fairly confident about one design. Figure 13 illustrates the converging process [Ward – Liker- Sobek, 1995]

![Diagram of Nippondenso’s R & D Process](image-url)

Fig. 13 Nippondenso’s R & D Process [Ward – Liker- Sobek, 1995]
2.5.3 Centre for Power Transformer Monitoring, Diagnostics and Life Management

The Centre for Power Transformer Monitoring, Diagnostics and Life Management (CPTM) has been established under the Science, Technology and Innovation (STI) initiative of the Government of Victoria, Clayton Campus located in the Monash University (Melbourne, Australia), The Centre is funded by the State Government and a consortium that initially consisted of Monash University and 12 power industry companies [A].

The primary objectives of the Centre are to develop new technologies, computer algorithms and equipment for monitoring, diagnostics and life management of power transformers. Other activities of the Centre include studies into vegetable oil for power transformers, winding looseness detection, thermal and moisture modelling of transformers, and providing training and consulting services to the industry [A].

The Centre comprises three laboratories: Electric Power Research Institute (EPRI) [D] Project Research Laboratory, Power Transformer Monitoring & Diagnostics Research Laboratory, and the new Transformer Testing Facility. The EPRI Project Research Laboratory supports research investigations into the effects of moisture and gas dynamics on the performance of oil-paper insulation systems of large power transformers. Sophisticated test rigs are available to precisely simulate conditions present in real transformers, so that new means to monitor these conditions in the field can then be developed [A].

2.5.4 Centers of Technology & Prototyping Development in Mexico

a) Manufacturing processes and prototyping:

- Centro de Ingeniería y Desarrollo Industrial (CIDESI)

CIDESI is a self-sufficient world-class institution located in Mexico, with offices in Queretaro and Monterrey, dedicated to technological research and development
offering products and services in both the domestic and international market places. They have highly trained, committed personnel, with an orientation to customer service. Operations are carried out in state of the art facilities with advanced design and operations control systems [ B ].

- **Centro de Tecnología Avanzada (CIATEQ)**
  
  CIATEQ is a public center of technology research that through the design and development of products, processes, systems and human resources forming, creates to their customers and associates. Their specialty areas are the process equipments, research, specialized machinery and manufacturing processes. They have facilities in Queretaro, Aguascalientes y San Luis Potosí [ J ].

b) **Materials development:**

- **Centro de Investigación de Materiales Avanzados (CIMAV)**
  
  CIMAV is an institution integrated into the Sistema Nacional de Centros Públicos (National System of Public Centers) that Achieves scientific investigation, technological development and human resources development in Materials Science and the Environment with the criteria of excellence to stimulate regional and national sustainable development of the social and productive sector. Their facility is located at Chihuahua [ K ].

- **Centro de Investigación en Química Aplicada (CIQA)**
  
  The research of CIQA is oriented to the development of new polymer materials need for new applications. The research groups focus to the areas of polymer synthesis, polymer processes, advanced materials and plastic processes. The main industries they work with are petrochemical, biotechnology, automotive, electric-electronics, food and environmental. They are located at Coahuila [ L ].
c) Electrical development:

- Instituto de Investigaciones Eléctricas (IIE)

IIE promotes and supports the innovation through the applied research and technological development with value added in order to increase the competitiveness of the electrical industry. It is an institution that groups recognized scientist and technical whose results add benefits to the electrical industry. They also contribute to the environmental care and the sustainable development of the energetic sector. They are located at Morelos [M].

d) Mathematical Models:

- Centro de Investigación en Matemáticas, A.C (CIMAT)

CIMAT is oriented to scientific research under schemes of excellence. This has led to the integration of a critical mass of groups of high scientific performance. The center has thus become a development nucleus in growing consolidation. It is also devoted to the generation, transmission and application of knowledge in specialized sectors, as well as to the formation of high-level human resources in the areas of Pure Mathematics, Probability and Statistics, and Computer Science. They are located at Guanajuato [N].

2.5.5 Case of an Electrical Manufacturer Company.

Many companies have developed the prototyping concept in different ways, based on internal standards or even external standards of manufacture. Between 2001-2002, an electrical manufacturer in Mexico used to have a department dedicated to develop projects, focused on a material cost reduction strategy. One part of their process was dedicated to the prototypes development for these projects.
The objective was to define the way for develop and control the partial or complete changes required in the design and the introduction of new materials or components, using a physical or virtual prototype for each specific project, including the mode for elaborate the prototypes since its conceptual stage, a methodology for risk analysis and the control and planning of the changes required for the design and testing information.

The efforts were good, but for indeterminate reasons this department was dissolved in the company. The process was a previous step of what, in our days, this company uses as a development strategy: The New Product Introduction (NPI).

2.6 Summary

An incorrect design can cost companies lots of money directly through attending to user calls for service and complains, and through returned goods. Indirectly costs can also be obtained through reduced sales due to poor consumer acceptance and poor product image.

The importance of the Technology Development Life Cycle is critical in a company that interacts with R & D projects involved with prototypes. Technology Development Lifecycle includes first a stage of Research where ideas are generated, then investigated and intellectually protected, a concept is validated and finally a prototype is designed and commercialized, there is an “adaption link” between the stages of feasibility validation and commercial development where the prototyping development can fit in order to complement this lifecycle.

A prototype is a physical simulation of a product, used to resolve one or more issues or characteristics during the development of the product. Prototyping communicates the visual layout and a product’s look.
Prototyping is a very important facet of the product design and development process. It reduces the design risks without committing to the time and cost of a complete production of a certain product. The idea of a prototype is to give to the user something real or at least something that has the appearance of being real. There are several types of prototypes and depending the project will be the type that will be selected according the needs specified.

New product development can be described as the identification of a project or product where a certain company’s skills could be most profitably employed, according to the vision of the company. New Technology can be defined as a new product, new knowledge, or a combination of both, that meets the same functional need as a present technology.

The use of a methodology shall be compared on one project with its use on other projects and also can be compared by one particular group to its use by other groups. A methodology can also be compared against other methodologies intended for similar purposes.

Figure 14 represents the importance of considering a prototype methodology in the production of a new concept or in a new technology or even in a new product, based on the technology development of the systems of materials/manufacturing used on R & D projects. The gap of the cycle is completed by this prototyping phase.
The intention of the author is to propose a method for develop prototypes of R & D project. This methodology will be explained of chapter 3.

Fig. 14 Adoption of Technology Development Life Cycle considering Prototyping (Adapted from [1] A White Paper on the Technology Development Lifecycle)
Chapter 3

3.1 Detection of R & D need

The Company analyzed on Chapter 3 and later on the case of study of chapter 4 will be known as “Company A”.

Company A is an electrical transformers manufacturer and its products are defined, developed and marketed in a very diverse and global environment. It is very important to ensure the next issues when a need is detected:

- If an R & D project is really needed and all resources are available.
- If the R & D project and program specifications are clear and in line with global market needs.
- If the R & D project is introduced only if the support infrastructure is in place (service, training, etc.).

With this in mind, it is very important the process needed to select an adequate R & D project, in order to have a big impact in the improvement of the product.

In Company A, The New Product Introduction (NPI) process has a solid presence and is managed for an Applied Technology Department. It begins with the proposal of an idea and progresses through a series of decision points to culminate in the release of a new product to the market.
3.2 Reference Framework for the Methodology Proposed

Figure 15 represent a framework of the methodology proposed, based on the literature review of chapter 2, specifically of the companies analyzed on section 2.5.

![Reference Framework for the Prototyping Methodology proposed](image_url)

Fig. 15 Reference Framework for the Prototyping Methodology proposed
3.2.1 Simplified flow chart of the Methodology proposed

![Flow Diagram for the Prototyping Methodology proposed](image_url)

Fig. 16 Flow Diagram for the Prototyping Methodology proposed
3.3 Roles

According to the Framework on Figure 15, the roles involved in the prototyping phase of an R & D project are:

- Technology Manager
- Technology Leader
- R & D Technology Leader
- Project Leader
- Working Group

According to the Framework on Figure 15, the areas involved in a Prototype R & D Project are:

- R & D Technology Department
- Applied Technology Department
- Engineering Department
- Outsourcing Company and/or Experts
- Prototype Development Laboratory (PDL)*

* New area to be created. It would include the infrastructure needed to manufacture and test R & D, NTI and NPI prototypes. Would be divided in areas depending if the prototype is Electrical (coils, core, etc), Mechanical (tank, supports, accessories, etc) or Control (Cooling, alarms, monitoring, etc), and depending the area, would have a kind of “testing banks” to simulate the real conditions that would be present in a real product. Depends of the project it would have testing equipments similar to the used on the testing labs used on the production plants. See section 3.4.1 later on.
3.4 Methodology proposed for Company A

According to the Framework on Figure 15, the 5 stages proposed for the development of prototypes of R & D projects are:

1. Prototype Definition Stage:
   
a) Once the R & D project is approved by the Technology Manager, R & D Technology Leader and Technology Leader decide if a prototype is needed, this occurs only if the Design of the Transformer needs to be modified or if it is a modification that affects a standard design. A prototype could not be required for projects where the concept is only an additional accessory of the product and no affections are needed to the design itself of the product. The prototype shall consider all the variables needed to validate the concept that will be analyzed. At this point is very important to have a clear idea if the project will have a high technology impact and at the same time if will be a feasible solution for a future possible user of the concept to be validated. The prototype shall include all the characteristics needed to prove the concept that will be validated through the tests mentioned later on stage 2 d).

   b) Technology Leader defines the quantity of prototypes needed to consider the project to be ready to be implemented. This will depend of the complexity of the concept to be validated and of the cost involved on the development of the prototype, which would be confirmed later on the cost / benefit analysis. At this stage is also defined the working group of the project and if an outsourcing company will be part of it for the development of the project.

   c) The Project Leader identifies with help from the technology leader or an expert if the prototype needs to be physical or virtual (digital) depending the concept to be validated and the tests required to validate it. Also the materials, equipments and select the company or companies suppliers required for the prototype development. It is very important to have clearly identified the key concept to be validated with the prototype, because it may be
necessary on a later stage of the project, the intervention of an expert in order to give orientation to the working group or to the outsourcing company about a possible unknown concept or concepts required for the development of the prototype.

d) The Project Leader makes a risks and benefits analysis in order to determine if the prototype is feasible, can use design tools as QFD, Parametric Analysis, FMEA, TRIZ, etc. This kind of tools can help to find possible problems, discover customer needs, detect innovation conflicts, etc.

e) The Project Leader identifies the nature of the prototype to the product categories: Electrical ( coils, core, etc ), Mechanical ( tank, supports, accessories, etc ) or Control ( Cooling, alarms, monitoring, etc ). Based on these divisions, the tests are identified later to be realized on different laboratories.

f) Depending the category selected, the project leader chooses an external research company to work with, as a part of the project team. The working group will have to develop a specification of the project including issues like technological objectives and challenges, inputs of the project and the deliverables needed from the external research company. With this specification, the external company makes a proposal of they work including their working plan. After both parts agree with this, the specification is adjusted as needed or “freezes” if no changes are done.

g) Before a physical prototype is developed, is recommended a virtual prototype of pilot in order to verify the feasibility of the concept, using tools such as CAD / CAE / CAM, see Appendix C section C.1 for a description of a possible tool for this purpose. The simulation of the pilot allows making several “runs” of the pilot, before a physical prototype is developed. The working group will interact with the external company in order to develop this simulation model in conjunction or separately, depending the complexity of the pilot.
2. Prototype Analysis Stage:

   a) The Project Leader makes an estimation of the prototype’s cost and confirms the feasibility of the prototype using a cost / benefit analysis. The technology leader approves the cost and authorizes the prototype or rejects it. This cost will help to define the quantity of prototypes that would be developed.

   b) The Project Leader and the working group make a list of the key verification points during the development of the prototype, including the manufacturing information and interactions with the external research company. A special checklist is needed on each verification point and also a minute of the relevant observations during each process.

   c) The Project Leader and the working group verify the manufacturing limitations and the specifications required in order to develop the detailed information according to this.

   d) The Technology Leader and project leader define the tests needed for the prototype. This is based on the nature of the concept is intended to be proved, this is, Electrical, Mechanical or Control and depending of this, the tests have to be defined simulating the real conditions and interactions present on a real product, considering the scale needed to represent this conditions.

3. Prototype Development Stage:

   a) The working group designs the information for the prototyping manufacture, interacting, as needed the engineering group and the external research company to review engineering concepts related with the prototype.

   b) The working group lists the information for the prototyping testing, previously defined. They have to include all the necessary tests needed to validate the concept defined, also the expected values in order to know if the tests are satisfactory.
c) The project leader delivers the manufacturing information to the plant and/or the external research company, depends of the case. This is a similar process to the one used by engineering department, delivering all the detailed drawings necessary to manufacture the prototype.

d) The project leader coordinates the manufacture of the prototype, including the inspection points needed in between the process. There will be needed special formats to control all the detected issues during the inspections, and a follow up of the pending actions will be required.

e) At the end of the manufacture stage, the working group confirms that the prototype was constructed according the information developed for manufacturing. This is the validation of the prototype since the manufacturing point of view. The drawings have to be checked against the prototype to confirm dimensions, materials and all the specified details included on the drawings.

4. Prototype Testing Stage

a) The manufactured prototype is received by the respective testing laboratory area, this is Electrical, Mechanical or Control. A test plan is needed for the prototype in order to complete all the sequence needed.

b) The prototypes testing laboratory begins the testing plan of the prototype, previously developed with the information and specifications made by the prototype working group.

c) The external research company interacts with the testing laboratory as needed, to verify that the part or process where they are involved is been tested according the specifications.

d) The testing laboratory generates a report of the results, including all the tests required and the results obtained, with a comparative against the expected valued in order to verify if they are satisfactory. In case that testing results are not satisfactory, the cause has to
be analyzed. A detailed report of the findings has to be developed in order to detect the root cause of the problem. If needed the process has to "go back" to the analysis stage # 2 and repeat the needed steps again until the results become satisfactory.

It is possible that during the validation tests of the prototype exists the possibility of having failures or problems of unknown nature non-contemplated during the definition stage. When this case is present, it is necessary to take a loop back to the analysis stage and inclusive having interaction with experts in order to find a solution of this possible problem.

5. Prototype Delivery & Recycling Stage:

   a) The Project Leader analyses with the technology leader the possibility of including the prototype into the New Product Introduction stage. The tests results are critical to decide if this is possible or if the prototype has to be modified.

   b) The Project Leader develops a final report, including all the results obtained and listing the main modifications that need to be implemented in the design information of the product where the concept validated can be included. This is necessary to close the project in an appropriate way.

   c) The R & D Technology Leader and the Project Leader propose to the Applied Technology Department leader to implement the project as a New Product. The prototype is delivered to the department dedicated to develop new products or NPI process

   d) The manufactured / tested prototype is analyzed by the working group in order to detect the possibility of being re-utilized (complete or some parts) for future prototypes of other projects.
3.4.1 Concept of the Prototype Development Laboratory (PDL) proposed for Company A.

A concept of a Prototype Development Laboratory is proposed for companies that don't have a specific area dedicated to this purposes. It is based on knowledge learned from the research centers and companies mentioned on section 2.5 of this work and in the following needs of the company A:

- There is a need of a laboratory for the technology development of Company A for improving the prototype manufacturing and assuring the success of the NPI process.
- For the last 10 years the technology department from Company A has been developed through projects with local Research Centers and manufacturing prototypes with time and resources from Company A. This work required investments of about $3.0 MUSD with important Re-Work caused by the lack of adequate resources and physical space.
- Some Research Centers from USA and Europe have successful laboratories that produce New Technology ant its implementation into businesses. Examples of these companies were explained before on section 2.5.

The main mission of this Technology Development Laboratory would be to create a specific area dedicated to prove the Industrial Feasibility of New Technology using prototypes in order to get successful R&D and NPI projects. The name of this laboratory proposed is Prototype Development Laboratory (PDL) and would be explained in detail later on this work.

A working scheme from Company A uses the different stages of an R & D project since it is identified as an opportunity until it is launched as a new product. There is a very important transition, which is the change from the Research to the Technology Development.
As it was mentioned on Section 1.4 the scope of this work, is located on the research stage, where a R & D project begins with the state of the art review, the feasibility analysis, a proposal solution and a technical and economical validation of the concept analyzed.

On Figure 17 can be seen the proposed concept of a Prototype Development Laboratory adapted from the organization levels analyzed on Figure 6 and covering the needs of Company A previously mentioned at the beginning of this section.

![Prototype Development Laboratory Diagram](image_url)
Looking at Figure 6, the base of a company are the activities and main operations. For the PDL proposed, the bases are the core competences and key facilities / tools. The middle level of a company is their processes and methodologies and for the PDL case would be the processes and methodologies. The top level in an organization is the business strategy, for the PDL would be the key businesses according to the market demand.

The core competence of Innovation plays an essential role in this PDL scheme and in the concept to be validated, because the future product has to include state of the art techniques. Time to market concept is also critical due to the concept of the product has to be implemented in a relative short period of time, due to the great advances of technology in industry. The time to market of a future product can be accelerated using tools as digital prototyping (See Appendix C, section C.1).

The PDL demands a specific area dedicated to develop the physical prototypes since the moment where the prototype is designed and defined, as stated on Stage # 3 mentioned on section 3.4. Depending on the nature of the concept, according to the prototype categories: Electrical (coils, core, etc.), Mechanical (tank, supports, accessories, etc.) or Control (Cooling, alarms, monitoring, etc.), the PDL would have specific areas dedicated to different tests according to the concept to be validated. A prototype including these 3 disciplines can be known as mechatronic system.

The full integration of the mechanical, electrical and control parts according to the type of prototype is a key issue. It is not a linear process, is a cyclic one. It is important to mention that this involves the synergy between mechanics, electronics, electricity and control systems. The system may be subdivided into simple elements to be analysed, but as part of a whole design. Having done this, the mechanical, electronic and electric parts can be modelled. [Guerra – Parkin – Jackson – Tomovic – Ramirez, 2008]
Figure 18 shows the control system in the center of the mechatronic integration, where the resulting block diagram from the control system helps in the understanding of how every part of the mechatronic design interrelate. For the diagram to be useful, the mechanic, electric and electronic components needed must be characterized. Also are shown stages for prototype, implementation and tests [Guerra – Parkin – Jackson – Tomovic – Ramirez, 2008].

As mentioned on Stage # 2 of section 3.4, the tests required for the specific prototype are defined and the PDL would need a base infrastructure in order to develop this test procedure previously defined on the prototype design stage.

According to the needs of the particular R & D prototype, the laboratory needs flexibility on processes developed to manage projects of different characteristics (machining, deforming,
molding processes, etc) and also to have the ability of develop processes for new materials and physical simulation of mechanical, thermal, electrical and dynamical effects in order to have almost real test conditions on the prototype. The PDL needs areas and resources dedicated to cover all the disciplines involved and tests required for the prototype. A good model of this type of laboratory can be the Centre for Power Transformer Monitoring, Diagnostics and Life Management (CPTM) in Melbourne Australia, described on section 2.5.3.

### 3.5 Summary

The Methodology for the NPI process in Company A is clearly defined and applied, including the prototyping stage. Their only need is the absence of a Testing Laboratory; they have to use the Production plant infrastructure to develop their prototypes. Regarding R & D projects, there is a need in the company of a defined process to develop prototypes. According to this, there is a proposed methodology for the development of prototypes according to the following stages:

1. Prototype Definition Stage
2. Prototype Analysis Stage
3. Prototype Development Stage
4. Prototype Testing Stage
5. Prototype Delivery & Recycling Stage

Based on the organization levels analyzed before on section 2.2 Figure 6 and covering the needs of Company A, it is proposed a concept of a Prototype Development Laboratory (PDL). The PDL demands a specific area dedicated to develop the physical prototypes since the moment when the prototype is designed and defined until is manufactured and tested. Depending on the nature of the prototype, according to the transformer’s categories: Electrical (coils, core, etc), Mechanical (tank, supports, accessories, etc) or Control (
Cooling, alarms, monitoring, etc), the PDL would have specific areas dedicated to different tests according to the concept to be validated.
Chapter 4

4.1 Introduction

In this chapter, a case study is developed in order to test the Methodology for the R & D Prototyping proposed on chapter 3. This case of study was taken from a portfolio of R & D projects from Company A. The methodology proposed on chapter 3, can be applied in general for any R & D prototype, in this case it will be applied for a distribution transformer prototype.

It was decided to develop a case of study using an R & D project already developed by Company A, analyzing the part of the project dedicated to validate the industrial feasibility described on figure 4 of section 2.2. It is relevant also to indicate the importance of the feasibility of the concept represented on the figure 4 of section 2.2 and it is critical to validate it with a conceptual pilot using digital tools, before to develop a physical prototype to validate a concept, as mentioned on section 3.4 stage 1 g). During the development of the project made by Company A, it was not developed a pilot to validate the feasibility of the concept, but the concept was justified in stages 2 & 3 of R & D process as is indicated on Figure 21 of section 4.4.1. Later on, it will be proposed on section 4.5.3.1 g) during the application of the methodology to the case of study, a representation of how a pilot of the product could be generated using digital tools.

This project used for the case of study consists in the development of a distribution transformer pole type with the ability of changing its transforming ratio automatically and in a remote mode using an internal electronic device with high current capacity in order to control the voltage on the user side (low voltage side) against voltage variations on the energy supply side (high voltage side). The main benefit of the transformer user is the costs reductions of the maintenance of the energy transmission lines because of the unnecessary
disconnection of the transformers, to keep stable the voltage received by the energy users. Also an increase on the energy quality is obtained.

A tap is defined as a predefined voltage level, which is obtained by selecting different positions of the winding with different ratio of turns of the coil.

The project used for the study case, was previously solved by the R & D Technology Projects department of Company A. The project was developed without following any specific methodology because they don't have any. The intention of this case of study is to analyze the development of the project using the framework and the methodology proposed on chapter 3, in order to detect the possible benefits of using this method on future R & D prototyping projects.

4.2 General description of the experiment

The scope of this experiment covers the prototype development of the distribution transformer that uses an electronic device needed to control the transformer’s tap changes required to control the voltage on the low voltage side (or secondary side) and keep it as stable as possible.

This electronic tap changer device is designed to be used in distribution transformers pole type of single phase with capacity of 25 kVA, high voltage side of 13200 V and able to keep the low voltage side regulated to a level of 127 V with a tolerance of 95%.

The control of the voltage is obtained with the interconnection of the different taps of the high voltage side (or primary side) winding using power thyristors controlled electronically [Ramírez & Leyva, 2006].
The electronic tap changer device takes voltage samples from the secondary side of the transformer and evaluates the current on the primary side of the transformer and takes the decision of which tap from the primary side has to interconnect in order to keep the voltage on the secondary side within the specified tolerance. The tap changes can be automatic or in manual mode and also in remote mode [Ramírez & Leyva, 2006].

The electronic tap changer device is divided in 2 stages: the control stage and the power stage. The control stage takes the decisions that the power stage has to execute. According to the voltage and current signals, this stage evaluates which group of thyristors from the different taps, must be triggered and the appropriate time to do this. The control stage is composed by voltage and current sensors, signal attenuate circuits, voltage comparators, a microcontroller and a remote control. The power stage is formed by an arrangement of thyristors and trip elements and its function is to drive the current flow through the appropriate tap using the thyristors connected to the transformer primary winding. All this electronic elements are mounted on several printed circuit boards (PCB). On Figure 19 can be seen a block diagram of the electronic tap changer device.
The transformer is designed to have 6 taps or voltage levels and considering that 2 taps are grouped on each PCB, a total of 3 PCB’s or plates are needed. This plates are stacked and mounted on an isolated base and then are placed into the transformer tank, just above the transformer core. So, the arrangement of the PCB’s is immersed on the oil inside needed for the cooling of the transformer. This can be seen on Figure 20 (a) [Ramírez & Leyva, 2006].
The control stage is composed of 1 PCB card in the outside part of the transformer and located inside a control box as can be seen on Figure 20 (b) [Ramírez & Leyva, 2006].

![Fig.20](image)

(a)          (b)

Fig.20  Electronic Tap Changer Device: (a) Printed Circuit Boards inside the transformer (Power Stage) and (b) Control Box with the PCB inside (Control Stage) [Ramírez & Leyva, 2006]

The oil used for cooling standard transformers is mineral oil. This was the intended oil to be considered originally but, as detailed on section 4.4.5 b), the prototype changed to the alternative of using vegetal oil instead.

4.3 Defining product requirements.

The product requirements are provided by Company A and the end users of the transformer and mainly is the development of a transformer for the electric energy distribution with the
ability of changing automatically its transforming ratio in order to control the voltage on the user’s side, when there are variations on the voltage supply side.

The objective is to develop a new product to give to the user a better control of the energy distribution circuits, having cost reductions of the maintenance of the energy transmission lines due to unnecessary disconnection of the transformers, keeping stability of the voltage received by the energy users and also an increase on the energy quality received by the user.

**4.4 Solution given by Company A – AS IS**

**4.4.1 Stages of the project.**

According to figure 3 seen on section 1.4, this project can be delimited into 3 main stages as shown on Figure 21:

*Fig. 21 Stages of the R & D project used as a case study.*

For this particular project, the R & D Process took about 8 months for Stage 1, 8 months for Stage 2 and 6 months for Stage 3.

NTI Process Stage 1 took about 18 months and Stage 2 is in process to be developed.

NPI Process has not been developed yet.
4.4.2 Development of the project.

The main steps followed for the development of the project were:

1) **Selection of the project.** There is a defined portfolio of projects available and the Technology Manager with the R & D Leader select the appropriate project based on the technology needs of the company.

2) **Selection of working group.** The Technology Manager with the R & D Leader selects the working group including the Project Coordinator, the R & D Engineer, the Project Specialist and the External Research Company to work with.

3) **Project starting meeting.** This is a “kickoff” meeting and the working group interacts with the external research company about the details of the project, and the project specifications and deliverables are indicated to the external research company. A confidential agreement is signed by the external research company in order to avoid that products of processes from Company A could be revealed to other competitors.

4) **Evaluation of the project specifications.** The external research company takes and evaluates the specifications and makes an economical proposal and a working plan of their activities including their deliverables. Company A analyzes the proposal and agrees or rejects any issue related with the proposal. The working team decided to prepare 2 sets of prototype PCB cards, 6 cards for Power Stage and 2 cards for Control Stage, in order to have backup cards for the case of any damage to the PCB’s during the testing process.

5) **Starting of activities.** After Company A and the external research company approved all the documentation and details; the activities begin according to the working plan. This plan includes all the activities developed by the external research company, by Company A and the interactions between them. The necessary review meetings between all the processes are included in the plan with the agreed recurrence by both parts.
6) **Development of activities.** During this stage, are realized all the activities included in the general plan of the project. The main activities are described later on section 4.4.4.

7) **Finishing the project.** This is the end of the scope of the project and all the activities defined are closed. All conclusions and knowledge learned is documented and the possible further work is defined. The documents for the NPI process are elaborated.

### 4.4.3 Roles and responsibilities

The Project was developed by a working group composed of 3 people from Company A and 2 people from the external research company, with the following roles and activities:

- **Project Coordinator:** Person from Company A. Activities: Electronic tap changer specifications, transformer/tap changer design and prototype development.
- **R & D Engineer:** Person from Company A. Activities: Critical to Quality (CTQ) issues from the user, materials supplier validation and prototype development.
- **Project Specialist:** Person from Company A. Activities: Process specification, design, tests and materials supplier validation.
- **External Research Company:** Activities: Electronic tap changer specifications and prototype development.
4.4.4 Activities realized

For this particular project, the activities were divided on 12 main segments for a total duration of the project of about 77 weeks (About 18 months). The R & D process (See section 4.4.1) was made the previous 6 months. The main realized were: a) Electronic tap changer design, b) Transformer – Electronic tap changer interface design, c) Transformer design, d) Control stage design, e) Communication design, f) Remote control design, g) Simulation of the complete system, h) Assembly and mounting design, i) Transportation strength design, j) Prototype manufacturing, k) Tests and l) Performance parameters analysis.

4.4.5 Problems reported during the project development

The following problems were present during the total development of the project:

a) It was detected late that it was necessary to consult an expert on Power Electronic Circuits. This caused loss of time on finding first the adequate expert and this caused delays on the project.

b) It was not detected that the use of mineral oil for the transformer would cause the Power PCB’s to be damaged, and the thyristors did not resist the contact with the oil. Because of this, the first test for the electronic tap changer had to be outside the transformer and the real conditions were not present. This caused also loss of time and the research of alternatives, such as the use of vegetal oil instead mineral oil and the complete test were completed.
4.5 Proposed solution: TO BE

4.5.1 Roles and areas involved

Working Group and Roles Involved in the project:

- Technology Manager
- Technology Leader
- R & D Technology Leader
- Project Leader
- External Research Company

Areas involved in the Project:

- R & D Technology Department
- Applied Technology Department
- Engineering Department
- Outsourcing Company and/or Experts
- Prototype Development Laboratory (PDL)

4.5.2 Adapting the Methodology to the project.

According to the framework, roles and methodology proposed on sections 3.3, 3.4 and 3.5 respectively, there is defined a series of steps to be followed in order to develop a prototype for a specific project. The intention with this is to propose an effective way to find appropriate solutions in order to validate a concept using an adequate prototype.

With this in mind, the method can be applied considering all the factors applicable to the specific project, adapting the necessary steps as needed.
4.5.3 Methodology activities for the project.

4.5.3.1 Stage 1: Prototype Definition

a) The project is selected by the R & D and Technology Leaders from the portfolio of projects available. Due to a change on the design of a standard distribution transformer is needed, it is decided that a prototype is required. At this point it is very important to verify if the project will have a high technology impact and at the same time if will be an attractive solution with good market for a future possible user of the concept to be validated, in this case, if an automatic tap changer is an attractive solution for companies dedicated to the installation of distribution transformers, for instance, in Mexico, companies such as Comisión Federal de Electricidad (CFE) or Compañía de Luz y Fuerza del Centro (CLyF); in USA, all companies known as “Utilities”.

b) Technology Leader, based on the concept to be validated, which is the use of an electronic device inside the distribution transformer in order to make the tap changes automatically, defines the quantity of prototypes needed to consider the project to be ready to be implemented. The cost involved on the development of the prototype in another parameter to be considered, which would be confirmed later on the cost / benefit analysis. In this case are considered, 1 prototype for the transformer with the provisions required to install on it the electronic tap changer device and at least 2 sets of prototypes of the PCB’s for control and power stages for a total of 2 Control PCB’s and 6 Power PCB’s. The justification for these quantities is based on the nature of the components; this is, for the distribution transformer is considered a strong component which is difficult to be damaged during the tests, so 1 prototype is considered; for the electronic PCB’s, these are components that easily can be damaged, so two prototypes are considered for the power PCB’s and two for the control PCB’s. An advantage of the power PCB’s is that if is damaged
one of the cards included in the package of 3 cards needed on each prototype, it can be replaced only the damaged and not the full package.

At this stage is also defined the working group of the project and the outsourcing company that will be part of it for the development of project, The roles and activities are described on section 4.5.1.

A “kickoff” or starting meeting is programmed for the official beginning of the project with the complete working group involved. The external company makes a proposal of their work and if no changes are needed for the specification, it is “frozen” per mutual agreement of both parts.

c) The Project Leader identifies with help from the Technology Leader that in this case the prototype is a concept or feasible prototype ( according to Table 1 on section 2.3.1 ) and also needs to be physical because the electronic concept of the tap changer needs to be tested under the real conditions inside the transformer. The limitations of a virtual prototype for a transformer are the difficulty to simulate all the specific tests required for a transformer and listed later on section 4.5.3.2 d). Maybe some responses could be simulated, but not the entire behavior of the results expected. Using a physical transformer prototype has the advantage of the visual observation of the results obtained during the tests done to the prototype, also gives a better idea of the improving opportunities that can be added to the development of the prototype. Another advantage is the use of test equipment similar to the one used for standard distribution transformers.

At this moment It is identified that a key concept is the use of electronic devices such as thyristors and because of this, it is a need to identify an expert in power electronics for possible consults during the development of the project.
d) At this point the Project Leader elaborates a risks and benefits analysis in order to determine if the prototype is feasible, design tools such as QFD, Parametric Analysis, FMEA, TRIZ, can be used for this. In this case a Failure Mode and Effect Analysis (FMEA) is recommended in order to have an early identification and elimination of potential failure modes.

e) The Project Leader identifies the nature of the prototype to the transformer's categories: Electrical (coils, core, etc), Mechanical (tank, supports, accessories, etc) or Control (Cooling, alarms, monitoring, etc). In this case the 3 disciplines are involved, Mechanical and Electrical in the transformer and Control in the electronic tap changer.

f) The Project Leader chooses an external research company to work with, as part of the project team. The working group will have to develop a specification of the project including issues like technological objectives and challenges, inputs of the project and the deliverables needed from the external research company. At the end of this stage can be done a register with the main characteristics of the prototype. A suggested format is attached bellow on Figure 22:
R & D Prototyping Methodology Applied to Power and Distribution Transformers

**Prototype Name:** Distribution transformer with electronic tap changer

**Project Leader:**

**Working Group:**

**Characteristics.**

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a) Purpose</strong></td>
</tr>
<tr>
<td><strong>b) Type (physical or virtual):</strong></td>
</tr>
<tr>
<td><strong>c) Quantity</strong></td>
</tr>
<tr>
<td><strong>d) Nature (Mechanical, Electrical, Control)</strong></td>
</tr>
<tr>
<td><strong>e) Key concept to be validated</strong></td>
</tr>
<tr>
<td><strong>f) Requires an Expert?</strong></td>
</tr>
<tr>
<td><strong>g) Requires an Outsourcing Company?</strong></td>
</tr>
<tr>
<td><strong>h) Estimated cost</strong></td>
</tr>
</tbody>
</table>

![Fig. 22](image)

Fig. 22 Suggested format with the main characteristics of the prototype

g) A virtual simulation is done using CAD / CAE in order to obtain pilot models. Also a simulation of the complete prototype functionality can be developed using CAM tools. This simulation is indented to validate the concept feasibility, as a previous step of the development of the physical prototype. On Figure 23 bellow is represented a way of how could be developed a pilot for this case of study.

Based on the concept of Figure 18 of section 3.4.1, it is recommended the decomposition of the disciplines involved, in this case, mechanical, electrical, control and electronics. The system may be subdivided into simple elements to be analysed, but as part of a whole design.
4.5.3.2 Stage 2: Prototype Analysis

a) Based on the specifications, materials needed and the results of the FMEA proposed on section 4.5.3.1 d), the project leader makes an estimation of the prototype’s costs and confirms the feasibility of the prototype using a cost / benefit analysis. The Technology Leader approves the cost and authorizes the prototype. This cost will confirm if 2 prototypes or more can be developed, as mentioned above on section 4.5.3.1 b.

b) The Project Leader and the working group make a list of the key verification points during the development of the prototype, including the manufacturing information and interactions with the external research company.
c) The Project Leader and the working group verify with the according design area the manufacturing limitations and the specifications required in order to develop the detailed information according to this. In this case, the electrical clearances are critical due to the additional components inside the transformer.

d) The Technology Leader and Project Leader define the tests needed for the prototype. This is based on the nature of the concept is intended to be proved, this is, Electrical, Mechanical or Control. In this case, the tests for a distribution transformer with an electronic tap changer are not standardized, it has to be developed a strategy for test the transformer using the tap changer, simulating real operating conditions. Because of this, the test routine must be such as the one required for a normal distribution transformer according to ANSI/IEEE Standard C57.12.90. The particular tests to be developed:

- Energizing at nominal voltage with no load (Excitation current).
- No load losses.
- Energizing at nominal voltage with full load.
- Load losses and Impedance.
- Dielectric Tests: (a) Applied voltage, (b) Induced voltage.
- Impulse test.
- Ratio.
- Short circuit test.

Besides the operation standard distribution transformer according the above tests, two critical parameters to be tested are:

- Primary/Secondary Ratio. This is a basic parameter for the correct function of the transformer.
Secondary winding voltage. If the tap changer works properly, it has to respond automatically to voltage changes simulated on the primary side and keep the low voltage side constant within a specified tolerance.

4.5.3.3 Stage 3: Prototype Development

a) The design process begins. The working group designs the information for the prototyping manufacture, interacting, as needed the engineering group and the external research company to review engineering concepts related with the prototype. In this case the design of the prototype includes two parts: the residential transformer and the electronic tap changer. The transformer can be designed and even manufactured at Company A as a standard transformer but with the provisions needed to install the power PCB’s cards inside of it. The working group shall coordinate all the design information of the transformer. The design of the electronic tap changer shall be developed by the outsourcing company selected in conjunction with the rest of the working group. The expert selected for the thyristors application, shall be consulted whenever is necessary in order to avoid delays in the design process of the electronic tap changer.

b) The working group generates the information for the prototyping testing, previously defined. In this case, the testing procedure, as mentioned on section 4.5.2.2 d) is according to the ANSI/IEEE Standard C57.12.90. This tests would be developed in the Prototype Development Laboratory (PDL) as described on section 3.5.1.

c) The Project Leader delivers the manufacturing information of the distribution transformer to the PDL department dedicated to manufacture the prototypes. The Project Leader also verifies with the external research company the manufacturing process of the electronic tap changer.
d) The Project Leader coordinates the manufacture of the distribution transformer and electronic tap changer PCB cards for the prototype. The inspections points are programmed at the middle and at the end of the manufacturing process at least. A special checklist or minute is needed on each verification point for the relevant observations during each process. In this case the inspection points are suggested at the middle and the end of each stage starting on the prototyping development stage.

On Figure 24 is a suggested format for the checklist / minute of observations:

<table>
<thead>
<tr>
<th>Prototype Stage</th>
<th>Pending issue</th>
<th>Responsible</th>
<th>Due date</th>
<th>Status</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3) Development</td>
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<td>4) Testing</td>
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<tr>
<td>5) Delivery</td>
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</tbody>
</table>

Fig. 24 Suggested format for the checklist / minute of observations

e) At the end of the manufacture stage for both prototypes, the working group confirms that the prototypes were constructed according to the design information.

4.5.3.4 Stage 4: Prototype testing stage.

a) The manufactured prototype transformer is received by the respective testing laboratory area, this is Electrical, Mechanical or Control. In this case, the Control part of the tap changer has to be tested first separately from the transformer, as mentioned on section 4.5.3.2.d). After the tests made to the electronic tap changer are satisfactory, the complete distribution transformer can be tested as a finished full prototype.
b) The PDL testing area begins with the testing plan of the prototype, previously developed with the information and specifications made by the prototype working group, as mentioned on section 4.5.3.3 d).

c) The external research company interacts with the PDL testing area and the working group as needed, to verify that the electronic tap changer works as expected during the tests made to the complete distribution transformer prototype.

d) In case that all the tests are completed and satisfactory, a detailed results report has to be elaborated by the PDL testing area, including all the tests done to the prototype, the expected value compared with the tested value. This report is presented to the project leader. In case that the tests result not satisfactory, a research is required and if necessary also to get back to stage # 2 for a detailed analysis. If the problem causing the failure is of unknown nature, it will be necessary to consults experts for the analysis required.

4.5.3.5 Stage 5: Prototype Delivery & Recycling Stage

a) The R & D Technology Leader and the Project Leader analyzes with the technology leader the possibility of including the distribution transformer prototype into the New Product Introduction stage.

b) The Project Leader develops a final report, listing the main modifications that need to be implemented in the design information of the product where the concept validated can be included. In this case, it would be the possibility of launch a new distribution transformers line of products with an automatic tap changer.
c) The Applied Technology Department Leader evaluates the project and decides if the implementation of this new distribution transformer with electronic tap changer is feasible to be implemented as a New Product, and begins the NPI process.

d) The manufactured / tested distribution transformer prototype is analyzed by the working group in order to detect the possibility of being re-utilized (complete or some parts) for future prototypes of other similar projects associated with distribution transformers..
Chapter 5

5.1 Results

The following results were obtained at the end of the development of this thesis:

- Some companies develop their own prototypes using their experiences, techniques and resources, and examples of these companies are described on section 2.5. Depending of their own applications are the methods and resources they follow. The methodology proposed can be a useful tool for prototyping projects.

- Different types of prototypes were found during the literature review development. The most of they can be applied to a specific R & D project with the characteristics needed by a company such as the analyzed on chapter 4 on the case of study. For this kind of projects, the concept or feasible prototypes ( according to Table 1 on section 2.3.1 ) are the most used, because of the nature of concepts that need to be validated. A virtual prototype could be an option, if the concept is not very complicated and can be tested and validated via software application.

- It was formed a framework ( shown on section 3.2 ) and developed a methodology ( described on sections 3.3 & 3.4 ) for the development of prototypes for R & D projects. These tools were defined based on the literature review and particular methods used by some companies reviewed and analyzed on section 2.5 during the research of this work. It was also proposed as a part of the methodology, the creation of a Prototype Development Laboratory ( PDL ) to prove the industrial feasibility of new technology through the development of prototypes.

- It was developed a case of study in order to validate the methodology proposed. The method was compared with the previous solution given to the same project by
Company A without any method; there were detected some advantages of the proposed methodology and are explained on the conclusions detailed in section 5.2.

- The obtained results, give to the author arguments to propose to Company A this methodology as a tool for develop the prototypes required by their projects. The obtained conclusions (explained on detail on section 5.2) sustain the precision of the methodology. Also the PDL as a part of this proposal can be implemented by them, avoiding with it the use of the production plant facilities.

### 5.2 Conclusions

The validation of a concept is the first step to introduce new technology and later new products. These processes include a series of considerations and subjects that need to be demonstrated through the use of prototypes. The prototype is the direct witness and participant of the conditions required by a project, so the importance of having an effective method to develop it, is essential. As far as the method used clarifies the way to be followed, the results of a specific project will be satisfactory, and the time required for developing it will be reduced considerably compared with an absence of a methodology. Wrong ways can be taken without a method established causing loss of time and money to the company owner of the project.

During this research was found that around a prototype, there are important aspects to be considered such as: similitude of conditions present on the real product, tests to be applied to the prototype in order to validate its functionality, an adequate working team with clear roles and activities and mainly, an appropriate method to develop the prototype since an idea or need is generated until the prototype is tested, validated and prepared to a next stage into the life cycle of a certain product.
As mentioned on chapter 4, the project used as case of study, was developed entirely by Company A without the use of a specific method to develop the prototype. This caused, since the point of view of the author of this thesis, several aspects that could be managed in a different way using the methodology proposed with the intention of improving the results of the project and the time invested on it. These aspects are:

- Due to the fact that no specific method was found for develop a prototype for a R & D project, the methodology proposed is a feasible solution for this need.

- The detection of an expert in the area of the concept to be validated, since an early stage of the project, this is, on the definition stage represented on the framework showed on section 3.2 and described on section 3.4 is very important. When the project was developed originally, the prototype was very advanced, when it was detected the need of contacting an expert on power electronics in order to get information about the application with thyristors. This caused that the prototype has to be stopped in order to found this expert, and time has to be invested because of this.

- The use of adequate design tools, such as QFD, FMEA, etc during the definition stage, can help to detect opportunities, additional customer needs or possible problems that can be present during the development of the prototype. It is critical to detect all the possible natures ( electrical, mechanical, physical, chemical, etc. ) of possible problems that can interact with the prototype. When the project was developed originally, when some tests were done to the prototype of the electronic tap changer inside the distribution transformer, one of the power PCB cards resulted damaged because the mineral oil contained inside the transformer attacked the thyristors. The working team and the external research company invested time on
finding a solution and they had to finish the tests of the prototype using alternate vegetal oil instead the mineral one. This is not an effective solution, since the mineral oil is the standard oil used by Company A in their transformers and vegetal oil is more expensive. In this case, a FMEA realized as mentioned on the definition stage of the methodology proposed, could help finding a possible mode of failure, the use of mineral oil with electronic devices and a possible solution could be searched since an early stage of the project, even a plan of possible failures and solutions could be elaborated. Nevertheless, it can be possible that during the validation tests of the prototype exists the possibility of having failures or problems of unknown nature non-contemplated during the definition stage. When this case is present, it is necessary to take a loop back to the analysis stage and inclusive having interaction with experts in order to find a solution of this possible problem.

- When a project is selected, it is critical to have clearly identified the market space where the future product will interact, having an attractive technological an economical opportunities. At the end of the tests of the original project, the prototype was ready to be launched as new technology and later as a new product on the market. As mentioned on section 4.4.1, the original project ended at the middle of a NTI stage. The part of the NTI and NPI processes have not been developed because it was detected on interviews with possible users of this transformer that this product would not have a big enough market as it was supposed at the beginning of the project. Although the technology impact is big, the cost and the low market have caused that the project is almost stopped at this moment. Actually, the second stage of the NTI process for this project is beginning to be developed, but a market space has to be developed, since a marketing point of view in order to have an attractive product to the end user. As mentioned on section 4.5.3.1, the methodology proposed
on stage 1, the early detection, since the project is selected, of the market opportunity for the possible future product. This causes that when the prototype of the NTI product is validated, can pass directly to the NPI process instead of looking at this point an opportunity in the market. In other words, the feasibility of the product shall be confirmed in the prototype definition stage, as the proposed methodology states.

- An adequate space dedicated to develop a prototype since it is designed and then manufactured and tested is required. During the process of manufacturing and testing the original prototype for case of study analyzed, the working team found difficulties because the company doesn’t have a specific facility for this purposes. When the information for manufacturing the prototype transformer was ready, they had to use the production plant to manufacture it, but the problem was that the priority for the plant is to manufacture the production and not the prototypes. This caused delays because the production plant has scheduled the orders programmed for long periods of time and the working team had to wait for an opportunity to get a slot production for the prototype. The testing phase of the prototype had similar problems but with the production testing laboratory. The case of the electronic tap changer was different, because in was manufactured with outsourced companies. Because of this problems, on section 3.5.1 is proposed the Prototype Development Laboratory (PDL). The use of this proposed facility includes physical space for the complete process of development of prototypes. Considering a PDL for this case of study, avoids all the interaction with the production plant and laboratory, decreasing the time invested to this stages of the project.
5.3 Further work

1) Regarding the methodology proposed a further investigation would be the analysis with an NPI prototype and compare the results with the defined NPI process to develop prototypes managed by Company A. Maybe some adaptations would be needed depending the project selected.

2) The future development of a documentation tool is suggested. Every project has different experiences and they have to be documented in order to learn from them and subtract ideas and tips for other projects. This is an essential part of a knowledge management process.

3) Another work for the future would be the analysis of the specific tools required for each sub-division of the PDL, this is Electrical, Mechanical or Control areas, which are commonly involved in a R & D project in general. These tools include all the design, manufacturing and testing equipment needed to develop the complete cycle of the prototypes. Based on these tools, an analysis of the space required for the laboratory, can be estimated in order to know if the PDL can be built inside the installations of Company A or in a separated area. According to the needs of Company A, mentioned on section 3.4.1, is suggested a separated area due to there is not space considered for this purposes in their own facilities. Usually, when this happens in other companies, a dedicated area must be selected in order to implement a laboratory like the proposed PDL. Some characteristics and functions recommended for this PDL, can be listed as follows:

- Link between research and innovation to facilitate the transfer of technology to new products developed by the company.
• To develop state of the art technology-based R & D projects

• To interact with Universities and other Research centers in order to share technology on open innovation schemes.

• To incubate projects that focus on new technologies.

• To promote economic development through the commercialization of new technologies.

The PDL shall have facilities with proper conditions and installations for the development of the projects, such as:

• Electric Power

• Power substation

• High-pressure natural gas.

• Potable water supply

• Drainage network for gray water, sewage and rain water

• Fiber optics infrastructure

Based on the key business shown of Figure 17 and managed by Company A, the PDL space needed should be segmented as follows:

• Prototypes for R & D projects of power transformers.

• Prototypes for R & D projects of distribution / industrial / 3ph pedestal transformers.

• Prototypes for R & D projects of porcelain insulators.
Appendixes

A. Definitions

- **ANSI**: American National Standards Institute.
- **CAD**: Computer Aided Design.
- **CAE**: Computer Aided Engineering.
- **CAM**: Computer Aided Manufacturing.
- **CFE**: Comisión Federal de Electricidad.
- **CIATQ**: Centro de Tecnología Avanzada.
- **CIMAT**: Centro de Investigación en Matemáticas.
- **CIMAV**: Centro de Investigación de Materiales Avanzados.
- **CIIA**: Centro de Investigación en Química Aplicada.
- **CIDESI**: Centro de Ingeniería y Desarrollo Industrial.
- **CLyF**: Compañía de Luz y Fuerza del Centro.
- **CPTM**: Centre for Power Transformer Monitoring, Diagnostics and Life Management.
- **CTQ**: Critical To Quality.
- **EPRI**: Electric Power Research Institute.
- **ERP**: Enterprise Resource Planning.
- **FMEA**: Failure Mode Effect Analysis.
- **GE**: General Electric.
- **GRC**: Global Research Center.
- **IIE**: Instituto de Investigaciones Eléctricas.
- **IEEE**: Institute of Electrical and Electronics Engineers.
- **kV**: Abbreviator of kilo Volt.
- **kVA**: Abbreviator of kilo Volt-Ampere (Capacity measure unit for a transformer).
- **MVA**: Abbreviator of MEGA Volt-Ampere (Capacity measure unit for a transformer).
- **Methodology**: is a collection of methods that can be organized by steps, written in the order in which they should be executed.
- **NPI**: New Product Introduction.
- **NPD**: New Product Development.
- **NTI**: New Technology Introduction.
- **PIIT**: Parque de Investigación e Innovación Tecnológica.
- **PCB**: Printed Circuit Board.
- **PDL**: Prototype Development Laboratory.
- **PLM**: Product Lifecyle Management.
- **QFD**: Quality Function Deployment.
- **R & D**: Research and Development.
- **STI**: Science, Technology and Innovation.
- **Thyristor**: a solid-state semiconductor device with four layers of alternating N and P-Type material. They act as a switch, conducting when their gate receives a current pulse.
- **TRIZ**: Teoriya Resheniya Izobretatelskikh Zadatch (Theory for Solving Inventive Problems).
- **V**: Volt
- **3D**: Abbreviator of three dimensions.
B. General Transformer Concepts.

ANSI / IEEE Standard define a transformer as a static electrical device, used in electrical power systems to transfer power between circuits using electromagnetic induction.

The term power transformer is used for those transformers between a generator and the power substations that feed the distribution circuits, with capacities up to 750000 kVA and voltages up to 545 kV.

The term distribution transformer is used for those transformers between the power substations and the distribution circuits. They can be divided on Residential or Pole type (with capacities from 5 to 100 kVA and voltages from 4.16 thru 34.5 kV), Commercial type for the pole type transformers (with capacities from 30 to 5000 kVA and voltages thru 34.5 kV) an Industrial type (with capacities thru 12000 kVA and voltages thru 34.5 kV).

The power systems typically consist in a great variety of generation centers, distribution points and interconnections with the proper system or another closer system.

The complexity of the system includes a variety of transmission and distribution voltages. The power transformers must be used on each of this places where there is a transition between the voltage levels.

The types of Power transformers can be defined as follows:

• **Generator Step Up:**
  Takes power at relatively low voltages from the generator at Power Stations, typically 13.8kV, 18kV and 23kV, delta connected, and steps up the voltage level for economical transmission. High Voltage is wye connected.

• **Autotransformers:**
  The main application is to tie two transmission systems of different voltages together. Both high and low voltage are wye connected with the LV winding common to the HV winding and...
normally require a delta tertiary winding for harmonic suppression and neutral stabilization. The use of Autotransformers affords cost savings over two winding transformers and are usually used at voltages of 69kV and higher.

• **Substation Step Down:**
Receives electrical power from high voltage transmission lines and steps down to lower voltage levels for bulk distribution. Most common connection for United States application is a delta high voltage and a wye low voltage. Load tap changers are commonly used on the low voltage wye connection to regulate the output voltage.

• **Station Auxiliary:**
Takes power from the generator (unit auxiliary or station service auxiliary) or the high voltage transmission system and steps down to the proper voltage levels for station load.
C. Alternatives for Prototyping

C.1 Digital Prototyping

A digital prototype is a digital simulation of a product that can be used to test form, fit or function. It becomes more complete when all associated disciplines such as conceptual, mechanical and electrical design data are integrated. A complete digital prototype is a true digital simulation of the entire final product and can be used to virtually optimize and validate a product in order to reduce the need of building an expensive physical prototype [ C ].

Digital Prototyping gives conceptual design, engineering and manufacturing areas the opportunity of explore in a virtual way, a complete product before it becomes real. It is possible to create, validate, optimize and manage projects beginning from the conceptual design until the manufacturing process. Using a digital model, it is possible to get more innovative products faster [ C ].

New product introductions depend on the design sign-off by a number of departments inside a company: product design, engineering, manufacturing, marketing, sales, etc. Actually, in some companies this process required the development of physical product prototypes that have a whole range of alterations before they meet the approval of all involved departments.

In the last few years, software developers introduced digital applications for electronic representations or prototype to accelerate this process. Digital prototyping is now defined as dealing with the complete product before it is real, that is creation, validation, optimization and design management from the conceptual design phase through the manufacturing process. Using a digital model improves the level of communication between different departments involved in the product development and accelerates the time to market. With digital prototypes, manufacturers can visualize and simulate the real conditions and performance of the design with fewer physical prototypes [ Wilson, 2007 ].

An efficient software tool for digital prototyping is presented on next Appendix C.1.1
C.1.1 AutoDesk solution for Digital Prototyping

Autodesk® is a well known software company, dedicated mainly to design tools. In terms of engineering design, several tools created by Autodesk®, can be very useful for many disciplines, such as industrial, mechanical, electrical, etc.

The Autodesk® Digital Prototyping Solution brings together design data from all phases of the product development process in order to create a digital model, which simulates the complete product and gives engineers the ability of visualize, optimize and manage their design before producing a physical prototype. Autodesk® provides the interoperable tools required to create a complete digital prototype from the conceptual phase of a project through the manufacture phase [C]:

- Autodesk® AliasStudio™ enables users to work digitally from the start of a project with best-in-class industrial design tools. Ideas can be captured digitally from initially sketches through to 3D concept models and share those models to the engineering team using a common format file in order to be incorporated to the digital prototype.

- AutoCAD® Mechanical as a part of the AutoCAD family products is built for mechanical designers to improve the design experience by simplifying complex mechanical design work, it can detail and document Autodesk Inventor models allowing engineering departments to use 3D to build digital prototypes.

- AutoCAD® Electrical passes electrical design intent information for cables and conductors directly to Autodesk Inventor to automatically create a 3D harness design, adding valuable electrical controls design data to the digital prototype created in Inventor.

- Autodesk Data Management Tools allows design work groups to manage and track all the design components for a digital prototype, providing the path through which the digital prototype moves and connects all design and manufacturing workgroups.
Autodesk® Inventor™ software is the foundation for Digital Prototyping. The model used with this software is an accurate 3D digital prototype that permits validate the design and engineering data as they work, minimizing the need of a physical prototype and reducing expensive engineering changes that some times are discovered after the design is delivered for manufacturing [C].

According to a study by the Aberdeen Group [F], best-in-class manufacturers use Digital Prototyping to build half the number of physical prototypes as the average manufacturers and get to market 58 days earlier than the average and have 48% lower prototyping costs, and ultimately drive greater innovation in their products. The Autodesk Digital Prototyping Solution help customers to achieve this results [C].

Autodesk is positioned to become the clear leader in digital prototyping and conceptual design with its broad product offering for new product development and data management. Autodesk will soon have to develop a road map for three key issues [Wilson, 2007]:

- How to move the newly acquired visualization technologies into an integrated product offering by the manufacturing solution group.
• How to distribute and support their new products.

• How to package the applications.

C.2 Rapid Prototyping

Rapid Prototyping allows the transformation of a prototype developed virtually through computer-aided design (CAD) tools to physical object. This technology is commonly used by manufacturer companies with a high variability in their assembly products, for example the electronic industry where pieces for electronic circuits are assembled and need to be simulated and tested with real dimensions [ Báez, José 2001 ].

Rapid prototyping methods are developing quickly and steadily and have progressed from being tools for fast product development to becoming tools for fast product formation. The early stages of product development have special significance for the success of a product when is launched to the market [ Gebhardt, 2003 ].

Rapid prototyping can be seen as synonym for computer-controlled and therefore automatic generative processes. Rapid prototyping together with its most prominent member, stereolithography, are well known processes. They are self-explanatory and fulfill the most important requirements of a standard term [ Gebhardt, 2003 ].

The terms rapid manufacturing and rapid tooling are subordinate to rapid prototyping and relate to special uses an areas of application. Rapid prototyping involves the science of generative production processes, and is therefore a technology. Rapid prototyping describes the technology of generative production processes [ Gebhardt, 2003 ].

Rapid Prototyping refers to the layer-by-layer fabrication of 3D physical models directly from a computer-aided design (CAD). This process allows designers and engineers the capability to literally print out their ideas in three dimensions. It provide a fast an inexpensive alternative for producing prototypes and functional models as compared to the conventional routs for parts production [ Cooper, 2001 ].
D. Materials used for prototypes

About the materials for the construction of the prototype, some criteria should be considered, in order to take a good decision [Otto-Wood, 2001]:

- Cost. It has to be minimized without sacrificing the quality and the goals of the prototype. It has to be considered all the risks or the advantages of a particular material.

- Availability. It is important to use common materials to avoid delays in the construction of the prototype.

- Capabilities of accept changes. The materials selected need to accept modifications for dimensions, surface requirements, etc.

- Ease of use and forming capability. Should be avoided special tools or safety equipment. The material shall be relatively easy to be formed.

- Scalable geometry. Unnecessary forming operations need to be eliminated, using simplified prototype shapes.

- Scalable properties. Properties must be chosen to comply with the prototype uses. Properties as mechanical, thermal, electrical and chemical should be considered.
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